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PhD Thesis

Age Estimation and Gender
Determination using Measurements
of Maxillary Central Incisor and
First Molar on Cone Beam
Computed Tomography

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ESCOLA DE DOUTORAMENTO
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TESE DE DOUTORAMENTO

**AGE ESTIMATION AND GENDER
DETERMINATION USING
MEASUREMENTS OF MAXILLARY
CENTRAL INCISOR AND FIRST MOLAR
ON CONE BEAM COMPUTED
TOMOGRAPHY**

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PROGRAMA DE DOUTORAMENTO EN CIENCIAS ODONTOLÓGICAS

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CONFLICTO DE INTERESES

Declaro que no existe ningún conflicto de intereses con los temas o materiales tratados en esta tesis de doctorado titulada: **Estimación de la Edad y Determinación del Género mediante la Medición del Incisivo Central y el Primer Molar Superiores con Tomografía Computarizada de Haz de Cono**

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Firma electrónica



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To my sister, because she is my sister and is always there for me.

Finally, most important, to my parents because they are my parents and no matter how much I do, I will never equal them.

DEDICATION

To my parents because I will never equal them

***“Education is the most powerful
weapon you can use to change
the world”***

Nelson Mandela

Introduction

Age estimation and gender determination are important aspects of forensic investigations and legal issues. Forensic techniques based on bone structures cease to be useful in the face of serious structural damage. However, as they are very difficult to destroy, teeth are one of the main forensic tools for age and gender estimation. Moreover, the literature suggests that dental indicators provide high accuracy for age estimation and gender determination. For these reasons, forensic dentistry has been playing an increasingly relevant role. Laccasagne was the first to attempt age determination using dentition in 1889 (Altini, 1983), and in 1925 Bodecker pointed out that certain morphological changes in teeth could be related to increased age. Since then, a number of tooth characteristics have been used to determine age: (i) tooth wear; (ii) root dentin transparency; (iii) secondary dentin deposition; (iv) cementum annuli measurement; (v) Retzius striae count; (vi) radio carbon analysis; and (vii) mineralization of third molars, among others. Methods based on biochemical and histological techniques which require tooth extraction are difficult to apply, time consuming and very expensive whenever there are many specimens to identify.

Regarding the characteristics of the dental parts to be taken into account to establish differences between men and women, in a succinct and generalized way, women have smaller teeth than men, with the upper central incisor being considered the tooth that presents greater dimorphism showing a larger size in the mesiodistal direction. Men also have more cuboid teeth, with flatter surfaces and sharper angles, while women have teeth with more rounded angles.

Dental imaging techniques, such as cone beam computed tomography (CBCT), can overcome many of these drawbacks. In addition, the fact that they enable long-term record storage and easy portability make these imaging techniques an unavoidable, valuable adjunct to forensic investigation. Secondary dentin deposition is an important parameter for age estimation because it continues throughout life, and it can be indirectly measured with non-destructive imaging techniques. Over one's lifetime, secondary dentin deposition causes a decrease in the size of the pulp cavity. Based on this fact, various authors have estimated chronological age resorting to imaging techniques. Two-dimensional imaging systems are insufficient because they produce dimensional variations, are limited to mesiodistal dimensions, and the analysis is hindered by factors such as malpositions and superpositions. Thus, 3D imaging is essential for an accurate forensic identification. Vanderwoort et al. (2004) were the first to apply 3D measurement methods to estimate age based on secondary dentin deposition. Subsequent research analyzing linear measurements, areas and volumes have been performed using either micro-CT, CT, or CBCT. Unlike previous research on the topic, the present study has included a much more thorough analysis involving multiple linear measurements and ratios in all three CBCT slices.

The identification of age and gender for forensic purposes is still difficult. Although different methods based on the analysis of teeth have been reported, it remains a challenge to find the ideal method. The aims of this research were: to evaluate possible differences in the right upper central incisor in age and gender onto a sample of adult humans; to evaluate possible differences in the right upper first molar in age and gender onto a sample of human adults; and to obtain regression equations for estimating age and gender in adults through linear measurements and ratios on sagittal, coronal and axial slices of maxillary central incisors and molars, using CBCT.

Material and Methods

Sample: A total of 360 randomly selected CBCTs were included in this cross-sectional study. The sample size was determined by means of the Slovin's formula. These CBCTs were performed from 2012 to 2017 for treatment planning of various oral surgical procedures in the Radiology Unit of the Medicine and Dentistry School at the Santiago de Compostela University. Linear measurements and ratios on sagittal, coronal and axial slices of upper central incisor and upper first molar using cone beam computed tomography (CBCT) were carried out.

Inclusion and exclusion criteria: The inclusion criteria were the following: (1) patients older than 18 years old; (2) maxillary with at least one upper central incisor; and (3) CBCT with a 0.3 mm minimum voxel size image quality. The exclusion criteria were as follows: (1) CBCT images which were impossible to rotate, blurred or incomplete; (2) decay, restoration or endodontic treatment; (3) ceramic/metal crowns or orthodontic elements; and (4) calcified root canal or root resorption.

Image evaluation: CBCT was carried out using i-CAT® Model 17–19 (Imaging Sciences International Inc., Hatfield, PA, USA) with a flat-panel detector of amorphous silicon, an exposure protocol of 120 kVp and a current of 5 mA for 14.7 s. Patient occlusal plane was set parallel to the floor base by means of ear rods and a chin rest. DICOM files were reconstructed on computer (Samsung R522, Samsung Electronics, Seoul, Korea) using 3D visualization software iCATVision® v. 1.9. CBCT slice thickness was set at 0.25 mm.

Ethics Statement: written informed consent was obtained from all patients. In compliance with ethical, methodological and legal requirements, this study was approved by the Galician Ethics Committee of Clinical Research (Ref: 2012/272). The methods were performed in accordance with relevant guidelines and regulations.

Standardized Incisor Measurement Protocol: multiplanar measurements (sagittal, coronal and axial) were performed by researcher as follows:

Sagittal Slice: sagittal measurements at cementoenamel junction level. Linear measurements were obtained in the “incisor neutral position” which was achieved by placing the horizontal red line of the CBCT program at the level of cementoenamel junction of the upper central incisor: (a) tooth width: from most palatine point to the most vestibular point of the incisor (sce_TW); (b) pulp width: from the most palatine point to the most vestibular point of the pulp (sce_PW). Sagittal measurement at pulp horn level. In order to locate this level, the red horizontal line was moved from the cementoenamel junction to the pulp horn. After the pulp horn level was located, the incisor crown width was measured (sph_CW). Sagittal vertical measurements: (a) root length: from the apex to the cementoenamel junction following the curvature of the tooth (s_RL); (b) pulp chamber length: from the cementoenamel junction to the end of the pulp at crown level (s_PCL) (c) incisal length: from the incisal edge to the

beginning of the pulp chamber (s_IL); (d) total tooth length: the sum of (a), (b) and (c) (s_TTL)

Coronal Slice: coronal measurements at cemento-enamel junction level: (a) mesiodistal tooth length:

from the most mesial point to the most distal point of the incisor (cce_MDTL); (b) mesiodistal pulp length: from the most mesial point to the most distal point of the pulp (cce_MDPL). Coronal measurements at pulp horn level: (a) mesiodistal tooth length: from the most mesial point to the most distal point of the incisor (cph_MDTL); (b) mesiodistal pulp length: from the most mesial point to the most distal point of the pulp (cph_MDPL).

Axial Slice: axial measurements at cemento-enamel junction level: (a) mesiodistal tooth length:

from the most mesial and central point to the most distal and central point (ace_MDTL); (b) mesiodistal pulp length: from the most mesial point to the most distal point of the pulp (ace_MDPL); (c) palatovestibular tooth length: from the most vestibular-central point of the tooth to the most palatine-central point of the incisor (ace_PVTL); (d) palatovestibular pulp length: from the most vestibular point to the most palatine point of the pulp (ace_PVPL). Axial measurements at pulp horn level: (a) mesiodistal tooth length: from the most mesial point to the most distal point of the incisor (aph_MDTL); (b) mesiodistal pulp length: from the most mesial point to the most distal point of the pulp (aph_MDPL); (c) palatovestibular tooth length: from the most palatine point to the most vestibular point of the incisor (aph_PVTL).

Finally, for further analysis, ratios were calculated from the linear measurements obtained on the different slices and levels.

Standardized Molar measurement Protocol: to begin the measurements of the upper right first molar, we apply the program "rest volume rotation", so that the rotations that we have made for the measurements of incisors do not affect molar measurements.

Coronal Plane: CBCT provides cross-sectional images following the curvature of the dental arch, so we used the coronal section of CBCT to see a lateral image of the molar. In this plane we have to rotate the image to place each molar parallel to the horizontal line of CBCT, matching its cemento-enamel junction in the vestibular and palatine points with the red cursor. We will call this position correction "molar in neutral position". Due to this process, we correct the patient's head inclination when performing CBCT.

In this plan we make the following measure: a) total length of palatine root (neutral position) - we rotate the image until the tooth is as vertical as possible, so we put the red cursor to pass to the level of the amelo-cemental line both in vestibular and palatine. Then we carry out a dynamic search of the image until we find the upper limit of apex of the palatine root. After that, we measure from the apex to the red line, obeying the curvature of the root (M.S_TTL). Still in this plan, we carry out a dynamic search of the image until we find the most coronal area of the pulp of horns. Here, we mark a line, then we make a dynamic search of the furca where we put the red cursor and we make the following measurement: b) the height of the pulp chamber goes from the furca level located, to the line that marks the most coronal level of the pulp horns (M.CACP: molar pulp chambre height).

Axial Plane: we look for the area where the camera pulp is bigger and we take the following measures, these measures are all in the same slice: a) vestibule-palatine length-

goes from the midpoint of the buccal surface to the midpoint of the palatal surface (M.aph_PVTL); b) internal mesio-distal length-goes from the most mesial point of the pulp to the most distal point of the pulp (M.aph_MDPL); c) mesio-distal length- goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxilar arch (M.aph_MDTL).

Statistical Analysis: statistical analysis was performed using SPSS®v. 26.0 for Windows (IBM Corporation, Armond, NY, USA). Intraobserver and interobserver variability were assessed using intraclass correlation coefficient. Descriptive statistics were performed. The Kolmogorov–Smirnov test and the Levene test were applied to check for normality and the homogeneity distribution of the sample. One-way analysis of variance (ANOVA) with post hoc Bonferroni multiple comparison tests were used to compare linear measurements and ratios between age groups. Multivariate linear regression analyses were performed for age estimation based on sagittal, coronal and axial linear measurements and ratios. Statistical significance was set at $p \leq 0.05$.

Results

Regarding the anatomical measurements of upper central incisive on sagittal slices compared by gender we found that the following measurements - sagittal tooth width at cemento-enamel junction level (sce_TW), sagittal root length (s_RL), sagittal incisal length (s_IL), sagittal total tooth length (s_TTL), and sagittal incisor crown width at pulp horn level (sph_CW) - showed statistically significant differences between gender ($p < 0.05$), being higher in males than females. The anatomical measurements of upper central incisive on coronal slices compared by gender indicated that coronal mesiodistal tooth length (cce_MDTL) and coronal mesiodistal pulp length at cemento-enamel junction level (cce_MDPL) were statistically significant higher in males than in females. Linear measurements carried out on upper central incisive on axial plane showed that mesiodistal tooth length at axial cemento-enamel junction level (ace_MDTL), axial mesiodistal pulp length at cemento-enamel junction level (ace_MDPL), and axial palatovestibular tooth length at pulp horn level (aph_PVTL) were statistically significant higher in males than females. Regarding the linear measurements of the upper first molar on three anatomical planes compared by gender, we found that molar total tooth length (M.S_TTL) and molar pulp chamber height (M.CACP) showed statistically significant differences between genders, being higher in males. Regarding ratios of the upper central incisive on three anatomical planes compared by gender showed significant differences in some ratios being higher for females in pulp chamber length/total tooth length (s_PCL/s_TTL) and axial palatovestibular pulp length at cemento-enamel junction level/ axial mesiodistal tooth length at cemento-enamel junction level (ace_PVPL/ace_MDTL), and being higher for males in coronal mesiodistal pulp length at pulp horn level/coronal mesiodistal tooth length at pulp horn level (cph_MDPL/cph_MDTL). None of the ratios of the upper first molar on three anatomical planes presented significant differences by gender.

Anatomical measurements of upper central incisive on sagittal slices compared by age groups indicated that the variables tooth width at sagittal cemento-enamel junction level (sce_TW), sagittal pulp width at cemento-enamel junction level (sce_PW), incisor crown at sagittal pulp horn level (sph_CW), and sagittal pulp chamber length (s_PCL) showed statistically significant differences by age groups. Anatomical measurements of upper central incisive on coronal slices showed statistically significant differences in mesiodistal pulp length at coronal cemento-enamel junction level (cce_MDPL), coronal mesiodistal tooth length at pulp horn level (cph_MDTL), and coronal mesiodistal pulp length at pulp horn level

(cph_MDPL) compared by age groups. Anatomical measurements of upper central incisor on axial slices regarding age showed that mesiodistal pulp length at axial cementoenamel junction level (ace_MDPL), palatovestibular tooth length at axial cementoenamel junction level (ace_PVTL), axial palatovestibular pulp length at cementoenamel junction level (ace_PVPL), axial mesiodistal tooth length at pulp horn level (aph_MDTL), axial mesiodistal pulp length at pulp horn level (aph_MDPL), and axial palatovestibular tooth length at pulp horn level (aph_PVTL) were statistically significant different in age groups, presenting decreased values with age increasing in ace_MDPL, ace_PVPL, aph_MDTL, and aph_MDPL. Anatomical measurements of the upper first molar on three anatomical planes compared by age groups indicated statistically significant differences for M.CACP, showing a decrease with age increasing. Several sagittal ratios showed statistically significant differences regarding age groups: incisal length/total tooth length (s_{IL}/s_{TTL}); pulp chamber length/total tooth length (s_{PCL}/s_{TTL}); root length/total tooth length (s_{RL}/s_{TTL}); incisal length+pulp chamber length/total tooth length ($s_{IL}+s_{PCL}/s_{TTL}$); and pulp width at sagittal cementoenamel junction level/ tooth width at sagittal cementoenamel junction level (sce_{PW}/sce_{TW}). Coronal ratios of upper central incisor compared by age groups indicated that coronal mesiodistal pulp length at cementoenamel junction level/coronal mesiodistal tooth length at coronal cementoenamel junction level (cce_{MDPL}/cce_{MDTL}), and coronal mesiodistal pulp length at pulp horn level/coronal mesiodistal tooth length at pulp horn level showed statistically significant differences (cph_{MDPL}/cph_{MDTL}). Axial ratios of upper central incisor compared by age groups indicated that axial mesiodistal pulp length at cementoenamel junction level/axial mesiodistal tooth length at cementoenamel junction level (ace_{MDPL}/ace_{MDTL}), palatovestibular pulp length at axial cementoenamel junction level/axial palatovestibular tooth length at cementoenamel junction level (ace_{PVPL}/ace_{PVTL}), axial palatovestibular pulp length at cementoenamel junction level/axial mesiodistal tooth length at cementoenamel junction level (ace_{PVPL}/ace_{MDTL}), axial mesiodistal pulp length at pulp horn level/axial mesiodistal tooth length at pulp horn level (aph_{MDPL}/aph_{MDTL}), and axial palatovestibular tooth length at pulp horn level/axial mesiodistal tooth length at pulp horn level (aph_{PVTL}/aph_{MDTL}) showed statistically significant differences by age groups. Sagittal and axial ratios of the upper first molar on three anatomical planes showed significant differences for M.CACP/M.S_TTL, regarding age groups.

Multiple linear regressions for age estimation based on sagittal, coronal, and axial linear measurements and ratios were independently performed. The equations obtained from sagittal linear measurements and ratios presented a standard error of the estimate (SEE) of 12.4 years ($R^2 = 0.36$), and a SEE of 12.4 years ($R^2 = 0.37$), respectively. The equations obtained from coronal linear measurements and ratios presented a SEE of 12.3 years ($R^2 = 0.37$), and a SEE of 13.7 years ($R^2 = 0.22$), respectively. The equations obtained from axial linear measurements and ratios presented a SEE of 10.9 years ($R^2 = 0.49$), and a SEE of 10.8 years ($R^2 = 0.50$), respectively.

The binary logistic regression models for predicting gender indicated that ace_MDTL demonstrates a significant positive effect on predicting male gender, ($\beta = 1.459$, aOR = 4.302, $p = 0.003$), indicating that higher values of ace_MDTL are associated with a substantially increased likelihood of being male. Similarly, M.aph_PVTL shows a significant positive effect on predicting male gender ($\beta = 0.563$, aOR = 1.757, $p = 0.014$). Ratios did not prove to be an accurate solution to predict gender male.

Conclusion

The present study shows that CBCT linear measurements on upper central incisors and upper first molar is an acceptable method for age and gender estimation. Regarding age estimation, CBCT multiplanar measurements, axial measurements and ratios are the methods than have better predictive capacity. It was not possible to establish a direct overall association between age and higher or lower measurement parameters. Nevertheless, there seems to be a reduction in the parameters over the years, mainly for variables that affect the pulp. Thus, for the sagittal plane, we should consider the sagittal pulp width at cemento-enamel junction level (sce_PW) and the sagittal pulp chamber length (s_PCL). For coronal plane, we should consider the coronal mesiodistal pulp length at pulp horn level (cph_MDPL) and the molar pulp chamber height (M.CACP). For axial plane, we should take into consideration the axial palatovestibular pulp length at cemento-enamel junction level (ace_PVPL) and the axial mesiodistal pulp length at pulp horn level (aph_MDPL). The most suitable characteristic for forensic age estimation is axial mesiodistal pulp length at pulp horn level (aph_MDPL). This study shows also that linear measurements on CBCT of the upper central incisor and upper first molar are higher in males than in females.

These higher male values of measurements related to males occur across all anatomic planes on CBCT, for both the upper central incisor and the upper first molar, with no apparent difference. Ratios were not better at establishing differences between males and females than the other measurements. Predictions concerning gender are useful to detect females, but not as much to detect males. The most suitable characteristic for forensic gender estimation is axial mesiodistal tooth length at cemento-enamel junction level (ace_MDTL). Although CBCT could be an important tool for forensic dentistry, future research should determine whether combining several CBCT age and gender estimation methods could improve results. Automatic software development is likely to make integrating measurement methods faster and more efficient.

Introducción

La estimación de la edad y la determinación del género es un aspecto importante de las investigaciones forenses y las cuestiones legales. Las técnicas forenses basadas en estructuras óseas dejan de ser útiles ante daños estructurales graves. Sin embargo, dado que los dientes son muy difíciles de destruir, suponen una de las principales herramientas forenses para la estimación de la edad y el género. Además, la literatura científica sugiere que ciertas medidas dentales proporcionan una alta precisión para la estimación de la edad y la determinación del género. Por estos motivos, la odontología forense está desempeñando un papel cada vez más relevante. Laccasagne, en 1889 (Altini, 1983), fue el primero en intentar determinar la edad utilizando la dentición. Posteriormente, en 1925, Bodecker señaló que ciertos cambios morfológicos en los dientes podrían estar relacionados con un incremento de la edad. Desde entonces, se han utilizado una serie de características dentales para determinar la edad: (i) desgaste del diente, (ii) transparencia de la dentina radicular, (iii) deposición de dentina secundaria, (iv) medición del anillo del cemento, (v) recuento de estrías de Retzius, (vi) análisis con radio carbono y (vii) mineralización de terceros molares, entre otros. Los métodos basados en técnicas bioquímicas e histológicas que requieren extracción dental son difíciles de aplicar, consumen mucho tiempo y son muy costosos cuando hay muchos especímenes que identificar.

En cuanto a las características de los dientes a tener en cuenta para establecer diferencias entre varones y mujeres, de manera sucinta y generalizada, se describe que las mujeres tienen dientes más pequeños que los hombres, siendo considerado el incisivo central superior el diente que presenta mayor dimorfismo, mostrando un mayor tamaño en dirección mesiodistal en el varón. Los varones también tienen dientes más cuboides, con superficies más planas y ángulos más agudos, mientras que las mujeres tienen dientes con ángulos más redondeados.

Las técnicas de imagen dental, como la tomografía computarizada de haz cónico (CBCT), podrían ser de gran ayuda. Además, el hecho de que permitan el almacenamiento de registros a largo plazo y su fácil portabilidad hace que estas técnicas de obtención de imágenes sean un complemento valioso e inevitable para la investigación forense. El depósito de dentina secundaria es un parámetro importante para la estimación de la edad porque continúa produciéndose durante toda la vida y puede medirse con técnicas de imagen. A lo largo de la vida, el depósito de dentina secundaria provoca una disminución del tamaño de la cavidad pulpar. En base a este hecho, diversos autores han estimado la edad cronológica con técnicas de imagen. No obstante, los sistemas de imágenes bidimensionales son insuficientes porque producen variaciones dimensionales, se limitan a dimensiones mesiodistales y el análisis se ve obstaculizado por factores como malposiciones y superposiciones. Por tanto, las imágenes 3D son esenciales para una identificación forense precisa. Vanderwoort et al. fueron los primeros en aplicar métodos de medición 3D para estimar la edad basándose en el depósito de la dentina secundaria. Se han realizado investigaciones posteriores que analizan mediciones

lineales, áreas y volúmenes utilizando micro-CT, CT o CBCT. A diferencia de investigaciones anteriores sobre el tema, el presente estudio ha incluido un análisis mucho más exhaustivo que involucra múltiples mediciones lineales y proporciones en los tres cortes del CBCT.

La identificación de la edad y el sexo con fines forenses sigue siendo difícil. Aunque se han reportado diferentes métodos basados en el análisis de los dientes, sigue siendo un desafío encontrar el método ideal. Los objetivos de esta investigación fueron evaluar posibles diferencias en el incisivo central superior derecho en edad y género en una muestra de humanos adultos; evaluar posibles diferencias en el primer molar superior derecho en edad y género y obtener ecuaciones de regresión para estimar la edad y el género en adultos a través de mediciones lineales y proporciones en cortes sagitales, coronales y axiales de incisivos centrales y primeros molares superiores utilizando CBCT.

Material y métodos

Muestra. En este estudio se seleccionaron aleatoriamente 360 CBCT. El tamaño de la muestra se determinó mediante la fórmula de Slovin. Los CBCT fueron realizados entre 2012 y 2017 con el objetivo de planificar el tratamiento de diversos procedimientos, principalmente quirúrgicos orales, en la Unidad de Radiología de la Facultad de Medicina y Odontología de la Universidad de Santiago de Compostela. Se llevaron a cabo mediciones lineales y proporciones en los cortes sagitales, coronales y axiales del incisivo central superior y del primer molar superior mediante CBCT.

Criterios de inclusión y exclusión. Los criterios de inclusión fueron los siguientes: (1) pacientes mayores de 18 años, (2) maxilar con al menos un incisivo central superior y (3) CBCT con una calidad de imagen de tamaño de vóxel mínimo de 0,3 mm. Los criterios de exclusión fueron los siguientes: (1) imágenes CBCT imposibles de rotar, borrosas o incompletas, (2) caries, restauración o tratamiento de endodoncia, (3) coronas o elementos de ortodoncia de cerámica/metal y (4) conducto radicular calcificado. o reabsorción radicular.

Evaluación electrónica de imágenes: cada CBCT se llevó a cabo utilizando i-CAT® Modelo 17–19 (Imaging Sciences International Inc., Hatfield, PA, EE. UU.) con un detector de panel plano de silicio amorfo, un protocolo de exposición de 120 kV y una corriente de 5 mA. durante 14,7 s. El plano oclusal del paciente se fijó paralelo al suelo adaptando unas varillas para las orejas y una mentonera. Los archivos DICOM se reconstruyeron en un ordenador (Samsung R522, Samsung Electronics, Seúl, Corea) utilizando el software de visualización 3D iCATVision® v. 1.9. El espesor del corte CBCT se fijó en 0,25 mm.

Respecto a la declaración ética se obtuvo el consentimiento informado por escrito de todos los pacientes. Cumpliendo con los requisitos éticos, metodológicos y legales, este estudio fue aprobado por el Comité de Ética de la Investigación Clínica de Galicia (Ref: 2012/272). Los métodos se llevaron a cabo de acuerdo con las directrices y reglamentos pertinentes.

Respecto al protocolo estandarizado de medición de los incisivos se realizaron mediciones multiplanares (sagitales, coronales y axiales) procediendo de la siguiente forma:

Plano sagital: mediciones sagitales a nivel de la unión del cemento esmalte. Las mediciones lineales se obtuvieron en la "posición neutra del incisivo" que se logró colocando la línea roja horizontal del programa CBCT a nivel de la unión cemento esmalte del incisivo central superior: (a) ancho del diente: desde el punto más palatino hasta el punto más

vestibular del incisivo(sce_TW); b) ancho de la pulpa: se obtiene desde el punto más palatino hasta el punto más vestibular de la pulpa (sce_PW). Para ubicar la medición sagital a nivel del cuerno pulpar la línea horizontal roja se movió desde la unión de la unión cemento-esmalte hasta el cuerno de la pulpa. Después de localizar el nivel del cuerno pulpar, se midió el ancho de la corona del incisivo (sph_CW). Las medidas verticales sagitales fueron: (a) longitud de la raíz: desde el ápice hasta la unión cemento-esmalte engañando la curvatura del diente (s_RL); b) longitud de la cámara pulpar: desde la unión cemento-esmalte hasta el extremo de la pulpa a nivel de la corona (s_PCL) c) longitud incisal: desde el borde incisal hasta el comienzo de la cámara pulpar (s_IL); d) longitud total de los dientes: la suma de los apartados a), b) y c) (s_TTL).

Corte coronal. Las medidas coronales a nivel de la unión del cemento-esmalte fueron: (a) longitud del diente mesiodistal: desde el punto más mesial hasta el punto más distal del incisivo (cce_MDTL); b) longitud de la pulpa mesiodistal: desde el punto más mesial hasta el punto más distal de la pulpa (cce_MDPL) Las medidas coronales a nivel del cuerno pulpar fueron: (a) longitud del diente mesiodistal: desde el punto más mesial hasta el punto más distal del incisivo (cph_MDTL); b) longitud de la pulpa mesiodistal: desde el punto más mesial hasta el punto más distal de la pulpa (cph_MDPL).

Corte axial. Las medidas axiales a nivel de la unión del esmalte de cemento fueron: (a) longitud del diente mesiodistal, desde el punto más mesial y central hasta el punto más distal y central (ace_MDTL); b) longitud mesiodistal de la pulpa, desde el punto más mesial hasta el punto más distal de la pulpa (ace_MDPL); c) longitud del diente palatovestibular, desde el punto más vestibular-central del diente hasta el punto más palatino-central del incisivo (ace_PVTL); d) Longitud de la pulpa palatovestibular: desde el punto más vestibular hasta el punto más palatino de la pulpa (ace_PVPL). Medidas axiales a nivel del cuerno pulpar: (a) longitud del diente mesiodistal: desde el punto más mesial hasta el punto más distal del incisivo (aph_MDTL); b) longitud mesiodistal de la pulpa: desde el punto más mesial hasta el punto más distal de la pulpa (aph_MDPL); c) longitud de los dientes palatovestibulares; desde el punto más palatino hasta el punto más vestibular del incisivo (aph_PVTL). Finalmente, para su posterior análisis, se calcularon las proporciones a partir de las mediciones lineales obtenidas en los diferentes cortes y niveles.

Protocolo estandarizado de medición molar: para comenzar las mediciones del primer molar superior derecho, aplicamos el programa "rotación de volumen en reposo", para que las rotaciones que hemos realizado para las mediciones de incisivos no afecten a las medidas molares.

Plano coronal: La CBCT proporciona imágenes transversales siguiendo la curvatura de la arcada dental, por lo que utilizamos la sección coronal de la CBCT para ver una imagen lateral del molar. En este plano tenemos que rotar la imagen para colocar cada molar paralelo a la línea horizontal del CBCT, haciendo coincidir su unión cemento-esmalte en los puntos vestibular y palatino con el cursor rojo. Llamaremos a esta corrección de posición "molar en posición neutra". Debido a este proceso, corregimos la inclinación de la cabeza del paciente al realizar CBCT. En este plano hacemos la siguiente medida: a) longitud total de la raíz palatina (posición neutra) - rotamos la imagen hasta que el diente quede lo más vertical posible, por lo que ponemos el cursor rojo para pasar al nivel de la línea amelo-cemental tanto en vestibular como en palatino. Luego realizamos una búsqueda dinámica de la imagen hasta encontrar el límite superior del ápice de la raíz palatina. Después de eso, medimos desde el ápice hasta la línea roja, obedeciendo la curvatura de la raíz (M.S_TTL). Siguiendo en este plano,

realizamos una búsqueda dinámica de la imagen hasta encontrar la zona más coronal de la pulpa de los cuernos. Aquí, marcamos una línea, luego hacemos una búsqueda dinámica de la furca donde ponemos el cursor rojo y hacemos la siguiente medición: b) la altura de la cámara pulpar va desde el nivel de la furca ubicado, hasta la línea que marca el nivel más coronal de los cuernos pulpar (M.CACP: altura de la cámara pulpar molar).

Plano Axial: buscamos la zona donde la pulpa de la cámara es más grande y tomamos las siguientes medidas, estas medidas están todas en el mismo corte: a) vestíbulo-longitud palatina- va desde el punto medio de la superficie bucal hasta el punto medio de la superficie palatina (M.aph_PVTL); b) longitud mesio-distal interna: va desde el punto más mesial de la pulpa hasta el punto más distal de la pulpa (M.aph_MDPL); c) longitud mesio-distal- va desde el punto más mesial y central hasta el punto más distal y central del diente, obedeciendo a la curvatura del arco maxilar (M.aph_MDTL).

Análisis estadístico: el análisis estadístico se realizó con el programa SPSS®v. 26.0 para Windows (IBM Corporation, Armond, NY, USA). La variabilidad intraobservador e interobservador se evaluó mediante el coeficiente de correlación intraclase. Se realizó estadística descriptiva. Se aplicó la prueba de Kolmogorov-Smirnov y la prueba de Levene para comprobar la normalidad y la distribución homogénea de la muestra. Se utilizó el análisis de varianza de una vía (ANOVA) con pruebas de comparación múltiple de Bonferroni post hoc para comparar medidas lineales y razones entre grupos de edad. Se realizaron análisis de regresión lineal multivariada para la estimación de la edad a partir de medidas y razones lineales sagitales, coroneles y axiales. La significación estadística se fijó en $p \leq 0,05$.

Resultados

En cuanto a las medidas anatómicas de los incisivos centrales superiores realizadas en los cortes sagitales y comparadas por género encontramos que el ancho del diente, en el plano sagital, a nivel de la unión del amelocementaria (sce_TW), la longitud de la raíz en el plano sagital (s_RL), la longitud incisal en el plano sagital (s_IL), la longitud total del diente en el plano sagital (s_TTL) y el ancho de la corona del incisivo, en el plano sagital, a nivel del cuerno pulpar (sph_CW), mostraron diferencias estadísticamente significativas entre géneros ($p < 0.05$), siendo mayores en varones que en mujeres. Las mediciones anatómicas de los incisivos centrales superiores en los cortes coroneles comparados por género indicaron que la longitud mesiodistal del diente, en el plano coronal, a nivel de la unión amelocementaria (cce_MDTL) y la longitud mesiodistal de la pulpa, en el plano coronal, a nivel de la unión amelocementaria (cce_MDPL) fueron estadísticamente significativamente mayores en los varones con respecto a las mujeres. Las mediciones lineales realizadas en el incisivo central superior en el plano axial mostraron que la longitud mesiodistal del diente, en el plano axial, a nivel de la unión amelocementaria (ace_MDTL), la longitud mesiodistal de la pulpa, en el plano axial, a nivel de la unión amelocementaria (ace_MDPL) y la longitud palatovestibular del diente, en el plano axial, a nivel del cuerno pulpar (aph_PVTL) fueron estadísticamente significativamente mayores en los varones. En cuanto a las medidas lineales del primer molar superior en los tres planos anatómicos, comparadas por género, encontramos que longitud total del diente molar (M.S_TTL) y altura de la cámara pulpar del molar (M.CACP) mostraron diferencias estadísticamente significativas entre géneros, siendo mayores en los varones. Con respecto a las proporciones de los incisivos centrales superiores en los tres planos anatómicos analizados atendiendo al género, se observaron diferencias estadísticamente significativas en algunas proporciones, siendo mayores para las mujeres la proporción longitud de la cámara pulpar, en el plano sagital respecto a la longitud total del

diente, en el plano sagital (s_PCL/s_TTL) y la proporción longitud palatovestibular de la pulpa, en el plano axial, a nivel de la unión amelocementaria respecto a la longitud mesiodistal del diente, en el plano axial, a nivel de la unión amelocementaria (ace_PVPL/ace_MDTL), y siendo mayores para los varones la proporción de longitud mesiodistal de la pulpa, en el plano coronal, a nivel del cuerno pulpar respecto a la longitud mesiodistal del diente, en el plano coronal, a nivel del cuerno pulpar (cph_MDPL/cph_MDTL). Ninguna de las proporciones del primer molar superior en los tres planos anatómicos mostró diferencias estadísticamente significativas por género.

Las mediciones anatómicas del incisivo central superior en los cortes sagitales comparadas por grupos de edad indicaron que las variables ancho del diente, en el plano sagital, a nivel de la línea amelocementaria (sce_TW), ancho de la pulpa, en el plano sagital, a nivel de unión amelocementaria (sce_PW), ancho de la corona del incisivo, en el plano sagital, a nivel del cuerno pulpar (sph_CW) y la longitud de la cámara pulpar en el plano sagital (s_PCL) mostraron diferencias estadísticamente significativas entre los distintos grupos de edad. Las mediciones anatómicas de los incisivos centrales superiores en los cortes coronales mostraron diferencias estadísticamente significativas en cce_MDPL , cph_MDTL y cph_MDPL , al realizar el análisis por grupos de edad. Las mediciones anatómicas de los incisivos centrales superiores en cortes axiales con respecto a la edad mostraron que ace_MDPL , ace_PVTL , ace_PVPL , la longitud mesiodistal del diente, en el plano axial, a nivel del cuerno pulpar (aph_MDTL), la longitud mesiodistal de la pulpa dental, en el plano axial, a nivel del cuerno pulpar (aph_MDPL) y aph_PVTL mostraron diferencias estadísticamente significativas, observándose que los valores disminuyen al aumentar la edad en ace_MDPL , ace_PVPL , aph_MDTL y aph_MDPL . Las mediciones anatómicas del primer molar superior en los tres planos anatómicos analizadas en los distintos grupos de edad indicaron diferencias estadísticamente significativas para M.CACP, mostrando una disminución con el aumento de la edad. Varios índices sagitales mostraron diferencias estadísticamente significativas con respecto a los grupos de edad. Estos son: s_IL/s_TTL , s_PCL/s_TTL , s_RL/s_TTL , s_IL+s_PCL/s_TTL y sce_PW/sce_TW . Las proporciones coronales de los incisivos centrales superiores comparadas por grupos de edad indicaron que cce_MDPL/cce_MDTL y cph_MDPL/cph_MDTL muestran diferencias estadísticamente significativas. Las proporciones axiales de los incisivos centrales superiores comparadas por grupos de edad indicaron que ace_MDPL/ace_MDTL , ace_PVPL/ace_PVTL , ace_PVPL/ace_MDTL , aph_MDPL/aph_MDTL y aph_PVTL/aph_MDTL mostraron diferencias estadísticamente significativas por grupos de edad. Las relaciones sagitales y axiales del primer molar superior en tres planos anatómicos mostraron diferencias significativas para M.CACP/M.S_TTL con respecto a los grupos de edad.

Se realizaron de forma independiente regresiones lineales múltiples para la estimación de la edad basadas en mediciones lineales, en los tres planos anatómicos, y proporciones. Las ecuaciones obtenidas a partir de las mediciones lineales y ratios, en el plano sagital, presentaron un error estándar de estimación (SEE) de 12,4 años ($R^2 = 0,36$) y un SEE de 12,4 años ($R^2 = 0,37$), respectivamente. Las ecuaciones obtenidas de las mediciones lineales, en el plano coronal, y de los ratios presentaron un SEE de 12,3 años ($R^2 = 0,37$) y un SEE de 13,7 años ($R^2 = 0,22$), respectivamente. Las ecuaciones obtenidas a partir de mediciones lineales, en el plano axial, y ratios presentaron un SEE de 10,9 años ($R^2 = 0,49$) y un SEE de 10,8 años ($R^2 = 0,50$), respectivamente.

Los modelos de regresión logística binaria para predecir el género indicaron que ace_MDTL demuestra un efecto positivo significativo en la predicción del género masculino

($\beta = 1,459$, aOR = 4,302, $p = 0,003$), lo que indica que valores más altos de ace_MDTL se asocian con una probabilidad sustancialmente mayor de ser varón. De manera similar, la longitud palatovestibular del molar, en el plano axial, a nivel del del cuerno pulpar (M.aph_PVTL) muestra un efecto positivo significativo en la predicción del género masculino ($\beta = 0,563$, aOR = 1,757, $p = 0,014$). Las proporciones no han mostrado una solución precisa para predecir el género masculino.

Conclusión

El presente estudio muestra que las mediciones lineales realizadas en CBCT sobre el incisivo central superior y sobre el primer molar superior son un método aceptable para la estimación del género y la edad. En cuanto a la estimación de la edad, las medidas multiplanares CBCT, las mediciones axiales y las razones son los métodos que tienen mejor capacidad predictiva. No fue posible establecer una asociación global directa entre la edad y los parámetros de medición más altos o más bajos. Sin embargo, parece haber una reducción de los parámetros a lo largo de los años, principalmente por variables que afectan a la pulpa. Por lo tanto, para el plano sagital, debemos considerar el ancho de la pulpa sagital a nivel de la unión del cemento esmalte (sce_PW) y la longitud de la cámara pulpar sagital (s_PCL). Para el plano coronal, debemos considerar la longitud de la pulpa mesiodistal coronal a nivel del cuerno pulpar (cph_MDPL) y la altura de la cámara pulpar molar (M.CACP). Para el plano axial, debemos tener en cuenta la longitud de la pulpa palatovestibular axial a nivel de la unión del cemento esmalte (ace_PVPL) y la longitud de la pulpa mesiodistal axial a nivel del cuerno de la pulpa (aph_MDPL). La característica más adecuada para la estimación forense de la edad es la longitud de la pulpa mesiodistal axial a nivel del cuerno pulpar (aph_MDPL). Este estudio también muestra que las mediciones lineales en CBCT del incisivo central superior y del primer molar superior son mayores en los hombres que en las mujeres. Estos valores masculinos más altos de las mediciones relacionadas con los hombres ocurren en todos los planos anatómicos en CBCT, tanto para el incisivo central superior como para el primer molar superior, sin diferencia aparente. Las proporciones no fueron mejores para establecer diferencias entre hombres y mujeres que las otras mediciones. Las predicciones sobre el género son útiles para detectar a las mujeres, pero no tanto para detectar a los hombres. La característica más adecuada para la estimación forense del sexo es la longitud del diente mesiodistal axial a nivel de la unión del cemento esmalte (ace_MDTL). Aunque el CBCT puede ser una herramienta importante para la odontología forense, investigaciones futuras deberían determinar si la combinación de varios métodos de estimación de la edad y el género usando el CBCT podría mejorar los resultados. Es probable que el desarrollo automático de un software haga que la integración de los métodos de medición sea más rápida y eficiente.

Introdución

A estimación da idade e da determinación do xénero é un aspecto importante das investigacións forenses e das cuestións legais. As técnicas forenses baseadas en estruturas óseas deixen de ser útiles ante danos estruturais graves. Sen embargo, dado que os dentes son moi difíciles de destruír, supoñen unha das principais ferramentas forenses para a estimación da idade e do xénero. Ademais, a literatura científica suxire que certas medidas dentais proporcionan unha alta precisión para a estimación da idade e da determinación do xénero. Por estes motivos, a odontoloxía forense está desempeñando un papel cada vez máis relevante. Laccasagne, en 1889 (Altini, 1983), foi o primeiro en intentar determinar a idade utilizando a dentición. Posteriormente, en 1925, Bodecker sinalou que certos cambios morfolóxicos nos dentes poderían estar relacionados cun incremento da idade. Desde entón, empregáronse una serie de características dentais para determinar a idade: (i) desgaste do dente, (ii) transparencia da dentina radicular, (iii) deposición da dentina secundaria, (iv) medición do anel de cemento, (v) recuento das estrías de Retzius, (vi) análise co radio carbono e (vii) mineralización dos terceiros molares, entre outros. Os métodos basados en técnicas bioquímicas e histolóxicas que requiren extracción dental son difíciles de aplicar, consumen moito tempo e son moi custosos cando hai moitos espécimes que identificar.

En canto ás características dos dentes a ter en conta para establecer diferenzas entre varones e mulleres, de maneira sucinta e xeneralizada, indica que as mulleres teñen dentes máis pequenos que os varón, sendo considerado o incisivo central superior o dente que presenta maior dimorfismo, mostrando un maior tamaño en dirección mesiodistal no varón. Os varóns tamén teñen dentes máis cuboides, con superficies máis planas e ángulos máis agudos, mentres que as mulleres teñen dentes con ángulos máis redondeados.

As técnicas de imaxen dental, como a tomografía computarizada de feixe cónico (CBCT), poderían ser de gran axuda. Ademais, o feito de que permitan o almacenamento de rexistros a longo prazo e a súa fácil portabilidade fai que estas técnicas de obtención de imaxes sexan un complemento valioso e inevitable para a investigación forense. O depósito da dentina secundaria é un parámetro importante para a estimación da idade porque continúa producíndose durante toda a vida e pode medirse con técnicas de imaxe. Ao longo da vida, o depósito da dentina secundaria provoca unha diminución do tamaño da cavidade pulpar. En base a este feito, diversos autores estimaron a idade cronolóxica con técnicas de imaxe. Non obstante, os sistemas de imaxes bidimensionais son insuficientes porque producen variacións dimensionais, se limitan a dimensións mesiodistais e a análise vese obstaculizado por factores como malposicións e superposicións. Por tanto, as imaxes 3D son esenciais para unha identificación forense precisa. Vanderwoort et al. foron os primeiros en aplicar métodos de medición 3D para estimar a idade basándose no depósito da dentina secundaria.

Investigacións posteriores analizan medicións lineais, áreas e volúmenes utilizando micro-CT, CT o CBCT. A diferenza de investigación feitas ata agora, o presente estudo incluíu un análise moito máis exhaustivo que involucra múltiples medicións lineais e proporcións nos tres cortes do CBCT.

A identificación de idade e xénero con fins forenses segue sendo difícil. Aínda que se informou de diferentes métodos baseados na análise dos dentes, segue sendo un reto atopar o método ideal. Os obxectivos desta investigación foron avaliar posibles diferenzas no incisivo central superior en idade e xénero nunha mostra de humanos adultos; ademais, avaliar posibles diferenzas no primer molar superior en idade e xénero e obter ecuacións de regresión para estimar a idade e o xénero en adultos a través de medidas lineais e proporcións en cortes saxitais, coronais e axiais do incisivo central e do primeiro molar superiores utilizando CBCT.

Material e métodos

Mostra. Neste estudo seleccionáronse aleatoriamente 360 CBCT. O tamaño da mostra determinouse mediante a fórmula de Slovin. Os CBCT foron realizados entre 2012 e 2017 co obxectivo de planificar o tratamento de diversos procedementos, principalmente quirúrxicos orais, na Unidade de Radioloxía da Facultade de Medicina e Odontoloxía da Universidade de Santiago de Compostela. Levaronse a cabo medicións lineais e proporcións nas cortes saxitais, coronais e axiais do incisivo central superior e do primer molar superior, mediante CBCT.

Criterios de inclusión e exclusión. Os criterios de inclusión foron os seguintes: (1) pacientes maiores de 18 anos, (2) maxilar con a lo menos un incisivo central superior e (3) CBCT cunha calidade de imaxe de tamaño de vóxel mínimo de 0,3 mm. Os criterios de exclusión foron os seguintes: (1) imaxes CBCT imposibles de rotar, borrosas ou incompletas, (2) caries, restauración ou tratamento de endodoncia, (3) coroas ou elementos de ortodoncia de cerámica/metal e (4) conducto radicular calcificado ou reabsorción radicular.

Evaluación electrónica de imaxes. Cada CBCT levouse a cabo utilizando i-CAT® Modelo 17–19 (Imaging Sciences International Inc., Hatfield, PA, EE. UU.) cun detector de panel plano de silicio amorfo, un protocolo de exposición de 120 kV e unha corrente de 5 mA. durante 14,7 s. O plano oclusal do paciente púxose paralelo ao chan adaptando unhas varillas para as orellas e unha mentoneira. Os ficheiros DICOM reconstruíronse nun ordenador (Samsung R522, Samsung Electronics, Seúl, Corea) utilizando o software de visualización 3D iCATVision® v. 1.9. O espesor do corte CBCT fixouse en 0,25 mm.

Declaración ética: o consentimento informado por escrito obtívose de todos os pacientes. En cumprimento dos requisitos éticos, metodolóxicos e legais, este estudo foi aprobado polo Comité Ético Galego de Investigación Clínica (Ref: 2012/272). Os métodos realizáronse de acordo coas directrices e regulamentos pertinentes.

Protocolo de medida incisor estandarizado: medidas multiplanares (saxital, coronal e axial) foron realizadas polo investigador do seguinte xeito: Sagittal Slice: medidas saxitais a nivel de unión cementoenamel. Obtivéronse medidas lineais na "posición neutra incisivo" que se conseguiu colocando a liña vermella horizontal do programa CBCT a nivel de unión cementoenamel do incisor central superior: (a) anchura dentaria: desde o punto máis palatino ata o punto máis vestibular do incisor (sce_TW); (b) ancho da polpa: desde o punto máis palatino ata o punto máis vestibular da polpa (sce_PW). Medición saxital a nivel de corno de polpa. Para localizar este nivel, a liña horizontal vermella trasladouse desde a unión do

cementoenamel ata o corno de polpa. Despois de localizarse o nivel do corno de polpa, mediuse o ancho da coroa incisor (sph_CW). Medidas verticais saxitais: (a) lonxitude da raíz: desde o ápice ata a unión cementoenamel enganando a curvatura do dente (s_RL); (b) lonxitude da cámara de polpa: desde a unión do cemento esmalte ata o final da polpa a nivel coroa (s_PCL) (c) lonxitude incisal: desde o bordo incisal ata o comezo da cámara pulpa (s_IL); d) lonxitude total dos dentes: suma de (a), b) e c) (s_TTL). Slic coronal: medidas coronais a nivel de unión de cementoenamel: (a) lonxitude do dente mesiodistal: desde o punto máis mesial ata o punto máis distal do incisor (cce_MDTL); b) lonxitude da polpa mesiodistal: desde o punto máis mesial ata o punto máis distal da polpa (cce_MDPL). Medidas coronais a nivel de corno de polpa: (a) lonxitude do dente mesiodistal: desde o punto mostmesial ata o punto máis distal do incisor (cph_MDTL); b) lonxitude da polpa mesiodistal: desde o punto máis mesial ata o punto máis distal da polpa (cph_MDPL). Slicing axial: medidas axiais a nivel de unión de cementoenamel: (a) lonxitude do dente mesiodistal: desde o punto máis mesial e central ata o punto máis distal e central (ace_MDTL); b) lonxitude da polpa mesiodistal: desde o punto máis mesial ata o punto máis distal da polpa (ace_MDPL); c) lonxitude dos dentes palatovestibulares: desde o punto central máis vestibular do dente ata o punto central máis palatino do incisor (ace_PVTL); d) lonxitude da polpa palatovestibular: desde o punto máis vestibular ata o punto máis palatino da polpa (ace_PVPL). Medidas axiais a nivel de corno de polpa: (a) lonxitude do dente mesiodistal: desde o punto máis mesial ata o punto máis distal do incisor (aph_MDTL); b) lonxitude da polpa mesiodistal: desde o punto máis mesial ata o punto máis distal da polpa (aph_MDPL); c) lonxitude dos dentes palatovestibulares; Desde o punto máis palatino ata o punto máis vestibular do incisor (aph_PVTL).

Finalmente, para unha análise posterior, calculáronse ratios a partir das medicións lineais obtidas sobre as diferentes porcións e niveis.

Protocolo estandarizado de medición molar: para iniciar as medidas da parte superior dereita primeiro molar, aplicamos o programa "rotación de volume de repouso", de xeito que as rotacións que realizamos para as medicións de incisivos non afectan ás medidas molares. Plano coronal: CBCT proporciona imaxes transversais seguindo a curvatura do arco dental, polo que usamos a sección coronal do CBCT para ver unha imaxe lateral do molar. Neste plano temos que xirar a imaxe para colocar cada molar paralelo á liña horizontal de CBCT, igualando a súa unión cemento-esmalte nos puntos vestibulares e palatinos co cursor vermello. Chamaremos a esta corrección de posición "molar en posición neutral". Debido a este proceso, corriximos a inclinación da cabeza do paciente ao realizar CBCT.

Neste plan facemos a seguinte medida: a) lonxitude total de raíz palatina (posición neutra) - rotamos a imaxe ata que o dente sexa o máis vertical posible, polo que poñemos o cursor vermello para pasar ao nivel da liña amelo-cemental tanto en vestibular como en palatino. Logo realizamos unha busca dinámica da imaxe ata atopar o límite superior de ápice da raíz palatina. Despois medimos desde o ápice ata a liña vermella, obedecendo á curvatura da raíz (M.S_TTL). Aínda neste plan, realizamos unha procura dinámica da imaxe ata atopar a zona máis coronal da polpa de cornos. Aquí marcamos unha liña, logo facemos unha busca dinámica da furca onde poñemos o cursor vermello e facemos a seguinte medida: b) a altura da cámara pulpa vai desde o nivel de furca situado, ata a liña que marca o nivel máis coronal dos cornos de polpa (M.CACP: altura de chambre de polpa molar). Plano axial: buscamos a zona onde a polpa da cámara é máis grande e tomamos as seguintes medidas, estas medidas están todas na mesma rebanda: a) lonxitude vestibule-palatina- vai desde o punto medio da superficie bucal ata o punto medio da superficie palatal (M.aph_PVTL); b) a lonxitude mesio-

distal interna vai desde o punto máis mesial da polpa ata o punto máis distal da polpa (M.aph_MDPL); c) lonxitude mesio-distal- vai desde o punto máis mesial e central ata o punto máis distal e central do dente, obedecendo á curvatura do arco maxilar (M.aph_MDTL).

Análise estatística: a análise estatística realizouse usando SPSS®v. 26.0 para Windows (IBM Corporation, Armond, NY, USA). A variabilidade intraobserver e interobserver foi avaliada usando coeficiente de correlación intraclase. Realizáronse estatísticas descritivas. O test de Kolmogorov-Smirnov e a proba de Levene foron aplicados para comprobar a normalidade e a distribución de homoxeneidade da mostra. A análise unidireccional da varianza (ANOVA) con probas de comparación múltiples de Bonferroni post hoc utilizáronse para comparar medidas lineais e proporcións entre grupos de idade. Realizáronse análises de regresión lineal multivariantes para a estimación de idade baseadas en medidas e proporcións lineais saxitais, coronais e axiais. A significación estatística estableceuse na $p \leq 0.05$.

Resultados

En canto ás medidas anatómicas do incisivo central superior feitos nos cortes saxitais e comparadas por xénero atopamos que o ancho do dente, no plano saxital, ao nivel da unión amelocementaria (sce_TW), a lonxitude da raíz no plano saxital, (s_RL), a lonxitude incisal no plano saxital (s_IL), a lonxitude total do dente, no plano saxital, (s_TTL) e o ancho da coroa do incisivo, no plano saxital, a nivel do corno pulpar (sph_CW), mostran diferenzas estatisticamente significativas entre xéneros ($p < 0,05$), sendo maiores en varóns que en mulleres. As medicións anatómicas dos incisivos centrais superiores nos cortes coronais comparadas polo xénero indicaron que a lonxitude mesiodistal do dente, no plano coronal, a nivel da unión amelocementaria, (cce_MDTL) e a lonxitude mesiodistal da pulpa, no plano coronal, a nivel da unión amelocementaria, (cce_MDPL) foron estatisticamente significativamente maiores nos varóns con respecto ás mulleres. As medicións lineais realizadas no incisivo central superior no plano axial mostraron que a lonxitude mesiodistal do dente, no plano axial, a nivel da unión amelocementaria (ace_MDTL), a lonxitude da pulpa mesiodistal, no plano axial, a nivel da unión amelocementaria (ace_MDPL) e a lonxitude palatovestibular do dente, no plano axial, a nivel do corno pulpar (aph_PVTL) mostran diferenzas significativamente maiores nos varóns. En canto ás medidas lineais do primeiro molar superior nos tres planos anatómicos comparados por xénero atopamos que a lonxitude total do dente molar (M.S_TTL) e a altura da cámara pulpar do molar (M.CACP) mostran diferenzas estatisticamente significativas entre xéneros, sendo maiores nos varóns. Con respecto ás proporcións do incisivo central superior nos tres planos anatómicos analizados atendendo ao xénero, observáronse diferenzas estatisticamente significativas nalgúns proporcións, sendo maiores para as mulleres a lonxitude da cámara pulpar, no plano saxital respecto a lonxitude total do dente, no plano saxital (s_PCL /s_TTL) e a lonxitude palatovestibular da pulpa, no plano axial, a nivel da unión amelocementaria respecto a lonxitude mesiodistal do dente, no plano axial, a nivel da unión amelocementaria (ace_PVPL /ace_MDTL), e sendo maiores para os varóns a lonxitude mesiodistal da pulpa, no plano coronal, a nivel do corno pulpar respecto a lonxitude mesiodistal do dente, no plano coronal, a nivel do corno pulpar (cph_MDPL/ cph_MDTL). Ninguna das proporcións do primeiro molar superior nos tres planos anatómicos mostrou diferenzas significativas por xénero.

As medicións anatómicas do incisivo central superior no plano saxital, comparadas por grupos de idade, indicaron que as variables ancho do dente, no plano saxital, a nivel da unión amelocementaria (sce_TW), ancho da pulpa, no plano saxital, a nivel da unión amelocementaria (sce_PW), ancho da coroa do incisivo, no plano saxital, a nivel do corno

pulpar (sph_CW) e a lonxitude da cámara pulpar, no plano saxital (s_PCL) mostraron diferenzas estatisticamente significativas entre os diferentes grupos de idade. As medicións anatómicas do incisivo central superior no plano coroanl mostraron diferenzas estatisticamente significativas en cce_MDPL, cph_MDTL e cph_MDPL, ao analizarse por grupos de idade. As medidas anatómicas do incisivo central superior no planoaxial con respecto á idade mostraron que ace_MDPL, ace_PVTL, ace_PVPL, a lonxitude mesiodistal do dente, no plano axial, ao nivel do corno pulpar (aph_MDTL), aph_MDPL e aph_PVTL mostraron diferenzas estatisticamente significativas, observando que os valores diminúen co aumento da idade en ace_MDPL, ace_MDPL e aph_MDPL. As medidas anatómicas do primeiro molar superior nos tres planos anatómicos analizados nos diferentes grupos de idade indicaron diferenzas estatisticamente significativas para M.CACP, mostrando unha diminución co aumento da idade. Varios índices saxitais mostraron diferenzas estatisticamente significativas con respecto aos grupos de idade. Estes son: s_IL/ s_TTL, s_PCL/ s_TTL, s_RL/ s_TTL, s_IL+ s_PCL/ s_TTL e sce_PW/sce_TW. As proporcións coroais dos incisivos centrais superiores comparadas por grupos de idade indicaron que cce_MDPL/cce_MDTL e cph_MDPL/cph_MDTL mostran diferenzas estatisticamente significativas. As proporcións axiais dos incisivos centrais superiores comparadas por grupos de idade indicaron que ace_MDPL/ace_MDTL, ace_PVPL/ace_PVTL, ace_PVPL/ace_MDTL, aph_MDPL/aph_MDTL e aph_PVTL/aph_MDTL mostraron diferenzas estatisticamente significativas por grupos de idade. As proporcións saxitais e axiais do primeiro molar superior nos tres planos anatómicos mostraron diferenzas estadísticamente significativas para M.CACP/M.S_TTL con respecto aos grupos de idade.

Realizáronse múltiples regresións lineais de forma independente para a estimación da idade baseada en medidas lineais, nos tres planos anatómicos, e proporcións. As ecuacións obtidas a partir de medicións lineais e proporcións, no plano saxital, presentaron un erro estándar de estimación (SEE) de 12,4 anos ($R^2 = 0,36$) e un SEE de 12,4 anos ($R^2 = 0,37$), respectivamente. As ecuacións obtidas das medicións lineais, no plano coronal, e as proporcións presentaron un SEE de 12,3 anos ($R^2 = 0,37$) e un SEE de 13,7 anos ($R^2 = 0,22$), respectivamente. As ecuacións obtidas a partir de medidas lineais, no plano axial, e proporcións presentaron un SEE de 10,9 anos ($R^2 = 0,49$) e un SEE de 10,8 anos ($R^2 = 0,50$), respectivamente.

Os modelos de regresión loxística binaria para predicir o xénero indicaron que ace_MDTL demostra un efecto positivo significativo na predicción do xénero masculino ($\beta = 1,459$, aOR = 4,302, $p = 0,003$), o que indica que os valores máis altos de ace_MDTL están asociados cunha probabilidade substancialmente maior de ser varón. Do mesmo xeito, a lonxitude palatovestibular do molar, no plano axial, ao nivel do corno pulpar (M.aph_PVTL) mostra un efecto positivo significativo na predicción do xénero masculino ($\beta = 0,563$, aOR = 1,757, $p = 0,014$). As proporcións non foron unha solución precisa para predicir o xénero masculino.

Conclusión

O presente estudo mostra que as medicións lineais realizadas sobre o CBCT no incisivo central superior e no primeiro molar superior son un método aceptable para estimar o sexo e a idade. En canto á estimación de idade, as medicións multiplanares CBCT, as medicións axiais e as proporcións son os métodos que teñen unha mellor capacidade predictiva. Non foi posible establecer unha asociación global directa entre a idade e os parámetros de medición máis altos ou inferiores. Con todo, parece haber unha redución dos parámetros ao longo dos anos,

principalmente para variables que afectan á polpa. Así, para o plano saxital, debemos considerar a anchura da polpa saxital a nivel de unión de cementoenamel (sce_PW) e a lonxitude da cámara de polpa saxital (s_PCL). Para o plano coronal, debemos considerar a lonxitude da polpa mesiodistal coronal a nivel de corno de polpa (cph_MDPL) e a altura de chambre de polpa molar (M.CACP). Para plano axial, debemos ter en conta a lonxitude da polpa palatovestibular axial a nivel de unión de cementoenamel (ace_PVPL) e a lonxitude da polpa mesiodistal axial a nivel de corno de polpa (aph_MDPL). A característica máis adecuada para a estimación da idade forense é a lonxitude da polpa mesiodistal axial a nivel de corno de polpa (aph_MDPL). Este estudo mostra tamén que as medidas lineais sobre CBCT do incisivo central superior e o primeiro molar superior son máis altas nos machos que nas femias. Estes valores masculinos máis altos de medidas relacionadas cos machos ocorren en todos os planos anatómicos da CBCT, tanto para o incisivo central superior como para o primeiro molar superior, sen diferenza aparente. As proporcións non eran mellores para establecer diferenzas entre machos e femias que as outras medidas. As predicións relativas ao xénero son útiles para detectar femias, pero non tanto para detectar machos. A característica máis adecuada para a estimación de xénero forense é a lonxitude do dente mesiodistal axial a nivel de unión de cementoenamel (ace_MDTL). Aínda que o CBCT pode ser unha ferramenta importante para a odontoloxía forense, as investigacións futuras deberían determinar se a combinación de varios métodos de estimación de idade e xénero mediante o CBCT poderían mellorar os resultados. É probable que o desenvolvemento automático dun software faga que a integración dos métodos de medición sexa máis rápida e eficiente.

KEYWORDS

Dentistry forensic; age estimation; gender estimation; cone beam computed tomography; CBCT.

PALABRAS CHAVE

Odontoloxía forense; estimación da idade; estimación do xénero; tomografía computarizada de feixe cónico; CBCT.

PALABRAS CLAVE

Odontología forense; estimación de la edad; estimación del género; tomografía computarizada de haz cónico; CBCT.

DERIVED PUBLICATIONS OF THIS THESIS

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LIST OF ABBREVIATIONS

ace_MDPL	axial mesiodistal pulp length at cementoenamel junction level
ace_MDTL	axial mesiodistal tooth length at cementoenamel junction level
ace_PVPL	axial palatovestibular pulp length at cementoenamel junction level
ace_PVTL	axial palatovestibular tooth length at cementoenamel junction level
ANOVA	analysis of variance
aOR	adjusted odds ratio
aph_MDTL	axial mesiodistal tooth length at pulp horn level
aph_MDPL	axial mesiodistal pulp length at pulp horn level
aph_PVTL	axial palatovestibular tooth length at pulp horn level
CBCT	cone beam computed tomography
CI	confidence interval
CLs	confidence intervals
CT	computed tomography
cce_MDPL	coronal mesiodistal pulp length at cementoenamel junction level
cce_MDTL	coronal mesiodistal tooth length at cementoenamel junction level
cph_MDTL	coronal mesiodistal tooth length at pulp horn level
cph_MDPL	coronal mesiodistal pulp length at pulp horn level
DICOM	digital Imaging and Communication in Medicine
DL	disto-lingual
DNA	deoxyribonucleic acid
2D	two dimension
3D	three dimension
DV	disto vestibular
FCS	fully conditional specification
Fov	field of view
IC	central incisor
ICRP	international Commission on Radiological Protection
IL	lateral incisor
i-CAT® Model 17–19	imaging Sciences International Inc., Hatfield, PA, USA
ITK-SNAP	interactive tool for semi-automatic segmentation of multi-modality biomedical images
LB	lower bound
LRM	linear regression model
M	means
M.aph_MDPL	molar axial mesiodistal pulp length at pulp horn level

M.aph_MDTL	molar axial tooth length at pulp horn level
M.aph_PVTL	molar axial palatovestibular tooth length at pulp horn level
MATLAB	semi-automatic software
M.CACP	molar pulp chambre height
MCAR	missing completely at random test
MCI	mandibular canine index
MD	mesio-distal
MDCT	multidetector computed tomography
MICE	multivariate imputation by chained equations
MIN	minimum
ML	mesio-lingual
mLRM	multiple linear regression model
M.S_TTL	molar sagittal total tooth length
MAX	maximum
MV	mesio-vestibular
ORs	odds ratios
PM	premolar
Rx	Xray
sce_PW	sagittal pulp width at cementoenamel junction level
sce_TW	sagittal tooth width at cementoenamel junction level
SD	standard deviations
SEE	standard error of the estimate
s_IL	sagittal incisal length
s_PCL	sagittal pulp chamber length
sph_CW	sagittal incisor crown at pulp horn level
SPSS	statistical Package for the Social Sciences
s_TTL	sagittal total tooth length
s_RL	sagittal root length
Sv	sievert
VL	vestibulo-lingual
UB	upper bound

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1 INTRODUCTION

Currently, with natural disasters and an increase in terrorist attacks, the availability of a greater number of techniques for identifying dead bodies has become increasingly important. Thus, the forensic dental medicine can play an increasingly important role in this identification, due to the fact that teeth are anatomical structures resistant and present advantages in human identification versus other identification techniques (Erbudak et al., 2012; Kvaal et al., 1995). For instance, structure pelvic may be fragmented, DNA analysis is very expensive and bones in non-adults did not develop sexual characteristics (Levine et al., 2007).

The first researcher using dentition for age determination was Laccasagne in 1889 (Altini, 1983), followed by Bodecker, in 1925, who revealed that age increase could be responsible for some of the teeth's morphological changes in humans. After these works, several characteristics of the teeth have been used to determine age: (i) tooth wear; (ii) root dentin transparency; (iii) secondary dentin deposition; (iv) cementum annuli measurement; (v) Retzius striae count; (vi) aspartic acid racemization of dentin; (vii) radio carbon analysis; (viii) mineralization of third molars; and (ix) pulp volume (more recently) (Alkass et al., 2010; Huda & Bowman, 1995; Kazmi et al., 2019; Kvaal et al., 1995; Lamendin et al., 1992; Paewinsky et al., 2005; Thevissen et al., 2010; Tomaru et al., 1993).

Currently, new 3D radiological techniques can be used for the identification of dead bodies. Cone beam computed tomography (CBCT) (With Arai et al., 1999, and Mozzo et al., 1998) brought new radiological equipment that allows for obtaining high-quality images of anatomic structures with thin cuts. Several studies show the usefulness and effectiveness of CBCT for the identification of corpses (*e.g.* Alamri et al., 2012), arguing that it is possible to estimate age and gender (Alamri et al., 2012). For age estimation, different anatomic structures were used, such as volume of pulp teeth (Agematsu et al., 2010; Ge et al., 2016; Kazmi et al., 2019; Vandevoort et al., 2004), spheno-occipital synchondrosis (Can et al., 2014), and variations in inferior alveolar canal location (Levine et al., 2007). The teeth can be analyzed for age and gender estimation. With regard to gender estimation several studies carry out the radiological evaluation of different structures, such as foramen magnum (Fatteh, 1973; Teixeira, 1982; Uysal et al., 2005), maxillary sinus (Saccucci et al., 2015), stiloide process (Camarda, 1989a; Lengelé & Dhem, 1988;), third molars (Hashemipour et al., 2013; Murtomaa et al., 1985) and mandibular dimensions (Humphrey et al., 1999).

1.1 CONE BEAM COMPUTED TOMOGRAPHY- CBCT

The word *tomography* results from the combination of two Greek words, *tomos* and *graphos*, which mean parts and registration, respectively. We can then define tomography as a radiological examination that consists of obtaining images of the body in sections, with different planes, which allow for the observation of different anatomical structures with no, or a little, overlap (Whaites, 2008). Within CT scans we have the conventional linear CT scans and computerized CT scans, the latter of which can be subdivided into traditional fan beam

computed tomography and cone beam computed tomography or volumetric cone beam computed tomography (CBCT) (Schutzer et al., 2013). The first clinical applications of computed tomography date from 1971, introduced by Godfrey Hounsfield, who developed the first 3D capture technique in 1967 based on the mathematical works of Cormack. In 1979 these two scientists (Godfrey Hounsfield and Cormack) were distinguished with the Nobel Prize in Medicine and Physiology (Hounsfield, 1980). The development of helical tomography in 1989 (Kalender et al., 1989) and the introduction of multi-cut detectors in 1998 helped in the development of TC techniques and, consequently, led to an improvement in the quality of the acquired data. In 1990, CBCT was first developed for angiography due to its resolution in temporal and spatial measurements (Rougée et al., 1994), and for radiotherapy (Cho et al., 1995). In 1998, in Verona, Mozzo et al. (1998) developed the CBCT to be used in the dentomaxillofacial region with the creation of the NewTom QR-DVT 9000 (Quantitative Radiology). This equipment was cheaper than the traditional TC and had lower radiation dose with an elevated spatial resolution (Miles, 2012). The first CBCT unit for the craniofacial region was available for sale in Europe in 1999. After this first CBCT, others, with different fields of vision (FOV), appeared on the market.

Therefore, we can say that the CBCT represented a revolution in the image of the craniofacial complex. It emits a conical beam of RX that emits much lower radiation than the conventional TC. It allows us to select only the anatomical region under study and, as a consequence, the radiation dose is much lower. This also makes it possible to reduce the number of artifacts caused by patient movements, reduce the time to acquire the image and the economic cost of the exam.

1.1.1 How cone beam computed tomography works

In order to perform a CBCT image, we have to comply with 4 steps: 1st - configuration of image acquisition; 2nd - image detection; 3rd - image reconstruction; 4th – display preview.

For image acquisition, a narrow beam of rays is applied, which is collimated, pulsatile and cone-shaped. This beam only needs a single rotation from 180 to 360 around the area of interest to acquire the image, unlike the conventional TC, which needs several rotations to obtain the image under study (Mah & Hatcher, 2005). Therefore, with CBCT, the time for image acquisition can vary between 10 to 70 seconds, with the patient's radiation exposure time being shorter, ranging from 3 to 6 seconds (Araki et al., 2004). Since CBCT radiation is pulsatile, it allows the effective dose absorbed by patients to be much lower than that absorbed when performing a conventional TC (Miles, 2012). The volume of the scanned area, also called FOV, has a cylindrical shape and a variable size. We can have five different types of exploration depending on the height of the area selected for scanning and examination: limited field with 5 or less cm (it is similar to the size of the periapical); only one arch between 5 to 7 cm (maxillary or mandibular); interarch between 7 to 10 cm; maxillofacial (from the mandible to the nasio) between 10 to 15 cm; and craniofacial with more than 15 cm (from the inferior border to the vertex of the head) (Durack & Patel, 2012). It is important to note that the greater is the FOV, the greater the image of the anatomical area studied, the greater the exposure of the patient to radiation and the lower the resolution of the image obtained, as opposed to an FOV, limited to a specific study area. CBCT also provides us with a smaller image, with higher resolution, and, consequently, the patient's exposure to radiation is lower (Adibi et al., 2012; Scarfe & Farman, 2008).

The total volume of the scanned area is composed of voxels (volumetric pixels with 3 dimensions), a volumetric unit of measurement. The voxel in CBCT is isometric, having,

therefore, equal dimensions of height, width and depth. The choice of beams does not interfere with the acquisition and reconstruction of CBCTs systems and it will always measure the same, no matter which way you are looking at a certain physical property or magnitude. This means that some errors that occur during the image acquisition (*e.g.* patient malposition) could be corrected and adjusted later, interactively, without any distortion problems (Cattaneo & Melsen, 2008).

CBCT image has an excellent resolution because each voxel varies between less than 0.076 mm and 0.4mm (Scarfe & Farman, 2008). A high precision and a good sharpness of the image were demonstrated by some studies carried out to establish the quantitative and qualitative validity for the analysis of anatomical structures (Araki et al., 2004; Kobayashi et al., 2004). They also demonstrated that the measurements are geometrically precise for the CBCT data in any plane (Cotton et al., 2007; Scarfe et al., 2006).

1.1.2 Advantages and limitations of cone beam computed tomography

Compared to conventional radiography, CBCT offers the following advantages: CBCT systems generate volumetric and geometrically precise images composed of voxels that give a correct anatomical relationship and do not present distortions characteristics of bi-dimensional Rx, as conventional digital radiography techniques, which use pixels (Cattaneo & Melsen, 2008); compared to conventional two-dimensional radiographs, the reliability of linear and angular measurements obtained with CBCT show that it is not necessary to perform panoramic radiographs in patients who have undergone a CBCT as a diagnostic method (Cattaneo et al., 2008); with CBCT, it is possible to fully study the maxillofacial skeleton.

Compared to conventional TC, the advantages of CBCT are as follows:

- CBCTs offer a higher resolution than conventional TCs because data acquisition is isotropic and submillimeter (between 0.4 and 0.076 mm). CBCTs allow to obtain high-quality multiplanar reconstructions and perform very accurate linear and angular measurements (Farman & Scarfe, 2006; Ludlow et al., 2006; Mischkowski et al., 2007);
- The conical beam geometry allows for scanning/covering a larger volume with a lower dose compared to conventional tomography;
- Possibility of collimating the beam, which allows to limit the radiation to the area of interest for a given pathology;
- CBCT offers greater comfort patients when performed because they can be standing or sitting, and the soft tissues can be in a natural position;
- The artifacts at the occlusal level are smaller;
- Since the acquisition of images is fast, there are also fewer artefacts resulting from the movements of the patients;
- CBCTs are of a suitable size so that they can be used routinely, and, as a consequence, they end up being less expensive than conventional TCs;
- CBCT allows for long-term data storage and easy portability (Issrani et al., 2022).

CBCT's disadvantages compared to conventional tomography, are the following:

- CBCT provides a subjective assessment of bone quality;
- Even though CBCT has a higher resolution in the vertical plane, the contrast is usually higher in TC. The main disadvantage of CBCT compared to conventional tomography, especially in larger FOVs, is a limitation in image quality in relation to noise and contrast resolution, due to the detection of large amounts of scattered radiation (Scarfe & Farman, 2008);

- CBCT has a limitation in the size of the anatomical area to be studied because the field of view is usually smaller than in conventional TCs (Watanabe et al., 2011). This is because in CBCT the FOV has a greater restriction in the axial plane compared to TC, due to the geometry of the ray beam (Scarfe & Farman, 2008);
- There is a lower capacity to differentiate soft tissues compared to conventional tomography; however, it is not very relevant, since in most cases the objective of oral and maxillofacial radiology is to study mineralized tissues - teeth and bones.

1.1.3 Effective dose, cumulative dose

The effective dose can be defined as the one used to estimate the effects of ionizing radiation on the population. The Sievert (Sv) is the unit of measurement of the effective dose defined by the International Commission on Radiological Protection (ICRP) in 1977 (ICRP, 1977). Therefore, the effective dose represents the risk that radiation poses to a patient with standard characteristics, including age, gender and genetic sensitivity to radiation. As we can see in the information recorded by the ICRP in 2007, the doses of CBCT are considerably higher than the ones recorded by conventional radiological methods (ICRP, 2007). In particular, Shin et al. (2014) claim that the effective dose of CBCT is 21 to 67 times higher than the effective dose of an orthopantomography. Several studies are available in the literature that has been carried out with the objective of trying to define the effective dose of CBCT systems. Thus, in 2011, the European Commission Sedentext defined that a patient receives, on average, a dose between 11 and 674 μ Sv when using a dentoalveolar field, and between 30 and 1073 μ Sv in a craneofacial field (Sedentext Consortium, 2011).

A meta-analysis by Ludlow et al. (2015) on the effective dose of different x-ray devices, using the protocol established by the ICRP in 2007, concluded that the average effective dose for an adult for standard exposure protocols according to FOV is 212 μ Sv (large FOV), 177 μ Sv (medium FOV) and 84 μ Sv (small FOV). However, it is difficult to generalize the effective doses of CBCT systems, due to the wide range of variations in exposure parameters and in the size of the explored area, as demonstrated in Table 1 (Ludlow et al., 2015).

Table 1. Effective doses from cone beam computed tomography units analyzed using tissue weighting factors, reviewed by the ICRP in 2007 (Data from Ludlow et al., 2015).

Classification of the different CBCT Units	FOV dimension (cm)	Kp	mAs	Effective Doses (μ Sv)
Craniofacial or large FOV units (FOV > 15cm)	16x16 - 19x20	80 - 120	8,1 - 145	46 - 1073
	Standard protocol			212*
Maxillofacial or average FOV units (FOV 10 – 15cm)	10x10 - 15x15	80 - 120	6,2 - 154	9 - 560
	Standard protocol			177*
Small FOV units (FOV < 10cm)	4x4 – 10x10	68 - 120	6 - 192	4 - 652
	Standard protocol			84*
Maxillary images	Standard protocol			4 – 240 53*
Mandibular images	Standard protocol			5 – 652 102*
Temporomandibular art. Images				10 - 279
Field between arches (FOV 7 - 10 cm)	5x10 - 10x10	70 - 120	6 - 192	4 - 652
Field an arcade (FOV 5 - 7 cm)	5x5,5 - 6x8	84 - 110	11,7 - 192	11,7 - 154
Limited field (FOV $\leq$ 5 cm)	4x4 - 5x5	68 - 120	11,7 - 153	5 - 127

*Mean effective dose (μ Sv) values obtained using standard exposure protocols established for each CBCT unit.

Regarding the effective dose to which patients are exposed, it is also important to consider that this dose can be reduced by 43% with use of a filter, as described by Ludlow (2011). It is also important to know that in a pulsed-beam CBCT device, the effective dose is lower than in a continuous-beam CBCT device (Ludlow, 2011). Despite all these issues, it is important to highlight that the effective dose of radiation in conventional TC is conceivably higher than those of CBCT (Lofthag-Hansen et al., 2008; Ludlow et al., 2006; Mozzo et al., 1998; Schulze et al., 2004).

Another aspect to consider as a disadvantage of CBCT is the lack of concrete information on long-term cumulative radiation, so its use has to be carefully adjusted to the true needs (Pauwels et al., 2015).

Exposure protocols are tailored to generate optimal image quality while delivering a justifiable dose to the patient. If the scanner is of limited volume, the effective dose is smaller, so the irradiated area is also smaller. The larger the field of view, the larger the anatomical area it represents, the greater the radiation exposure to the patient and the lower the resolution of the resulting images. In contrast, a more limited field of view system results in a smaller image, the exposure of the patient is lower and the image resolution is higher. The images that present/display a greater resolution imply the use of protocols of exposition that generates a greater dose. However, subjecting patients to a higher dose to obtain high quality images without justification regarding the diagnosis is unacceptable (Ludlow et al., 2015). Thus, a modification of the concept *as low as reasonably achievable* was introduced, giving rise to the concept “ALADA”, which means *as low as diagnostically achievable* (Boice, 2015). As proposed by Vandenberghe et al. (2011), the concept refers to the need to determine the ideal exposure parameters to optimize image quality with a low radiation dose.

The risk of cumulative dosing is reported to be greater for youngsters than for the elderly, and greater for females than males. Over the years, with the optimization of CBCT devices, the cumulative dose has been decreasing, but it is still important for the clinician to try to reduce FOV to the intended intervention area (Rios et al., 2017).

1.1.4 Applications of cone beam computed tomography in dentistry

Before being used in dentistry, the *cone beam* technique was already applied in other areas of medicine: first it was used in angiography (Robb, 1982) and more recently in radiotherapy (Cheung et al., 2009), mammography and microtomography (Ning et al., 2001).

CBCT provides more information and greater precision than the two-dimensional Rx, namely the periapical one and the ortopantomography. This tool is also very useful for communication with the patient and with other dentists. In dental medicine, nowadays, CBCT is used in practically all areas (*e.g.*: endodontics, periapical surgery, orthodontics, implantology, maxillofacial surgery, TMJ analysis). When we want to analyze a larger area and in a more generalized way, we can use a larger FOV; however, CBCT devices also provide us with more detailed images if we use a smaller FOV.

In implantology, the use of CBCT is very useful in the following situations:

- Location of vital anatomical structures and their relationship to implant placement;
- Assessment of root morphology and associated pathology for extraction and reconstruction;
- Pre-implantation evaluation of bone;
- Evaluation of complications from previously placed implants;
- Design surgical guidelines (Lofthag-Hansen et al., 2009; Verhamme et al., 2015).

Regarding the use of CBCT to assess the risk to periodontal structures in patients requiring tooth movement, a 2017 study by Mandelaris et al. concludes that CBCT imaging is effectively the only radiographic modality with which such changes can be detected (Mandelaris et al., 2017). However, for the diagnosis of periodontitis, the use of CBCT is not so much useful, so it is not indicated in that case (Pauwels et al., 2015).

In orthodontics, CBCT is of great importance for assessing tooth position, for cephalometric analysis and for the application of microimplants (Jacobs, 2011). With regard to endodontics, this diagnostic is very useful to locate canals, to assess the presence of root fractures, the size and location of apical lesions and resorptions (Gamba et al., 2016). CBCT is still an important means of study in forensic dentistry, namely in identifying the gender and age of corpses, in particular when using the detailed measurement of pulp areas and sizes of dental pieces (Alamri et al., 2012) (Figure 1).

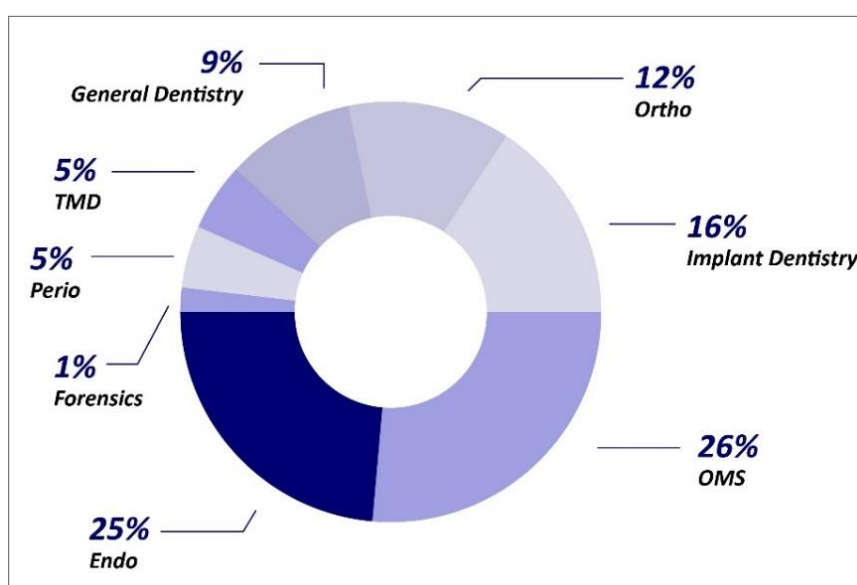


Figure 1. Clinical Value Awareness.
Source: Own elaboration with Microsoft Word.

Despite all these applications, it is important to mention that there is a problem that affects the image quality and diagnostic accuracy of CBCT images, which is the dispersion produced by the presence of nearby structures or high-density materials such as crowns, implants and spikes (İlgüy et al., 2014; Tambawala et al., 2016). Image quality is dependent on several factors such as device type, field of view, voxel size, and tube voltage (Dong et al., 2015; İlgüy et al., 2014; Yang et al., 2020). Usually, the older the patients, the more artifacts there are, so the worse is image quality (Kharoshah et al., 2010).

1.2 AGE IDENTIFICATION METHODS BEFORE CONE BEAM COMPUTED TOMOGRAPHY

For a very long time, teeth and anatomical parts of the head and neck have been used to identify corpses. As teeth are structures that are difficult to destroy in any accident, radiology is one of the main tools for identifying age (Manigandan et al., 2015; Panchbhai, 2011). Saunders was the first dentist to publish information on dental implications for age assessment by presenting a pamphlet entitled “teeth a test of age” to the English parliament in

1837 (Patnana et al., 2014). He performed a study with 1000 children and highlighted the importance of dentition in age assessment (Saunders, 1847, as cited in Patnana et al., 2014).

The factors authors usually study to determine an individual's chronological age are: tooth wear; root dentin transparency; secondary dentin apposition; cementum ring measurement; ritziu streak count; aspartic acid racemization of dentin; mineralization of 3rd molars; and, with the appearance of three-dimensional radiology, the pulp volume (Alkass et al., 2010; Huda & Bowman, 1995; Kazmi et al., 2019; Kvaal et al., 1995; Lamendin et al., 1992; Paewinsky et al., 2005; Thevissen et al., 2010; Tomaru, 1993).

As early as 1925, Bodecker described that the deposition of secondary dentin is correlated with the individual's chronological age, a fact confirmed by Gustafson, who, in 1950, described a method that showed dentin transparency and secondary dentin values were directly related to the age of the individual and are continuous through the life (Morse, 1991). In other words, the pulp chamber volume decreases with age due to the deposition of secondary dentin (Alkass et al., 2010; Bodecker, 1925). Non-destructive imaging techniques can be used for an indirect measurement of the secondary dentin deposition (Cameriere et al., 2007; Kvaal et al., 1995; Solheim, 1992). Throughout life, the size of the pulp cavity decreases due to the secondary dentin deposition, which led several authors to estimate the chronological age through imaging techniques (Cameriere et al., 2007; Ikeda et al., 1985; Kvaal et al., 1995). The systems of two-dimensional imaging present some disadvantages: (i) they originate dimensional variations; (ii) they are limited by mesiodistal dimensions; (iii) they are affected by several factors (*e.g.* malpositions and superpositions) (Issrani et al., 2022). So, the systems of three-dimensional imaging are very important and crucial for a correct and concise forensic identification. The first researchers using three-dimensional imaging as a measurement method to estimate age based on secondary dentin deposition were Vandervoort et al. (2004).

It is described that cementum increases in thickness with age, that is, cementum is a connective tissue that surrounds the roots of teeth in elementary layers, resulting in the appearance of concentric lines in the cement (salter lines), and each pair of lines corresponds to one year of life. For this reason, the counting of cemental annealing can offer a very accurate method for age determination (Kvaal et al., 1995).

A few years ago, scales were created to determine age based on tooth development. Kraus and Jordan created a scale of prenatal development, which includes 10 stages of development and is based on the mineralization of lower deciduous 1st definitive molar (Nayyar et al., 2016).

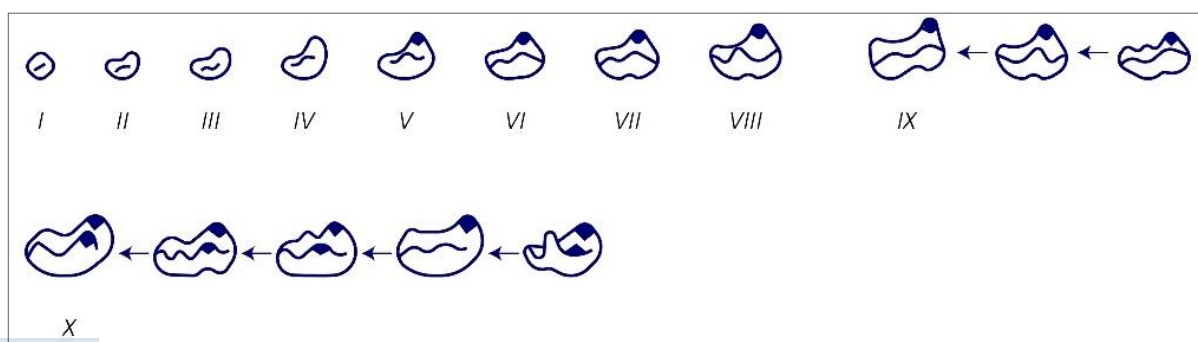


Figure 2. Developmental stages of lower deciduous first molar by Kraus and Jordan. The development is described in ten stages denoted by Roman numerals from I to X; the IXth stage includes three stages and the Xth stage includes five stages).Source: Own elaboration with Microsoft Word.

Alongside this scale, others for determining age in children and adolescents were also created, namely Schour's stages, Moorees's stages, Demirijane's stages and Nolla's stages (which can only be used to identify the chronological age in children and adolescents), and 3rd molar mineralization scales (Demirjian et al., 1973; Moorees et al., 1963, as cited in Panchbhai, 2011; Nolla, 1960; Schour & Massler, 1941).

Age assessment methods are relatively simple and involve identifying the mineralization stage on radiographic images followed by comparison with the standard stage. The scale described by Schour in 1941 consists of 21 stages of development, from 4 months to 21 years, and was updated by the American Dental Association in 1982 (Schour & Massler, 1941) (Figures 2 e 3).

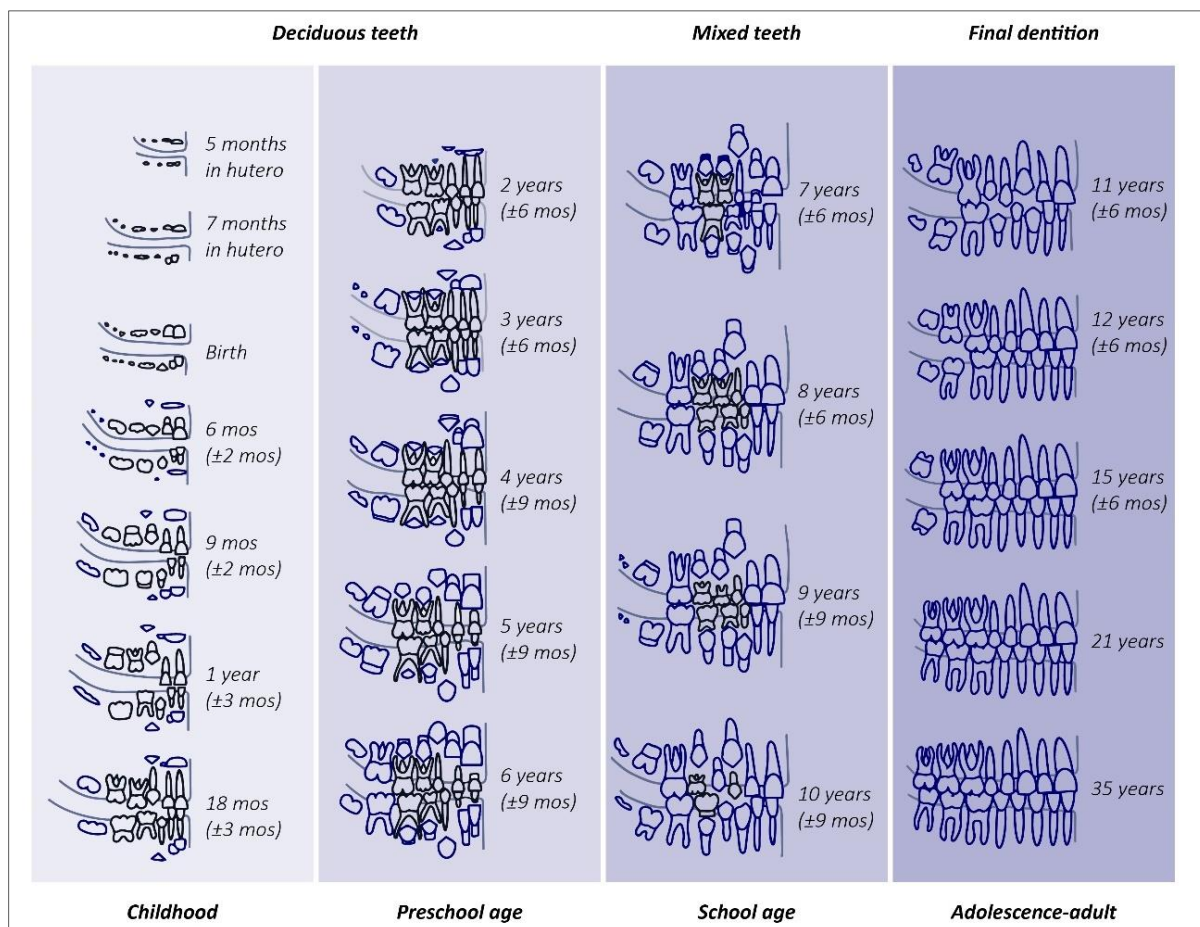


Figure 3. Illustrative image of tooth development according to Schour and Massler (1941).

Source: Own elaboration with Microsoft Word.

As can be seen in Figure 4, Moorees et al. (1963 as cited in Panchbhai, 2011) described 14 stages of mineralization. In this scale, the analysis was carried out from 6 months until the mineralization of the 3rd mandibular molar (Moorees et al., 1963, as cited in Panchbhai, 2011).

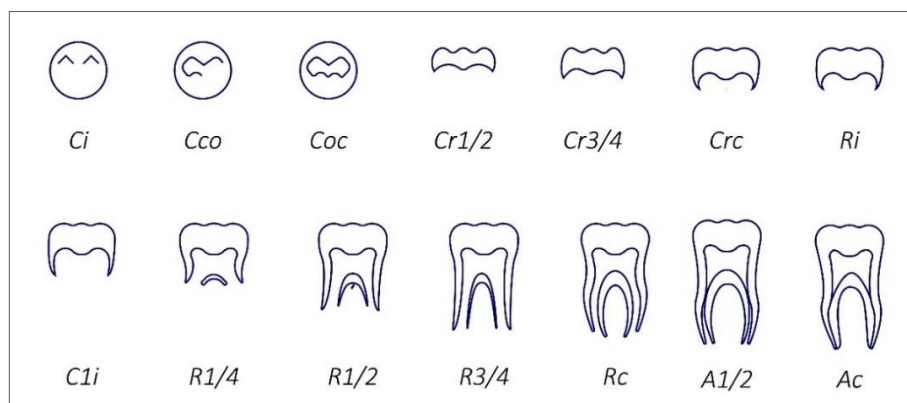


Figure 4. 14 stages of tooth formation of multi-rooted tooth (Moorees et al., 1963 as cited in Panchbhai, 2011). Initial cusp formation (Ci), coalescence of cusps (Cco), cusp outline complete (Coc), crown half complete (Cr1/2), crown three quarter complete (Cr3/4), crown complete (Crc), initial root formation (Ri), initial cleft formation (C1i), root length quarter (R1/4), root length half (R1/2), root length three-quarters (R3/4), root length complete (Rc), apex half closed (A1/2), apical closure complete (Ac)
Source: Own elaboration with Microsoft Word.

The most developed method is the one described by Demirjian et al. (1973, as cited in Panchbhai, 2011) which presents 8 stages from A to H. This method assumes that there are differences in development between men and women, and up to 5 years this difference is not significant. The authors use a mathematical formula to determine the age. However, this method has two limitations: it does not include the 3rd molar and all teeth in the lower arch must be present (Figure 5; Demirjian et al., 1973 as cited in Panchbhai, 2011).

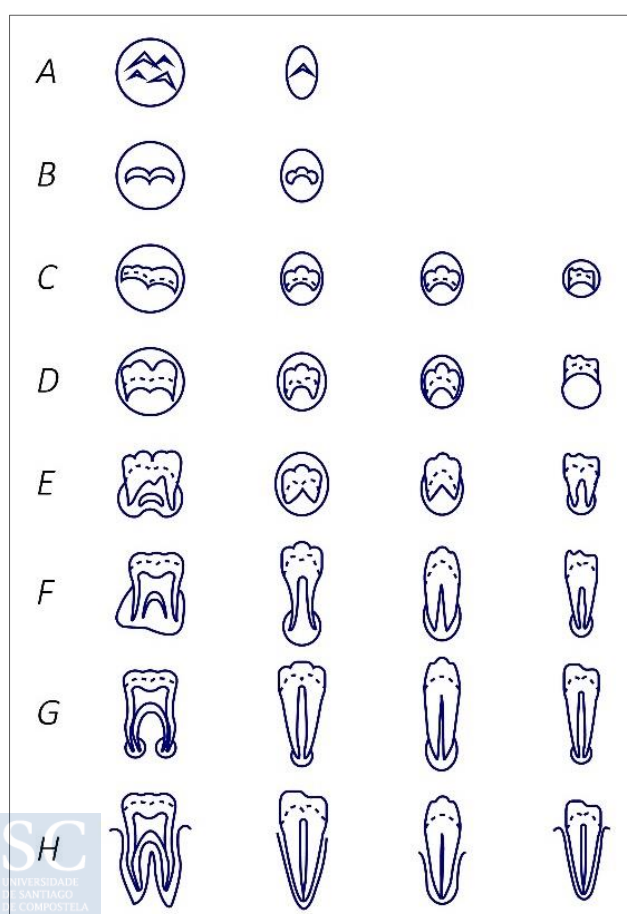


Figure 5. Eight stages (A to H) of mineralization of a tooth (Demirjian system). A - beginning of calcification in the form of an inverted cone or cones; B - mineralized cusps are united to show coronal morphology; C - crown half formed, pulp chamber is evident; D - crown formation is completed up to cemento-enamel junction, with beginning of root formation; E - initial formation of the root bifurcation; F - the apex ends in a funnel shape; G - the walls of root canal are now parallel, apical end partially open; H - the apical end of the root canal is completely closed; the periodontal membrane of uniform width around the root and the apex.

Source: Own elaboration with Microsoft Word.

The method described by Nolla in 1960 is also a reference to determine age. This author described 10 stages of development (fig 6). These stages can be applied even in individuals who do not have a 3rd molar and this author approaches girls separately from boys (Nolla, 1960). It is thus relatively simple to identify the age in children and adolescents using dental development stages, and it is not so simple for adults since permanent dentition presents a complete development.

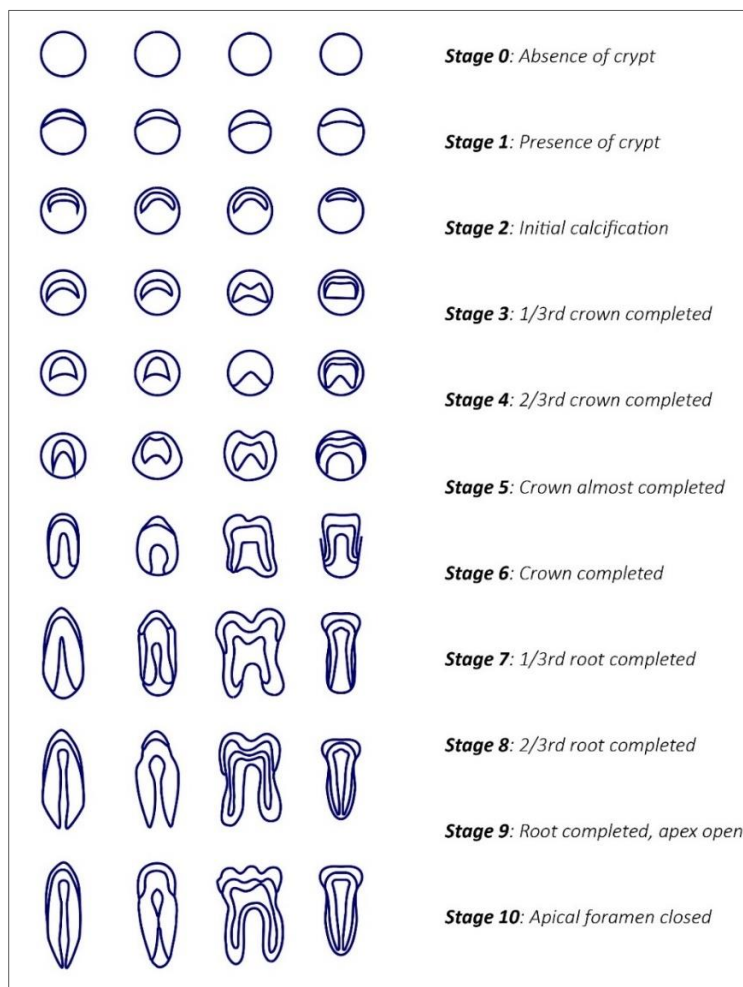


Figure 6. Ten stages of tooth formation with description (Nolla's method)

Source: Own elaboration with Microsoft Word.

Another method widely used in age identification is the mineralization of 3rd molars, but we can only identify individuals until around 21 years of age, which it is when the mineralization of these teeth ends (Olze et al., 2006). Over time, several studies have been carried out on this topic, with the most cited being the one described by Demirjian et al. in 1973. As we have seen previously, the stages described by this author are the ones that allow us to have values closer to the real age of individuals, but this scale excludes 3rd molars (Demirjian et al., 1973). Chronological scales of 3rd molar remineralization are also described; however, they are much more complex. The Harris and Nortje scale presents 5 stages of development (Figure 7) and the Van Heerden scale describes 5 stages of development of the mesial root using orthopantomography. This author does not report significant differences between men and women (Harris & Nortjeas, 1984 as cited in Panchbhai, 2011; Van Heerden, 1985 as cited in Panchbhai, 2011).

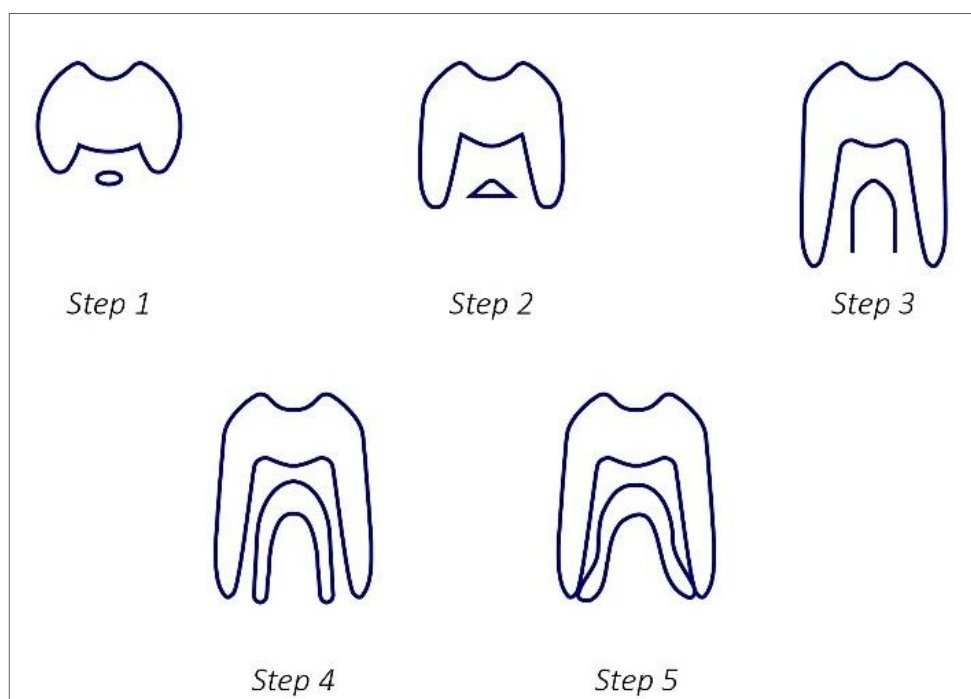


Figure 7. Five stages of lower third molar root development (Harris and Nortje's method)

Source: Own elaboration with Microsoft Word.

Both Harris and Gergoni have reached a conclusion that is important to retain: third molar mineralization is completed in the black race a year earlier (Olze et al., 2006).

The Rantamen and the Haavikko scales were also compared with the Demirjian scale, through a study that was carried out in 1992 in a group of 911 Japanese, and the authors concluded that the complexity of these scales did not justify their use as the results were not better than those obtained when using the Demirjian scale (Daito et al., 1992 as cited in Panchbhai, 2011).

It is important to bear in mind that the identification of age using only the information offered by 3rd molar remineralization scales has several limitations. When different populations are studied (Japanese, German and South African) using orthopantomographies, it appears that there are significant differences between the different populations (Olze et al., 2006). The development of the 3rd molar is variable, as lifestyle affects its development. When we approach 18 years of age, this variation is less significant and it becomes important to know the sex since the development is different between women and men (Lewis & Senn, 2010).

With the appearance of three-dimensional radiology, namely computerized axial tomography, studies that determine the volume of the pulp to reach the individual's chronological age began to appear. Vanderwoort et al. (2004) were the first to apply 3D measurement methods to estimate age based on secondary dentin deposition. In 2005 by Aboshi and, posteriorly, in 2009, by Someda et al., the first studies that calculate the real volume of the pulp in a three-dimensional way using micro-ct and that were able to reach the age of individuals based on these studies were conducted. Agematsu et al. (2010) designed a study using micro-ct and were able to relate age with pulp volume. Nevertheless, they also confirmed that there is a higher relation of pulp volume with age in women than in men, which is related to the fact that estrogen activates a receptor on odontoblasts to form

secondary dentin (Hirayama & Maeda, 1993 as cited in Agematsu et al., 2010; Itagaki, 1974 as cited in Agematsu et al., 2010; Iwaka, 2006).

1.3 GENDER IDENTIFICATION METHODS BEFORE CONE BEAM COMPUTED TOMOGRAPHY

In identifying cadavers, it is also very important that the genus be identified. In forensic dentistry, the use of analysis of anatomical structures of the head and dental parts is crucial for the identification of gender, and the latter is usually defined using the analysis of radiographs with anteroposterior incidence and cephalometric analysis (Shahin et al., 2013).

With regard to anatomical structures, there are characteristics that are different for men and women:

- The weight of the jaw is greater in men than in women, but the angle of the jaw is greater in women;
- The jaw in women is thinner and lower in the symphysis;
- In men, the condyles are larger, the gonio is more accentuated and the chin is straighter and squarer (Pereira, 2012).

Shahin et al. (2013) described some skeletal differences between men and women, as shown in the following table.

Table 2. Skeletal differences between men and women.

Anatomical structure	Woman	Man
Ascending branch	lower amplitude	bigger amplitude
Frontal sinus	less developed	more developed
Mandible size	Smaller	bigger
Palate	smaller and parable form	broaden, bigger, U form
Condyles	minor	bigger
Gonial angle	more obtuse	less obtuse

Regarding the characteristics of the dental parts to be taken into account as to establish differences between men and women, in a succinct and generalized way, women have smaller teeth than men, with the upper central incisor being considered the tooth that presents greater dimorphism, showing a larger size in the mesiodistal direction. Men also have more cuboid teeth, with flatter surfaces and sharper angles, while women have teeth with more rounded angles (Pereira, 2012).

As the need to identify cadavers is increasingly pertinent over the years, there have been many studies in the sense of having more and more information for sex identification. Pettenati-Soubayroux et al. (2002) carried out a study where they evaluated 1432 permanent teeth of the mandible, 1284 permanent teeth of the maxilla, 125 primary teeth of the maxilla and mandible of 238 primary teeth of French corpses. Statistical analysis was performed with SPSS and used the incisor index. With this study, they found that the canines show the greatest dimorphism in relation to sex. Sonika et al. (2011) studied a population of 200 Indian individuals (100 men and 100 women) aged 17 to 25 years old. They measured the mesiodistal (MD) and vestibulelingual (VL) length in the mouth and in models of the 1st

molar. To assess sexual dimorphism, they used a formula (Formula: Sexual dimorphism = $X_m - 1 \times 100 X_f$, where X_m = mean value for males and X_f = mean value for females). With this evaluation, the authors verified that there is sexual dimorphism at the level of the 1st molars, particularly those on the left side. In the same year Anuthama et al. (2011) performed a study with 100 South Indian individuals (41 women and 59 men) aged between 20 and 30 years old. They measured the diagonal MD and VLE lengths: MV/DL-DV/ML of the teeth 1.3 and 2.3. and thus, were able to identify the gender of 90% of the population studied.

Of the studies we have reported so far, the authors have analyzed only 1 or 2 teeth; however, there is one study which analyzed all teeth except for 3rd molars: Angadi et al. (2013). This study used 669 Indian individuals (323 men and 346 women) aged between 18 and 32 years old, and measured the distance MD and VL of the different teeth. They reached the conclusion that the distance MD from tooth 4.3 is the one with the greatest sexual dimorphisms, although the aid of these distances in gender identification do not give 100% guarantee. Khamis et al. (2014) also measured the MD and VL length in several teeth, also with the exception of 3rd molars, of a population of 136 Malays, 134 Tamils and 130 Chinese, the three principal ethnic groups in Malaysia. They also came to the conclusion that the lower canine is more dimorphic for Malaysian Malays and Tamils than for Malaysian Chinese. This studied showed the greatest dimorphism differences in MD dimension of the 2nd molar in these three ethnic groups. It becomes important to realize that there are ethnic differences (Khamis et al., 2014). In Greece, Zorba et al. (2014) studied 102 cadavers (58 men and 44 women) and measures: central Incisor (IC) lateral incisor and (IL) 1° premolar (PM) 2°PM roots. The results presenting greater sexual dimorphism are the ones regarding IL and canines. We can only measure the roots by extracting the teeth, which it is impossible to do in a living population. Nevertheless, this represents relevant data for a corpse's identification. In the same year, Shankar et al. (2013) studied a South Indian youth population aged between 5 and 13 years old. The teeth studied were 53, 63, 54, 64, 55 and 65. In the canines, two measurements were carried out (MD and VL) while in the molars they made three measurements (MD and VL and the diagonal Mesiovestibular- distolingual (MV-DL) and distovestibular- mesiolingual (DV-ML). With these measurements, the authors came to the conclusion that the maxillary right first molar allows for the identification of sex in 87.2% to 88% of the population.

All the studies above mentioned and described show the relevance of the measurements of teeth anatomical structures for determination of gender in human remains.

1.4 CBCT APPLICATION TO AGE ESTIMATIVE

1.4.1 Spheno-occipital synchondrosis

The study of osseodensification points is common practice in forensic dental medicine for the determination of age in human remains. One of the structures used for this determination is the spheno-occipital synchondrosis (Can et al., 2014), which formed by the cartilaginous union between the body of the sphenoid and the basilar portion of the occipital. This structure is one of the three synchondrosis of the cranial base and is a very important growth center of the craniofacial skeleton. The late fusion and closure of the spheno-occipital synchondrosis can help in age estimation, which can be an important and useful tool for the forensic anthropology. The degree of fusion of this structure can be used as a reference for age

estimation (Sinanoglu et al., 2016). Franklin and Flavel (2014) proposed the use a four-stage system to evaluate the degree of fusion of spheno-occipital synchondrosis (table 3).

Table 3. Stage system to evaluate the degree of fusion of the spheno-occipital synchondrosis.

Stage	Status	Description
0	Unfused	Completely open with no evidence of fusion between the basilar portion of the occipital and the sphenoid-no bone present in the gap
1	Fusing endocranially	No more than half the length of the synchondrosis is fused proceeding endo – to ectocranially
2	Fusing ectocranially	Greater than half the length of the synchondrosis is fused- the ectocranial (inferior) border remains unfused
3	Completed fusion	Completely fused with the appearance of normal bone throughout- a fusion scar may be present

For the utilization of this tool, it is important to take into account that the fusion begins 2 years earlier in women but ends at around 17 years in both sexes (Can et al., 2014).

Several studies had been publishing over the years, demonstrating the usefulness of the valuation of fusion degrees of spheno-occipital synchondrosis in human age determination. For example, in 2010, Bassed et al. (2010) carried out a study in 666 Australian individuals, of whom they had CT images, and concluded that spheno-occipital synchondrosis fusion was a good marker to determine age up to 18 years. Can et al. (2014) analyzed 1mm CBCT images and, taking into account the analysis of the degree of fusion of spheno-occipital synchondrosis, were able to determine the age of their sample between 11 and 17 years. In 2016, Sinanoglu et al. (2016) evaluated the degree of synchondrosis fusion of a Turkish population using CBCT images and taking into account the degrees of fusion described by Franklin and Flavel (2014). In this study the authors were able to identify individuals who had an average age of 18 years. This study also concluded that the ability of CBCT to provide us with images with very thin cuts facilitates the identification of the fusion degree of sincondrose.

1.4.2 Inferior alveolar canal

In 1998, Williams et al. described the inferior alveolar canal like the one that descends obliquely forward the branch from the mandibular foramen and then follows a previous course horizontally in the body under the alveoli, establishing a relationship with the first and second premolar roots. Under the premolar area, the channel is divided into a branch mental and another incisive. The mental branch emerges from the mandible through the mental foramen. The mandibular canal contains the inferior alveolar nerve, the inferior alveolar artery and the inferior alveolar vein (Sobotta, 2000).

Several studies relate the anatomy of the alveolar canal with age and it has been described that the relative position of the canal and mental foramen varies with age (Gershenson et al., 1986; Levine et al., 2007). It is the case of the study of Levine et al. (2007), who describe that older individuals have shorter distances between the lower edge of the alveolar canal and the lower edge of the mandible. The study by Angel et al. (2011) analyzed variations in inferior alveolar canal to relation with age. The measurements were made in CBCT images at 3 different sites to evaluate the position of the inferior alveolar canal: 1-axial view with anterior

and posterior measurements at the level of mandibular foramen; 2- coronal view with superior, inferior, buccal, and lingual measurements at the level of first molar; 3- coronal view with superior and inferior measurements at the level of mental foramen. These authors concluded that, in general, the results show that the relative location of the alveolar canal and the associated foramens remain quite constant in relation to age and sex.

However, there are also studies that observe a great variability of the relative position of the mandibular foramen but do not correlate with age (Afsar et al., 1998; Kieser et al., 2005).

1.4.3 Pulp cavity and hard tissues

The information obtained about the spheno-occipital synchondrosis and the inferior alveolar canal related to the age estimation described above and the appearance of CBCT led several researchers to vary out studies to calculate the pulp volume using a new imaging technology. With this information and with the appearance of CBCT, several different authors began to make studies to calculate the pulp volume using this new imaging technology. For example, in 2006, a study conducted by Yang et al. (2006), with a sample of 8 men and 20 women, calculated the pulp volume of 28 teeth (15 incisors, 12 canines and 1 premolar, all inferior and monoradicular) in ages between 23 and 70 years. They used a semi-automatic software (MATLAB) together with CBCT images to determine de teeth volume and to confirm the results used teeth prepared endodontically, using the method described by Archimedes (1897). They observed a moverate correlation between the pulp/tooth volume ratio and the biological age with a coefficient of determination of 29%, which is an important value that demonstrates the relevance of this technique to age estimation. Star et al. (2011) calculated the pulp volume of 64 canine, 32 incisors and 15 premolars in a sample of 57 women and 54 men aged between 10 and 65 years old. They store the data in a DICOM file using OnDemand 3D software. These files were imported into CBCT diagnostic software, allowing for the calculation of the volume of the pulp to confirm the results, just as Yang et al. (2006), who used the Archimedes method (Archimedes, 1897). In this study, the authors concluded that the relationship of pulp volume with age is higher in the incisors followed by the premolars and finally the canines. Hence, they believe that it is possible to arrive at more precise results if the techniques and the qualities of CBCT are improved. A study in the Zurich University, conducted by Jagannathan et al. (2011), managed to obtain good results for age determination using images of CBCT and the modified Yang formula. In this case, the authors studied a sample of Indian population aged between 10 and 70 years, where 188 lower canines were measured. All canines that present caries lesions, excessive restorations and wear and tear were excluded. All the measured canines were submitted to CBCT with constant cuts of 250µm and an exposure of 140 Kv and 550mA. Longitudinal and transverse sections were made to then calculate the pulp volume, and after calculating the age using the modified Yang equation ($\text{age} = 57.18 + (-413.41 \times \text{PTV})$ — PTV is the ratio of pulp volume to tooth). With this study, the authors verified that there were no significant differences between samples with regard to the right or left tooth type and to the genus. It was an important discovery for the forensic dental medicine because sometimes human dentition remains is not complete, and the left or right side of the mouth arch may be missing. Ge et al. (2015), in a sample of 190 women and 213 men aged 12-69 years, calculated the pulp chamber volume of 373 upper 1st molars and 372 lower 1st molars. To validate the results obtained, the authors made measurements in micro-ct in addition to those made in CBCT images. To calculate the volume of the pulp camera, they exported the data of the images to the DICOM-software ITK-SNAP 2.4, where they made the calculation. After having the volume, they resorted to 4

different formulas to calculate the age: one for male maxillary first molars; another to male mandibular first molars; a third one to female maxillary first molars; and a fourth to female mandibular first molars. The authors verified that the volume of the pulp chamber of the 1st molars is a good element to age determination which was more accurate for women than men. It is important to state that the data obtained with micro-ct are more precise than those in CBCT; however, the use of the micro-ct implies the extraction of the teeth, which does not happen with the use of CBCT. This is a very relevant finding because sometimes the extraction of the teeth that we need to study is not possible. The methods that depend on teeth extraction, as histological and biochemical techniques, are harder to apply, more expensive and also take longer, especially when there are several human remains to identify, than the CBCT method (Issrani et al., 2022).

In 2015, Pinchi et al. have concluded that the narrowing of the dental pulp over the years is a significant parameter for age determination. From the results obtained in the study, they could see that the age brackets that present values with greater precision are between 30 and 59 years. To reach this conclusion, the authors used a sample of 148 individuals (measured left central incisors) aged 10 to 80 years. A formula was used to calculate the age and to make 9 different measurements on the incisor images in the CBCTs, and these measurements were exported to calculate the pulp volume for the DICOM program with the osinix software. Of these 9 measurements, 3 were in the sagittal plane and 6 in the coronal plane. To validate the measurements, the authors used three teeth that had been extruded and calculated the actual volume of the pulp to compare the obtained volume with the measurements made in the CBCT images. As a continuation of the study that they had carried out in 2015 (above mentioned), Ge et al. (2016) developed a new one, with 13 different teeth, excluding 1st upper premolars because of the complex root canal. For the monoradicular teeth, they calculated the total volume of the pulp, and for the molars only recalculated the volume of the pulp chamber. They also used measurements in micro-ct images to compare with the ones of the images obtained by CBCT. With these data, the authors concluded that of the 13 types of teeth analyzed, the volume of the pulp chamber of the upper 2nd molars is the one that has the greatest correlation with age, being, however, statistically significant the relation of age to the volume of the pulp of all the teeth studied. In this study, as in the other mentioned above, it becomes pertinent to carry out further studies towards this direction, with a larger sample. In 2018, Gulsahi et al. (2018) determined the pulp and tooth volume by taking measurements on central incisors, lateral incisors and maxillary canines, as well as on 1st premolar and 2nd mandibular premolar. They introduced the measurements in the DICOM program to calculate the area, and with these results concluded that the greatest relationship was established with the measurements performed on the maxillary central incisors regardless of gender. This authors' study design was based on two studies carried out by Camerieri et al., in 2004 and 2007, which present the tooth/pulp area as an indicator of age (Cameriere et al., 2004, 2007; Drusini et al., 1997). On the other hand, Anastácio et al. (2018) also used the Camerieri method using measurements of 2nd premolars, but they were unable to validate them. Despite of the same method used, these different researchers did not have similar results, perhaps due to different equipment or handling of the procedures. Kazmi et al. (2019) determined the pulp volume of upper and lower left canines and they concluded that there is actually a relationship between pulp volume and age, and also a significant difference in pulp volume between men and women up to 55 years. From this study, we can see that the authors report a greater relationship between pulp volume and age in lower canines (De Angelis et al., 2015). Haghanifar et al. (2019) used canines and upper and lower central incisors of 377 CBCT from an Iranian population. In this study, several measurements were made in the axial and sagittal

planes. The pulp area was calculated through the Ondeman 3D Dental Tm software, and the authors concluded that as age increases, the pulp area decreases in the 2 planes in both teeth and sexes. However, as in the studies of Biuki et al. (2017), Gulsahi et al. (2018) and Wu et al. (2016), the best results were obtained with the measurements of maxillary central incisors (Cameriere et al., 2004, 2007, 2009, 2012). As in other studies, Rai et al. (2016) also concluded that the results obtained in the measurements carried out in the axial plane are superior to those obtained in sagittal plane (Cameriere et al., 2007; Zhang et al., 2019). The age determination margin in this study was less than 10 years, a result that in forensic science is quite significant (Cameriere et al., 2007).

The different studies demonstrate that it is possible to estimate the age of humans being by measuring the dental pulp of different types of teeth with an interval of about 10 years. Different types of teeth have different correlations with age or sex determination, but, regardless of this, it is possible to use this very useful tool for forensic dental medicine, especially in situations of wars, terrorism or conflicts with many mortal humans' remains to identify, with different ages and sex.

1.5 CBCT APPLICATION TO GENDER IDENTIFICATION

1.5.1 Maxillary sinuses

The maxillary sinus is the largest air sinus in the body. It is a pneumatic space inside of maxillary bone, bilaterally. This sinus has a pyramidal quadrangular format, based facing the side wall of the nasal cavity. The maxillary sinus presents different sizes during growth and a triangular shape. It varies from person to person and there are differences between the left and the right side (Saccucci et al., 2015; Whyte & Boeddinghaus, 2019). Whyte and Boeddinghaus (2019) described the maxillary sinus maintain its structure even when the skull and other bones are completely destroyed. Due to this characteristic, it has been proposed for corpse identification.

Amin and Hassan (2012) concluded, with CT images, in an Egyptian population, that the size of left sinus is different between males and females. Uthman et al. (2012), with CT images, using measurements of the maxillary sinus, obtained an accuracy rate of 73.9%, showing viable results for sex estimation. CBCT images can be important to determine the maxillary sinus volume (Whyte & Boeddinghaus, 2019). In 2015, Saccucci et al. (2015) made a study and concluded there were no differences between the right and the left sinus volume. They also found no statistical differences between males and females.

1.5.2 Mandibular measurements

The skull is the second most dimorphic bone. Craniofacial structures are very resistant and indestructible (Patil & Mody, 2005; Verzé, 2009; Yadav et al., 2019). Mandible is the last skull bone to cease growth and the most dimorphic skull bone (Hu et al., 2006; Rogers, 2005). The mandible is composed of a part that consists of a horizontal body and two other parts that are perpendicular – the ramus.

The first authors who verified the usefulness of the mandible to define sex were Morant et al. (1936 as cited in Humphrey et al., 1999) and Martin (1936 as cited in Humphrey et al., 1999). In the same year, Weidenreich stated that the female jaw was on average 92.4% of the size of the male (Weidenreich, 1936 as cited in Humphrey et al., 1999). After checking the

importance of the jaw to determine the sex, the authors used different areas of the jaw to verify which would be more dimorphic. Humphrey et al. (1999) verified that the greater dimorphism appeared in the ramus and the condyle. In 1968, De Villiers had already seen that the differences between genders were higher in ramus size. Saini et al. (2011) made five measurements in mandible (maximum ramus breadth; minimum ramus breadth; condylar height/maximum ramus height; projective height of ramus; coronoid height) from 116 adult mandibles and concluded that the ramus of the mandible is the structure with greater potential to differentiate the sex. Other authors analyzed different mandible measurements to determine gender estimation on CBCT (table 4).

Table 4. Different mandible measurements to determine gender estimation on CBCT.

Author/date	Country	Measurements
Gamba et al. (2016)	Brazil	Gonial angle; Ramus length; Minimum ramus breadth; Gonion-gnathion length; Bicondylar breadth; Bigonial breadth.
Dong et al. (2015)	China	Bi-condylar breadth; Bi-gonial breadth; Bi-antegonial notch breadth; Bi-mental foramina breadth; Distance between mental foramen and mandibular inferior border; Maximum mandibular ramus height; Maximum mandibular ramus breadth; Maximum mandibular length; Maximum mandibular body length; Mandibular angle; Mental angle.
Kharoshah et al. (2010)	Egypt	Gonial Angle; Ramus length; Minimum ramus breadth; Gonio-gnathion length; Bigonial breadth; Bicondylar breadth.

Gamba et al. (2016) used 160 CBCT from 74 males and 86 females and they concluded that it is possible to reach a high accuracy rate (95.1%) for sexual prediction. They verified that all measurements have significant differences between males and females, except for Minimum ramus breadth. Dong et al. (2015) believe that mandible can be a reliable indicator of sexual dimorphism. The measurements that have better dimorphism are maximum mandibular length and bi-gonial breadth, whose accuracy rate is 80%. Kharoshah et al. (2010) studied six measurements, three of which being significantly higher in men than in women (bicondylar breadth; gonial angle, minimum ramus breadth). In 83.9% they can determine the sex resorting to four measurements (bicondylar breadth, gonial angle, minimum ramus breadth and ramus length).

1.5.3 Foramen Magnum Measurements

The foramen magnum is an oval hole and it is the large opening through the occipital bone in the middle of the posterior fossa of the neurocranium. It is important for the communication between the cranial cavity and the spinal canal, as it crosses the accessories nerves, the medulla oblongata and its membranes, the vertebral arteries, the anterior and posterior spinal arteries, the tectorial membrane and alar ligaments (Sobotta, 2000). In 1973, Fatteh carried out a study and concluded that the foramen magnum is larger in males than in females. In 1982, Teixeira also stated that the size of the foramen magnum is import for sex identification. Catalina-Herrera (1987) also described that transversal and sagittal dimensions of FM were higher in males. Günay et al. (1997) verified that the foramen magnum diameter could be used in sex identification while the total area was not a good indicator. In 2005, Uysal et al. reported sexual dimorphism by analysing the dimensions of the FM in three-dimensional (sD) CT with 81% accuracy in determining the gender. Uthman et al. carried out a study on CT, in 2012, with 88 patients (43 males and 45 females). They made six different measurements of FM (sagittal diameter, transverse diameter, circumference, area, head circumference, and head width) and they concluded that these measurements were very important to study sexual dimorphism because they showed significant differences between genders. Günay and Altinkök (2000) realized the importance of foramen magnum in sex determination. In this study they made measurements from foramen magnum length and foramen magnum breadth from 209 skulls (170 males and 39 females). They confirmed, like the other two studies, that foramen magnum was larger in males. In addition, in this study they confirmed that the area of the foramen magnum is larger in males than in femal

In literature there are only two studies for evaluating gender estimation of foramen magnum on CBCT images (İlgüy et al., 2014; Tambawala et al., 2016). İlgüy et al. (2014) used 161 CBCTs (66 males and 95 females) to made measurements of the mandible and foramen magnum for determining gender. These authors used the sagittal and transverse diameters of foramen magnum as measurements. They concluded that is possible to determine sex with an accuracy of 83.2%. In 2016, Tambawala et al. conducted a study to try to prove that it is possible to determine sex with measures of the foramen magnum. They used 266 CBCTs (111 males and 115 females) for measuring maximum length and width of the foramen magnum and two areas (Area 1: $A = 1/4 \times \pi \times \text{length} \times \text{width}$ and Area 2: $A = \pi \times ((\text{length} + \text{width})/4)^2$). They found significant mean differences in four measures between sexes although the higher value was found in Area 2.

1.5.4 Third molars impaction

Third molar development and mineralization has been the subject of several radiographic studies as an accurate method for age determination in different human populations. These studies are primarily based in the radiographic observation of 3rd molar mineralization according to Demirjian's scale, although Nolla's method was also used. Several authors (*e.g.* Hashemipour et al., 2013; Hugoson & Kugelberg, 1988; Murtomaa et al., 1985; Quek et al., 2003) concluded that the third molars are most impacted in women than in men, because in the latter jaw growth is not yet completed at the time of eruption of third molars, contrary to what happens in women. However, other studies like Haidar and Shalhoub's (1986) and Hattab et al.'s (1995) did not find a relationship between gender and third molar impaction. Conducting a study in a sample of 400 Spanish subjects (200 males, 200 females) aged between 14.5-25 years, De Salvia et al. (2004) found evidences that the

diagnosis of biological age in subjects around the age of 18 could have a relative degree of accuracy when carried out by the radiological examination of the development of the third mandibular molar, and that it could be the preferential method in age determination in forensic applications. Also in the Spanish population, Prieto et al. (2005) found that both genders presented the same correlation factors, regarding differences between third molar for both sides of the jaws. They also found that third molar maturity was attained faster in males than in females, with a difference ranging from six to nine months. Comparing their study of 1,054 persons (462 males, 592 females) with an age range between 14 and 21 years with other similar studies, in populations with different ethnicity, they also concluded that the third molar development rate of the Spanish population was faster than in Americans, French-Canadians, Germans, Japanese and South Africans, and closer to US Hispanics. Meinel et al. (2007) studied Austrian population and analyzed third molar development in 610 subjects (275 males, 335 females). They found that at the time enamel formation in the occlusal surface is complete, dentin deposition has already started, and the pulp chamber has a curved shape, with the occlusal border being reached by individuals of the Austrian sample about 0.8–1.3 years earlier than in individuals in Prieto et al. (2005)'s Spanish sample, although apex closure was reached 2.8 to 3.2 earlier in the latter. When comparing the Austrian sample with American and Japanese subjects, the Austrians entered the early stages of third molar development earlier, but the last stages were reached later. South African and German subjects reached the last stages of development later than Austrians.

In 2007, a Turkish population study addressed third molar development and mineralization. Conducted by Sisman et al. (2007), this study found that in their sample of 900 persons (380 males, 520 females, all white, aged between 8–25 years old), the third-molar development among the Turkish white population occurs at an earlier age than in other populations, regarding almost all stages. Only in the Spanish population the last stages of third-molar development took place earlier than in Turkish individuals. It was also found that the use of third molars as a developmental marker is appropriate, although, in order to increase the accuracy of age determination, indications of sexual maturity and ossification should also be evaluated in addition to third-molar mineralization. Studying a Croatian population sample, in 2010, Legović et al. reached the conclusion that mineralization of the crown of the mandibular third molar was completed when the subjects were 15 years old, and that mineralization of the roots started at the earliest after the 10th year. In this study, with a sample of 979 persons (489 males, 490 females) between 5.7–14.6 years, differences between mineralization of the mandibular wisdom tooth with regard to sex were found to be significant. Although Demirjian's scale is the most common tool regarding the study of 3rd molar development, in this case the author's used Nolla's method and found it to be accurate as a tool for age estimation in Croatian children. Zeng et al. (2010) studied 3,100 southern Chinese and Han persons that were well-nourished and free of any known serious illness, with normal growth, development and dental conditions (1,900 females, 1,200 males) between 4.1 and 26.9 years old. They concluded that, in the same gender group, the mineralization ages between two sides in upper or lower jaw were very similar, the chronology of mean age and complete time of third molar mineralization of male were earlier than that of female. They also found that, regardless of male or female, the chronological age of third molar mineralization was symmetrical of left and right sides and no difference was found between the two sides in the same gender group. More recently, Jung and Cho (2015) analyzed CBCT of 395 maxillary third molars of 234 patients (120 males and 114 females). In this study the authors divided in 4 groups of the classification level of eruption and the level at which the molars were impacted was more common in

women. They concluded that is more common the third molars impaction in females than in males.

1.5.5 Styloid process

Styloid process is a thin bone portion which born below the tympanic bone. It is located on the immanent face of the temporal bone and it has an antero-inferior direction (Sobotta 2000). The common length of styloid process is between 2.5 cm and 3 cm (Eagle, 1948).

There are also some studies that try to observe a relationship between the length of the styloid process and the gender. In a study of 1135 patients, no correlation was found between length and sex. Nonetheless, an elongated styloid process was more common in older people (Keur et al., 1986). Other studies did not find any relation between the length of styloid process and age (Camarda et al., 1989a, 1989b; Lengelé & Dhem, 1988). In the same study, Camarda et al. (1989a, 1989b) demonstrated that the styloid process was longer in males than females. However, Guttu and Laskin's (1987) study considered that there was no correlation between length and sex. In 1986, Keur carried out another study and noted that the styloid process was slightly higher in men, but with no statistically significant differences. Gözil et al. (2001) carried out a study with 105 patients. They measured the size of the styloid process with images of computerized axial tomography. The authors concluded that an elongated styloid process is more frequently in males, but there isn't any relation between length and age. In 2013, Ekici et al. conducted a study using MDCT to verify if there was a correlation between age and gender, and anatomic variations of the styloid process. They used images from 822 patients (412 males and 410 females) and a statistically significant difference was observed between genders. Like Gözil et al. (2001), they concluded that the styloid process is higher in males than in females. Regarding age, this study refers significant differences between different age tracks unlike Gözil et al. (2001) and Başekim et al. (2005), who did not find any significant differences between age groups. Andrei et al. (2013) used CBCT images of the styloid process from 44 patients (16 males and 28 females) and observed that the sagittal angle and the length of the styloid process are not influenced by gender, but the transverse angle is larger in males than in females. They also demonstrated that the styloid process length is not influenced by aging.

2 HYPOTHESIS AND OBJECTIVES

The identification of age and gender for forensic purposes is still difficult. Although different methods based on the analysis of teeth have been reported, it remains a challenge to find the ideal method. Taking this into account, we have considered the following hypothesis:

- H1) It is possible to find differences in the upper central incisive and/or in the upper first molar based on CBCT measurements that could predict gender.
- H2) It is possible to find differences in the upper central incisive and/or in the upper first molar based on CBCT measurements that could predict age.
- H3) It is possible to combine these results and apply them in Forensic Dentistry for identification of human remains in relation to age and gender.

The following aims are established:

- To evaluate the suitability of linear measurements of the upper central incisor and upper first molar for gender prediction on CBCT.
- To assess whether linear measurements of the upper central incisor and upper first molar on CBCT could be used for age estimation.
- To obtain regression equations for estimating age and gender in adults through linear measurements and ratios on sagittal, coronal, and axial slices of the upper central incisor and the upper first molar using CBCT.

3 MATERIAL AND METHODS

This section has been partially adapted/extracted from our published manuscript titled “**Age Estimation Using Maxillary Central Incisor Analysis on Cone Beam Computed Tomography Human Images**” Santos et al (2022)

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In the present study, we analyzed CBCTs from the Radiology Unit of the Faculty of Medicine and Dentistry of the University of Santiago de Compostela of central incisor and first molar teeth. The total sample consisted of 1551 consecutive CBCTs, performed from 2012 to 2017.

Ethical and legal aspects

Our study was carried out taking into account the follow-up of the requirements accepted in the Helsinki declaration (Seul review, October 2008) and good epidemiological practices (EEUU and Europe), as well as the legislation in force in Spain, in accordance with the provisions of the ministerial order SAS/3470/2009

The processing of the personal data of all the individuals who participated in the study was carried out considering the provisions of “Ley Organica” 15/1999, of December 13, of the protection of personal data and the regulation that develops it.

Once collected and worked on, all data were analyzed anonymously. Access to personally identifiable data, which requires verification, was restricted to duly authorized individuals by the investigation team.

Written informed consent was obtained from all patients. In compliance with ethical, methodological and legal requirements, this study was approved by the Galician Ethics Committee of Clinical Research (Ref: 2012/272). In the case of underage patients, consent was given by the responsible adult considering autonomous law 3/2005, March 7, modified from law 3/2001, of May 28, which regulates consent and medical history. This consent contains the information that the data will be stored in a database that can be used for scientific research purpose. Patients must understand that their participation is voluntary and understand that their data will be used freely under the detailed conditions.

3.1 STUDY POPULATION- INCLUSION FACTORS/ EXCLUSION FACTORS

3.1.1 Study group selection

The sample size was calculated with G*Power 3, version 3.1.9.4 (Faul et al., 2007).

As we have mentioned before, CBCTs analyzed in the study were obtained from the unit of Radiology Unit of the Faculty of Medicine and Dentistry at the University of Santiago de Compostela (USC). In this unit, CBCTs are performed both for patients at the faculty services as well as for patients referred from private external clinics. In patients with more than one CBCT, we used the most recent one.

3.1.2 Inclusion factors

The inclusion criteria were the following: (1) patients over 18 years old; (2) maxillary with at least one upper central incisor; and (3) CBCT with a 0.3 mm minimum voxel size image quality.

3.1.3 Exclusion factors

The exclusion criteria were as follows: (1) CBCT images which were impossible to rotate, blurred or incomplete; (2) decay, restoration or endodontic treatment, (3) ceramic/metal crowns or orthodontic elements; and (4) calcified root canal or root resorption.

3.1.4 Determination of Sample size

The sample size was calculated with G*Power 3, version 3.1.9.4 (Faul et al., 2007) considering a linear regression model to predict age based on a set of 23 predictors. Criteria for sample size calculations were 5% significance, 95% power and a moderate effect size ($f^2=0.15$) for each predictor. The total sample size calculated was set at a minimum of 234. Figure 8 shows the option of moderate effect size, $f^2=0.15$ and to more options, one more conservative, which sets f^2 at 0.1, and another, less conservative, which sets f^2 at 0.2.

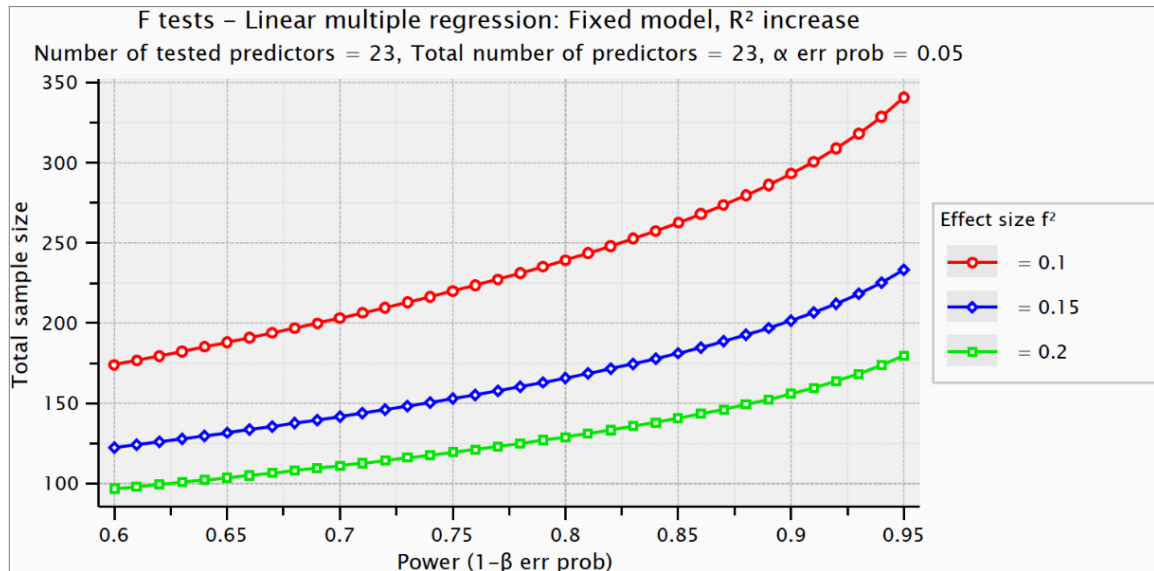


Figure 8. Sample size analysis.

A total of 360 CBCTs were included in the study. In 41 CBCTs, some measures were missing, mostly due to imaging problems associated teeth 11 and 21. Missing completely at random test (MCAR) was conducted to assess distribution of missing cases. The significance of this test was higher than 0.05, allowing to conclude that missing data were completely at random. Hence, multiple imputation was performed using fully conditional specification (FCS), known as multivariate imputation by chained equations (MICE), using R package MICE, as described in Van Buuren and Groothuis-Oudshoorn (2011). After multiple imputation, the sample was maintained at 360 for all the analyses.

Sample size calculations were also performed for logistic regression, attempting to predict gender, based on the same 23 predictors. Under the same conditions of significance (5%), we set the odds ratio at 2.0, achieving 80% power.

From the total 360 CBCTs, 120 were males (33.3%), and 240 were females (66.7%) (Figure 9).

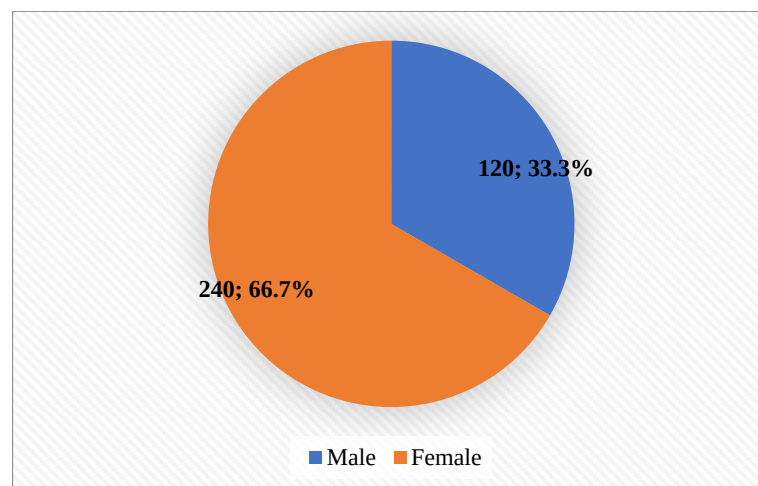


Figure 9. Sample for gender.

The groups regarding age were as follows: 93 subjects (25.8%) were 30 years old; 68 (18.9%) between 31 and 40 years old; 61 (16.9%) between 41 to 50 years old; 68 (18.9%) between 51 to 60 years old; and 70 (19.5%) higher than 60 years old (Table 5).

Table 5. Age group distribution

Age group	Frequency		Percentage
≤ 30	93		25.8%
31 - 40	68		18.9%
41 - 50	61		16.9%
51 - 60	68		18.9%
>60	70		19.5%
Total	360		100.0%

3.2 IMAGE EVALUATION AND HOW TO PUT THE PATIENT FOR CBCT REALIZATION

CBCT was carried out using i-CAT® Model 17–19 (Imaging Sciences International Inc., Hatfield, PA, USA) with a flat-panel detector of amorphous silicon, an exposure protocol of 120 kVp and a current of 5 mA for 14.7 s. The patient's occlusal plane was set parallel to the floor base by means of ear rods and a chin rest. DICOM files were reconstructed on computer (Samsung R522, Samsung Electronics, Seoul, Korea) using the 3D visualization software iCAT Vision® v. 1.9. CBCT slice thickness was set at 0.25 mm.

Rx technician sits the patient in de i-CAT unit with the head between the beam of rays and the receiver. The patient's height has to be adjusted until the system is stable in the mentum support without losing a straight posture. The head position has to be confirmed by the position of two vertical laser lines and a horizontal laser line protruding into the patient's head. One of the vertical lines passes 3.5 cm over the condyle and the other line passes through the sagittal plane of the patient's head. The horizontal line is known as the occlusal plane. A preview scan of the patient's head is carried out and then the scan is performed. The images collected are processed on the computer.

3.3 MEASUREMENTS

In this research, measurements were carried out in the sagittal, coronal and axial planes. In all measurements taken in these plans, we zoomed the image up to the maximum zoom limit, where there is no image distortion.

3.3.1 Upper Central Incisor measurements

All measurements were performed on the upper right central incisor, in the sagittal, coronal, and axial planes.

✓ Sagittal plane

To measure the upper central incisor, we begin by rotating the image of the CBCTs so that the tooth is as vertical as possible to make the measurements on it. This rotation is important to obtain a neutral position of all the incisors. In this way, we will be able to avoid

the inclination of the patient's head which can occur when performing the CBCT. That is to say we will place each incisor parallel to the horizontal line of the CBCT, matching its cemento-enamel junction in the vestibular and palatine points with the cursor red. We will call this position correction "incisive in a neutral position".

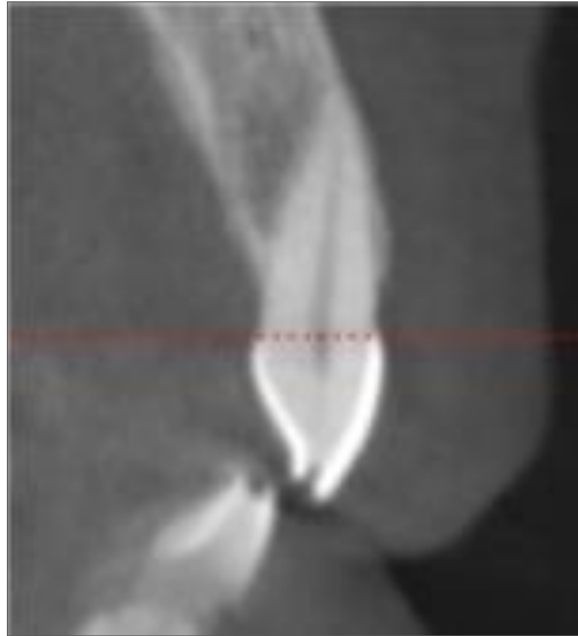


Figure 10. Upper central incisor in the neutral position with red horizontal line at cemento-enamel junction.

Locating the cemento-enamel junction and positioning the red line with the cursor, we make the following measurements:

- a) Tooth width - goes from the most palatine point to the most vestibular point of the tooth at cemento-enamel junction (**sce_TW**: sagittal tooth width at cemento-enamel junction level);
- b) Pulp width - goes from the most palatine point of the pulp to the most vestibular point of the pulp at cemento-enamel junction (**sce_PW**: sagittal pulp width at cemento-enamel junction level);

After these measurements we carry out a dynamic search of the image until we find the most incisive limit of the pulp horn, and mark a line. We carry out a dynamic search of the image until we find the uppermost limit of the tooth apex and then we make the following measures:

- c) Root length - goes from the tooth apex to the cemento-enamel junction, respecting the curvature of the tooth (**s_RL**: sagittal root length);
- d) Chamber length - goes from the cemento-enamel junction to the end of the pulp at the level of the crown (**s_PCL**: sagittal pulp chamber length);
- e) Coronal length - goes from the incisal edge to the beginning of the pulp chamber (**s_IL**: sagittal incisal length);
- f) Total tooth length - is the sum of c), d) and e) (**s_TTL**: sagittal total tooth length).

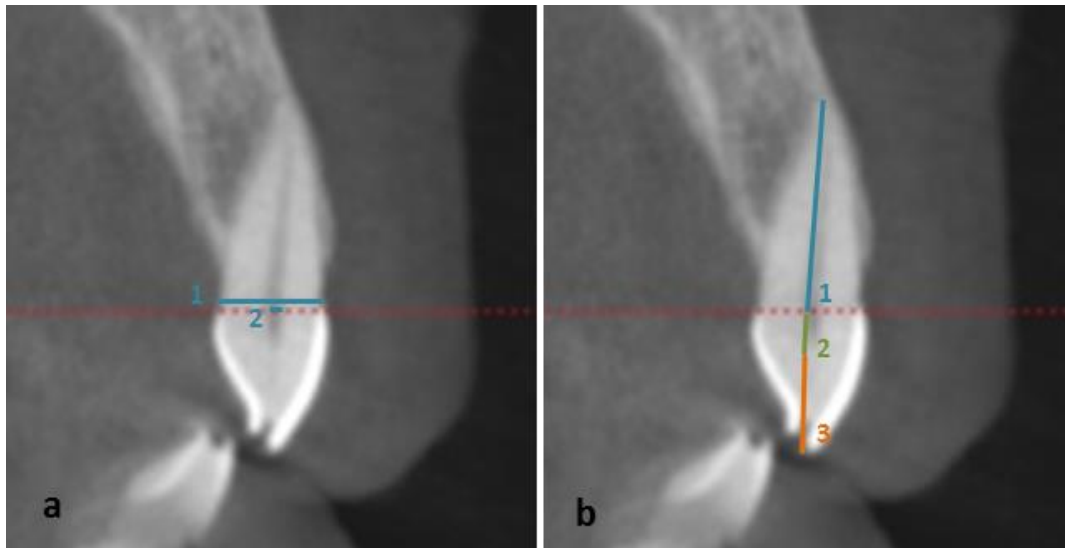


Figure 11. (a) Sagittal upper central incisive measurements at cemento-enamel junction: 1) tooth width (sce_TW), 2) pulp width (sce_PW); and (b) sagittal vertical measurements: 1) root length: (s_RL), 2) pulp chamber length (s_PCL), and 3) incisal length: (s_IL).

✓ Coronal plane

Keeping the red line in the position it was in the sagittal plane (at the level of the cemento enamel junction, without moving the cursor of the sagittal plane) we do a dynamic search of the image in coronal plane until we find the pulp as wide as possible at this level, and we make the following two measurements:

- a) Mesio-distal length- runs from the most mesial point to the most distal point of the tooth (**cce_MDTL**: coronal mesiodistal tooth length at cemento-enamel junction level) (Figure 12 sum of 1 to 3);
- b) Mesio-distal pulp length- goes from the most mesial point to the most distal point of the pulp (**cce_MDPL**: coronal mesiodistal pulp length at cemento-enamel junction level) (Figure 12).

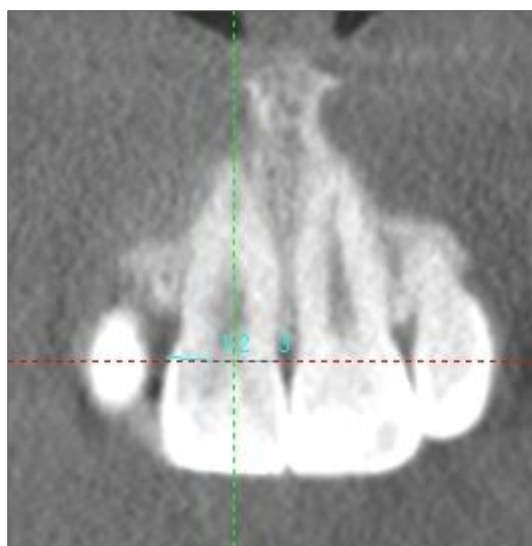


Figure 12. Upper central incisive with the measurements made in the coronal plane at the level of the cemento-enamel junction. Cce_MDTL: this measurement is the sum of 1 to 3 values, the width of the incisor in the mesio-distal direction. Cce_MDPL (2): the width of pulp incisor in the mesiodistal direction.

After making these measures, in sagittal plane, the red cursor is moved up to coronal level of the pulp. Before moving the cursor, the measurements of the axial plane corresponding to the level of the cemento-enamel junction are made: ace_MDTL (axial mesiodistal tooth length at cemento-enamel junction level), ace_MDPL (axial mesiodistal pulp length at cemento-enamel junction level), ace_PVTL (axial palatovestibular tooth length at cemento-enamel junction level), ace_PVPL (axial palatovestibular pulp length at cemento-enamel junction level) (see the axial plane section). We can see the following image and make the following measurements:

The red cursor is moved to the most coronal level of the pulp and then the width measurement of the crown is made (**sph_CW**).

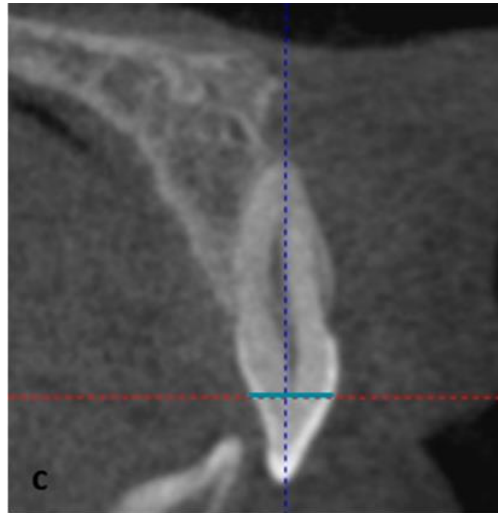


Figure 13. sph_CW: the width of the crown at the most coronal level of the pulp.

The following measures are also made:

- a) Mesiodistal length- runs from the most mesial point to the most distal point of the tooth (**cph_MDTL**) (Figure 14 sum of 1 to 3);
- b) Mesiodistal pulp length- goes from the most mesial point to the most distal point of the pulp (**cph_MDPL**) (Figures 5, 2).

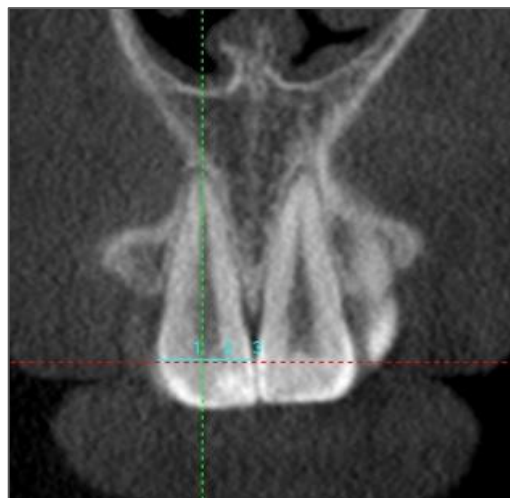


Figure 14. Upper central incisor with the measurements made in the coronal plane at the level of the coronal zone of pulp. cph_MDTL: this measurement is the sum of 1 to 3 values, the width of the incisor in the mesio-distal direction. cph_MDPL (2): the width of pulp incisor in the mesio-distal direction.

✓ Axial plane

In this plane, but at cemento-enamel junction level, we make the following measurements:

- Mesio-distal length- runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxilar arch (**ace_MDTL**);
- Internal mesio-distal length- goes from the most mesial point of the pulp to its most distal point (**ace_MDPL**);
- Palatal-vestibular length- runs from the most vestibular and central point of the tooth to its most palatine and central point (**ace_PVTL**);
- Internal palatal-buccal length- runs from the most vestibular point of the pulp to its most palatine point (**ace_PVPL**).

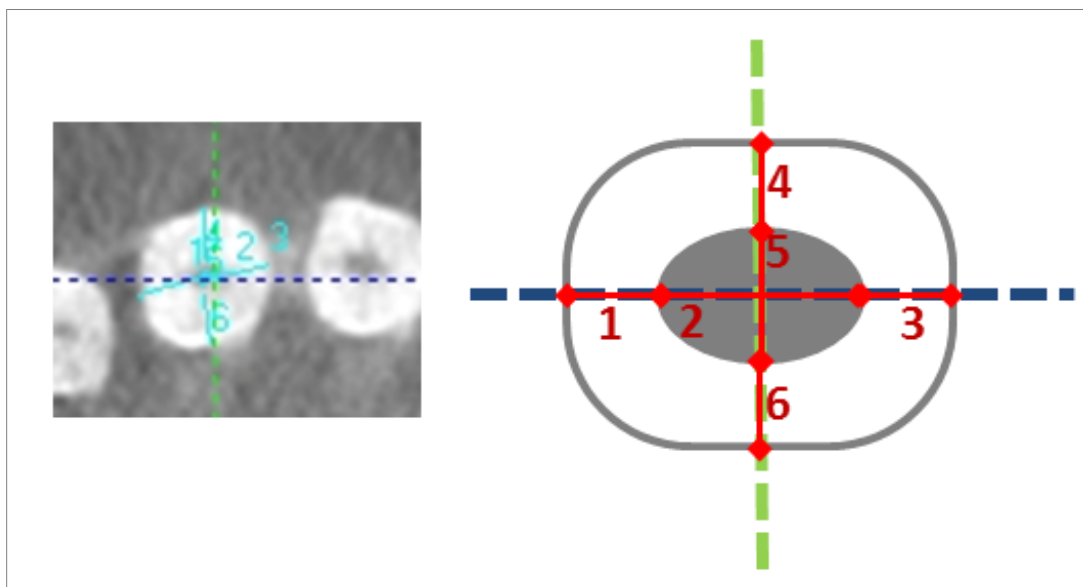


Figure 15. Upper central incisive with measurements made in the axial plane at the cemento-enamel junction level. A) ace_MDTL, sum of the values 1+2+3: mesio-distal length: from the most mesial and central point to the most distal and central point; b) ace_MDPL (2), internal mesio-distal length: from the most mesial point of the pulp to its most distal point; c) ace_PVTL, sum of the values 4+5+6: palatal-vestibular length: from the most vestibular and central point of the tooth to the most palatine and central point of the incisor; d) ace_PVPL (5), internal palatal-buccal length- runs from the most vestibular point of the pulp to its most palatine point.

In sagittal plane, we keep the red line at the coronal level we have previously have marked and make the following measurements:

- Mesio-distal length- runs from the most mesial point to the most distal point obeying the curvature of the maxilar arch (**aph_MDTL**: axial mesiodistal tooth length at pulp horn level).
- Internal mesio-distal length- goes from the most mesial point of the pulp to its most distal point (**aph_MDPL**: axial mesiodistal pulp length at pulp horn level)
- Palatal- vestibular length- runs from the most palatine point of the tooth to its most vestibular point (**aph_PVTL**: axial palatovestibular tooth length at pulp horn level).

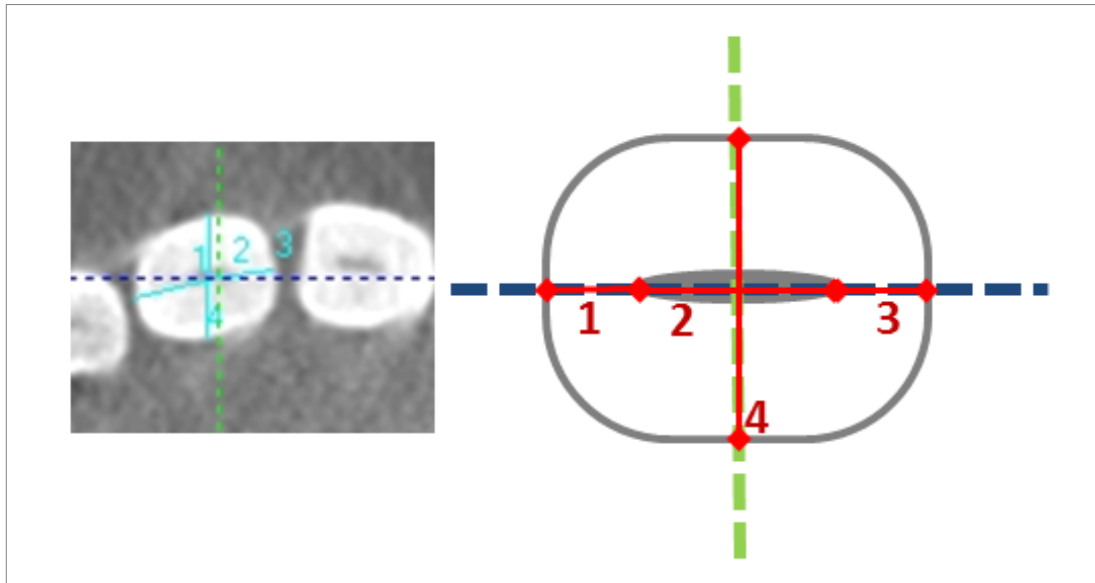


Figure 16. Upper central incisor with measurements made in the axial plane at the level of the SCL line. a) aph_MDTL, sum of the values 1+2+3: mesio-distal length: from the most mesial point to the most distal point, obeying the curvature of the maxilar arch; b) aph_MDPL (2) internal mesio-distal length: from the most mesial point of the pulp to its most distal point; c) aph_PVTL (4) palatal-vestibular length: from the most palatine point of the tooth to its most vestibular point.

3.3.2 Upper first molar measurements

To begin the measurements of the upper right first molar, we apply the program "rest volume rotation", so that the rotations that we have made for the measurements of incisors do not affect molar measurements.

✓ Coronal Plane

CBCT provides cross-sectional images following the curvature of the dental arch, so we used the coronal section of CBCT to see a lateral image of the molar.

In this plane we have to rotate the image to place each molar parallel to the horizontal line of CBCT, matching its cemento-enamel junction in the vestibular and palatine points with the red cursor. We will call this position correction "molar in neutral position". Due to this process, we correct the patient's head inclination when performing CBCT.

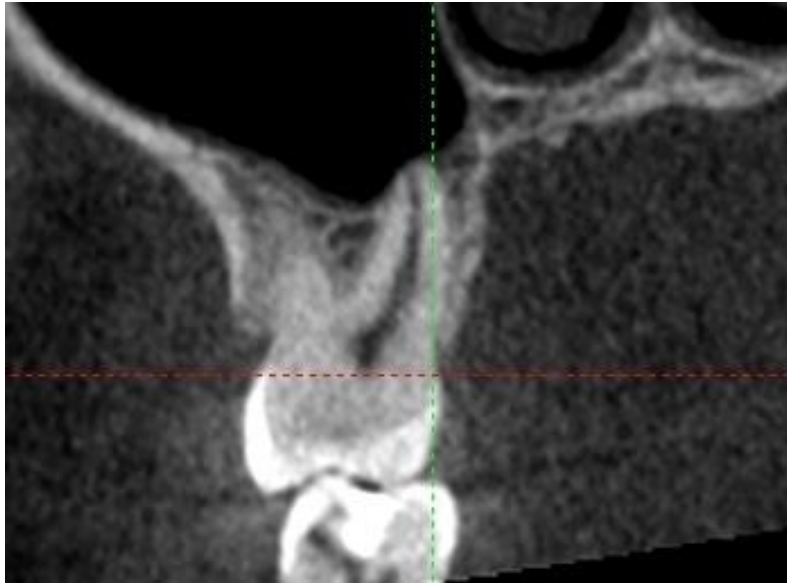


Figure 17. Upper first molar in "neutral position": the horizontal red line parallel to cemento-enamel junction at vestibular and palatine points of the molar.

In this plan we make the following measure:

- a) Total length of palatine root (neutral position) - we rotate the image until the tooth is as vertical as possible, so we put the red cursor to pass to the level of the amelocemental line both in vestibular and palatine. Then we carry out a dynamic search of the image until we find the upper limit of apex of the palatine root. After that, we measure from the apex to the red line, obeying the curvature of the root (**M.S_TTL**).

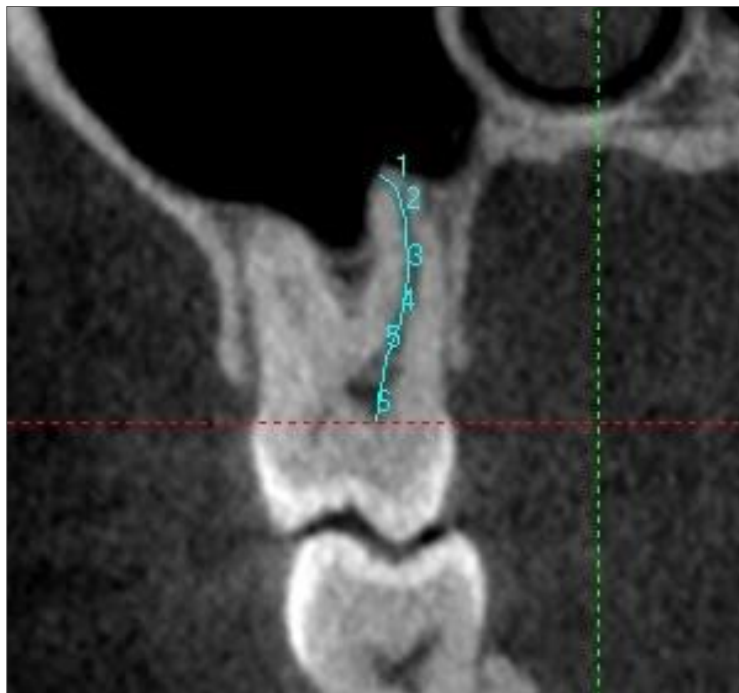


Figure 18. M.S_TTL. The measure of the total length of upper first molar palatine root is the sum of all values respecting the curvature of the root to precision measurement.

Still in this plan, we carry out a dynamic search of the image until we find the most coronal area of the pulp of horns. Here, we mark a line, then we make a dynamic search of the furca where we put the red cursor and we make the following measurement:

- b) The height of the pulp chamber goes from the furca level located, to the line that marks the most coronal level of the pulp horns (**M.CACP**: molar pulp chambre height) (Figure 19).



Figure 19. M.CACP: The height of the upper first molar pulp camera (2). To calculated M.CACP, two lines are needed to perform: the red horizontal line is situated at the most coronal level of pulp horn and the blue line (1) indicates furca level.

✓ Axial Plane

We look for the area where the camera pulp is bigger and we take the following measures, these measures are all in the same slice (Figure 20):

- a) Vestibule-palatine length- goes from the midpoint of the buccal surface to the midpoint of the palatal surface (**M.aph_PVTL**);
- b) Internal mesio-distal length-goes from the most mesial point of the pulp to the most distal point of the pulp (**M.aph_MDPL**);
- c) Mesio-distal length- goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxilar arch (**M.aph_MDTL**). (Figure 20)

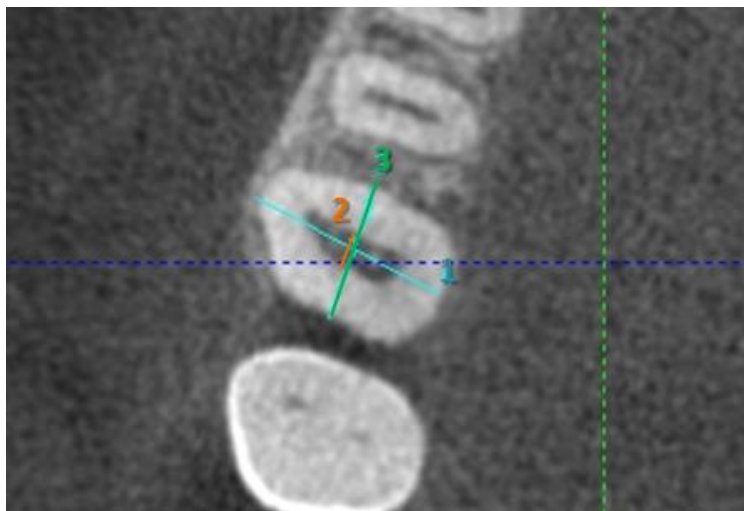


Figure 20. Upper first molar measurements in the axial plane. M.aph_PVTL (1) - the width of the molar in the palatovestibular direction; M. aph_MDPL (2)- the width of the molar pulp in the mesio-distal direction; and M.aph_MDTL (3) - the width of the molar in the mesiodistal direction.

3.4 STATISTICAL ANALYSIS

To check the intraobserver variability, measurements were again made of 20 CBCTs, 1 month later. These 20 CBCTs were selected by an external observer who recoded CBCTs so that observer 1 could not identify them. To check the interobserver variability, an external observer made the measurements of 20 CBCTs included in the study, to contrast with the measurements of observer 1.

Data was analyzed with SPSS, version 28.0 (IBM Corp., 2021) and R [4.2.3] (R Core Team, 2022). R packages used included Naniar to assess the distribution of missing values with MCAR test and {mice} package to perform imputation. CBCT measurements were described as means (M), standard deviations (SD), minimums and maximums. These statistics were computed after exploring variables distributions with histograms and the normality test Kolmogorov-Smirnov. Normality was considered for $p > 0.05$ (Field, 2018).

T-tests and ANOVAs were conducted to examine group differences in CBCT measurements. Specifically, independent sample t-tests were used to compare means between two groups, while one-way ANOVAs were employed for comparisons involving more than two groups. Bonferroni tests were performed as post-hoc tests to determine specific between-group differences following significant ANOVA results. The significance level for these analyses was set at $\alpha = 0.05$ (Field, 2018).

Logistic regression analyses were conducted to investigate the predictive capacity of the CBCT measurements and ratios for determining gender. These analyses aimed to estimate the odds ratios (ORs) and corresponding confidence intervals (CIs) to assess the association between the predictor variables and the binary outcome of gender (Agresti, 2013; Hosmer et al., 2013).

Additionally, multiple linear regression models were employed to predict age based on CBCT measurements and ratios. The adjusted R-squared values, standard error of estimate (SEE), and p-values were reported to evaluate the goodness of fit and the significance of the predictors (Field, 2018). Assumptions of linearity, independence, homoscedasticity, and normality of residuals were assessed to ensure the validity of the regression models (Field, 2018).

4 RESULTS

This section has been partially adapted/extracted from our published manuscript titled “**Age Estimation Using Maxillary Central Incisor Analysis on Cone Beam Computed Tomography Human Images**” Santos et al (2022)

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4.1 DESCRIPTIVE RESULTS

Table 6 presents descriptive statistics for all CBCT measurements analyzed in the study. Appendix 1 shows histograms for all distributions. Visual inspection suggested that all variables were normally distributed. Kolmogorov-Smirnov tests confirmed normal distribution for all variables having obtained $p > 0.05$ for all. Hence, we calculated and presented means and standard deviations to describe all variables. We also presented minimums and maximums to all distributions.

All measurements are categorized into different sections based on the specific dental structures and the type of measurement conducted.

4.1.1 Anatomical measurements of the right upper central incisor on three anatomical planes

Considering the sagittal linear measurements of the right upper central incisor, several parameters were measured. The mean sagittal linear measurement for the sce_TW parameter was found to be 7.16 mm, with a standard deviation (SD) of 0.53 mm. The minimum and maximum values recorded for this parameter were 5.52 mm and 8.8 mm, respectively. Similarly, measurements were taken for parameters such as sce_PW (mean = 1.56 mm, SD = 0.38 mm, Min = 0.50 mm, Max = 3.30 mm), s_RL (mean = 13.16 mm, SD = 1.87 mm, Min = 6.00 mm, Max = 18.06 mm), s_PCL (mean = 3.11 mm, SD = 1.19 mm, Min = 0.25 mm, Max = 6.50 mm), s_IL (mean = 6.6 mm, SD = 1.29 mm, Min = 0.93 mm, Max = 10.61 mm),

s_TTL (mean = 22.86 mm, SD = 2.27 mm, Min = 15.08 mm, Max = 31.34 mm), and sph_CW (mean = 6.58 mm, SD = 0.87 mm, Min = 4.50 mm, Max = 8.75 mm). Delving into the coronal linear measurements of the right upper central incisor, within this category, various parameters were examined to assess the dental features. Beginning with the "cce_MDTL" parameter, it exhibited an average measurement of 6.36 mm, with a standard deviation of 0.58 mm. The minimum and maximum values recorded for this parameter were 5.50 mm and 7.80 mm, respectively. Moving on to the "cce_MDPL" parameter, it displayed a mean measurement of 1.84 mm, with a standard deviation of 0.34 mm. The minimum and maximum values recorded for this parameter were 0.75 mm and 3.00 mm, respectively. The "cph_MDTL" parameter had an average measurement of 7.57 mm, with a standard deviation of 0.88 mm. The minimum and maximum values recorded were 4.50 mm and 10.25 mm, respectively. For the "cph_MDPL" parameter, the mean measurement was 2.06 mm, with a standard deviation of 0.58 mm. The minimum and maximum values recorded for this parameter were 0.75 mm and 3.75 mm, respectively. In the context of axial linear measurements of the right upper central incisor, several parameters were examined. The "ace_MDTL" parameter exhibited an average measurement of 6.57 mm, with a standard deviation of 0.6 mm. The minimum and maximum values recorded for this parameter were 4.44 mm and 8.25 mm, respectively. Another parameter, "ace_MDPL," had a mean measurement of 2.09 mm, with a standard deviation of 0.51 mm. The minimum and maximum values recorded for this parameter were 0.75 mm and 3.35 mm, respectively. Moving on to the "ace_PVTTL" parameter, it was observed to have a mean measurement of 7.47 mm, with a standard deviation of 0.54 mm. The minimum and maximum values recorded were 6.25 mm and 9.51 mm, respectively. For the "ace_PVPL" parameter, the mean measurement was 1.70 mm, with a standard deviation of 0.35 mm. The minimum and maximum values recorded were 0.75 mm and 3.25 mm, respectively. Shifting our focus to the "aph_MDTL" parameter, it exhibited a mean measurement of 7.73 mm, with a standard deviation of 0.83 mm. The minimum and maximum values recorded for this parameter were 5.70 mm and 10.36 mm, respectively. In terms of the "aph_MDPL" parameter, the mean measurement was 2.37 mm, with a standard deviation of 0.78 mm. The minimum and maximum values recorded were 0.50 mm and 4.32 mm, respectively. Lastly, the "aph_PVTTL" parameter had a mean measurement of 6.40 mm, with a standard deviation of 0.95 mm. The minimum and maximum values recorded were 3.00 mm and 9.20 mm, respectively.

4.1.2 Anatomical measurements of the right upper first molar on three anatomical planes

Moving forward to the measurements of the right upper first molar, the following parameters were examined. The "M.S_TTL" parameter had a mean measurement of 14.05 mm, with a standard deviation of 1.85 mm. The minimum and maximum values recorded for this parameter were 8.32 mm and 18.10 mm, respectively. For the "M.CACP" parameter, the mean measurement was 3.61 mm, with a standard deviation of 0.77 mm. The minimum and maximum values recorded were 1.75 mm and 6.00 mm, respectively. The "M.aph_MDTL" parameter exhibited a mean measurement of 8.42 mm, with a standard deviation of 0.75 mm. The minimum and maximum values recorded were 6.42 mm and 11.72 mm, respectively. For the "M.aph_MDPL" parameter, the mean measurement was 2.72 mm, with a standard deviation of 0.52 mm. The minimum and maximum values recorded were 0.92 mm and 5.02 mm, respectively. Lastly, the "M.aph_PVTTL" parameter had a mean measurement of 11.43 mm, with a standard deviation of 0.81 mm. The minimum and maximum values recorded were 9.24 mm and 14.14 mm, respectively.

4.1.3 Ratios of the anatomical measurements of the right upper central incise on three anatomical planes

Next, we will describe the axial ratios of the right upper central incise. These ratios help assess the relationship between different axial measurements. Starting with the "ace_MDPL/ace_MDTL" parameter, it exhibited an average ratio of 0.31, with a standard deviation of 0.06. The minimum and maximum values recorded for this ratio were 0.10 and 0.49, respectively. Moving on to the "ace_PVPL/ace_PVTL" parameter, the mean ratio was 0.22, with a standard deviation of 0.04. The minimum and maximum values recorded for this ratio were 0.10 and 0.48, respectively. Furthermore, the "ace_PVPL/ace_MDTL" ratio had a mean measurement of 0.26, accompanied by a standard deviation of 0.06. The minimum and maximum values recorded for this ratio were 0.13 and 0.60, respectively. For the "aph_MDPL/aph_MDTL" parameter, the mean ratio was 0.30, with a standard deviation of 0.08. The minimum and maximum values recorded for this ratio were 0.07 and 0.48, respectively. Lastly, the "aph_PVTL/aph_MDTL" ratio displayed an average measurement of 0.84, with a standard deviation of 0.17. The minimum and maximum values recorded for this ratio were 0.30 and 1.26, respectively.

4.1.4 Ratios of the anatomical measurements of the right upper first molar on three anatomical planes

Finally, we present the sagittal and axial ratios of the right upper first molar, providing insights into its dimensional proportions and relationships. Beginning with the "M.CACP/M.S_TTL" ratio, it exhibited an average measurement of 0.26, with a standard deviation of 0.05. The minimum and maximum values recorded for this ratio were 0.13 and 0.42, respectively. Moving on to the "M.aph_PVTL/M.aph_MDTL" ratio, it had a mean measurement of 1.36, accompanied by a standard deviation of 0.10. The minimum and maximum values recorded for this ratio were 0.92 and 1.66, respectively. Similarly, for the "M.aph_MDPL/M.aph_MDTL" parameter, the mean ratio was 0.32, with a standard deviation of 0.05. The minimum and maximum values recorded for this ratio were 0.10 and 0.46, respectively.

Table 6. Descriptive statistics for all measurements.

n = 360	Mean (mm)	SD (mm)	Min (mm)	Max (mm)
Right upper central incise	Sagittal linear measurements of right upper central incise			
sce_TW	7.16	0.53	5.52	8.8
sce_PW	1.56	0.38	0.50	3.30
s_RL	13.16	1.87	6.00	18.06
s_PCL	3.11	1.19	0.25	6.50
s_IL	6.6	1.29	0.93	10.61
s_TTL	22.86	2.27	15.08	31.34
sph_CW	6.58	0.87	4.50	8.75
Right upper central incise	Coronal linear measurements of right upper central incise			
cce_MDTL	6.36	0.58	5.50	7.80
cce_MDPL	1.84	0.34	0.75	3.00
cph_MDTL	7.57	0.88	4.50	10.25
cph_MDPL	2.06	0.58	0.75	3.75

n = 360	Mean (mm)	SD (mm)	Min (mm)	Max (mm)
Right upper central incisive	Axial linear measurements of right upper central incisive			
ace_MDTL	6.57	0.6	4.44	8.25
ace_MDPL	2.09	0.51	0.75	3.35
ace_PVTL	7.47	0.54	6.25	9.51
ace_PVPL	1.70	0.35	0.75	3.25
aph_MDTL	7.73	0.83	5.70	10.36
aph_MDPL	2.37	0.78	0.50	4.32
aph_PVTL	6.40	0.95	3.00	9.20
Right upper first molar	Sagittal and axial linear measurements of right upper first molar			
M.S_TTL	14.05	1.85	8.32	18.10
M.CACP	3.61	0.77	1.75	6.00
M.aph_MDTL	8.42	0.75	6.42	11.72
M.aph_MDPL	2.72	0.52	0.92	5.02
M.aph_PVTL	11.43	0.81	9.24	14.14
Right upper central incisive	Sagittal ratios of right upper central incisive			
s_IL /S_TTL	0.29	0.05	0.04	0.48
s_PCL/S_TTL	0.13	0.05	0.01	0.29
s_RL/S_TTL	0.57	0.05	0.40	0.79
s_IL+S_PCL/S_TTL	3.40	1.16	0.57	6.81
sce_PW/sce_TW	0.21	0.05	0.07	0.44
Right upper central incisive	Coronal ratios of right upper central incisive			
cce_MDPL/cce_MDTL	0.29	0.05	0.13	0.46
cph_MDPL/cph_MDTL	0.27	0.06	0.11	0.48
Right upper central incisive	Axial ratios of right upper central incisive			
ace_MDPL/ace_MDTL	0.31	0.06	0.10	0.49
ace_PVPL/ace_PVTL	0.22	0.04	0.10	0.48
ace_PVPL/ace_MDTL	0.26	0.06	0.13	0.60
aph_MDPL /aph_MDTL	0.30	0.08	0.07	0.48
aph_PVTL/aph_MDTL	0.84	0.17	0.30	1.26
Right upper first molar	Sagittal and axial ratios of right upper first molar			
M.CACP/M.S_TTL	0.26	0.05	0.13	0.42
M.aph_PVTL/M.aph_MDTL	1.36	0.10	0.92	1.66
M.aph_MDPL/M.aph_MDTL	0.32	0.05	0.10	0.46

sce_TW, Amelo-cemental length: goes from the most palatine point to the most vestibular point of the tooth; **sce_PW**, Pulpal amelo-cemental length: goes from the most palatine point of the pulp to the most vestibular point of the pulp; **s_RL**, Root length: goes from the apex to the tooth to cemento-enamel junction respecting the curvature of the tooth; **s_PCL**, Chamber length: goes from the cemento-enamel junction to the end of the pulp at the level of the crown; **s_IL**, Coronal length: goes from the incisal edge to the beginning of the pulp chamber; **s_TTL**, Total tooth length: is the sum of s_RL, s_PCL and s_IL; **sph_CW**, coronal width at pulpar horn level; **cce_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cce_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **ace_MDTL**, Mesio-distal length: runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxilar arch; **ace_MDPL**, Internal mesio-distal length: goes from the most mesial point of the pulp to the most distal point of the pulp; **ace_PVTL**, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; **ace_PVPL**, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; **cph_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cph_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **aph_MDTL**, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxilar arch; **aph_MDPL**, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; **aph_PVTL**, Palatal- vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth; **STTL**, Total length of palatine root: measure from the apex to the red line obeying the curvature of the root; **M.S_TTL**, molar sagittal total tooth length; **M.CACP**, molar pulp chambre height; **M.aph_MDTL**, molar axial mesiodistal tooth length at pulp horn level; **M.aph_MDPL**, molar axial mesiodistal pulp length at pulp horn level; **M.aph_PVTL**, molar axial palatovestibular tooth length at pulp horn level.

4.2 ANATOMICAL MEASUREMENTS AND RATIOS OF UPPER CENTRAL INCISIVE AND UPPER FIRST MOLAR COMPARED BY GENDER

4.2.1 Anatomical measurements of the right upper central incisor on three anatomical planes compared by gender

Table 7 presents the results of anatomical measurements of the upper central incisor on sagittal slices measurements compared by gender. Measurements include *sce_TW*, *sce_PW*, *s_RL*, *s_PCL*, *s_IL*, *s_TTL*, and *sph_CW*. The mean values and standard deviations were calculated for each measurement, and t-tests were conducted to evaluate the significance of gender differences.

For the parameter *sce_TW*, males had a mean measurement of 7.25 mm (SD = 0.60 mm), while females had a slightly lower mean of 7.12 mm (SD = 0.48 mm). The t-value for the comparison of means was 2.072 ($p = 0.039$), indicating a statistically significant difference between genders.

Regarding *sce_PW*, males had a mean measurement of 1.54 mm (SD = 0.39 mm), while females had a slightly higher mean of 1.57 mm (SD = 0.38 mm). However, the t-test showed no significant difference between males and females ($t = -0.560$, $p = 0.576$).

For *s_RL*, males had an average measurement of 13.66 mm (SD = 1.75 mm), whereas females had a slightly lower mean of 12.92 mm (SD = 1.88 mm). The t-test indicated a statistically significant difference between the genders ($t = 3.307$, $p = 0.001$).

For *s_PCL*, males had a mean measurement of 2.96 mm (SD = 1.23 mm), and females had a slightly higher mean of 3.18 mm (SD = 1.16 mm). However, the t-test did not reveal a significant difference between males and females ($t = -1.485$, $p = 0.139$). Moving on to *s_IL*, males had a mean measurement of 6.91 mm (SD = 1.38 mm), while females had a slightly lower mean of 6.46 mm (SD = 1.23 mm). The t-test showed a statistically significant difference between genders ($t = 2.859$, $p = 0.005$). Regarding *s_TTL*, males had a mean measurement of 23.48 mm (SD = 2.27 mm), and females had a slightly lower mean of 22.57 mm (SD = 2.21 mm). The t-test indicated a statistically significant difference between the genders ($t = 3.344$, $p = 0.001$). Lastly, for *sph_CW*, males had a mean measurement of 6.72 mm (SD = 0.94 mm), while females had a slightly lower mean of 6.51 mm (SD = 0.82 mm). The t-test revealed a statistically significant difference between genders ($t = 2.029$, $p = 0.043$).

Table 7. Anatomical measurements of upper central incisor on sagittal slices compared by gender.

Measure	Gender	Mean (mm)	Std. Deviation (mm)	t	p
sce_TW	Male	7.25	0.60	2.072	0.039*
	Female	7.12	0.48		
sce_PW	Male	1.54	0.39	-0.560	0.576
	Female	1.57	0.38		
s_RL	Male	13.66	1.75	3.307	0.001*
	Female	12.92	1.88		
s_PCL	Male	2.96	1.23	-1.485	0.139
	Female	3.18	1.16		
s_IL	Male	6.91	1.38	2.859	0.005*
	Female	6.46	1.23		
s_TTL	Male	23.48	2.27	3.344	0.001*
	Female	22.57	2.21		
sph_CW	Male	6.72	0.94	2.029	0.043*
	Female	6.51	0.82		

sce_TW, Amelo-cemental length: goes from the most palatine point to the most vestibular point of the tooth; **sce_PW**, Pulpal amelo-cemental length: goes from the most palatine point of the pulp to the most vestibular point of the pulp; **s_RL**, Root length: goes from the apex to the tooth to cemento-enamel junction respecting the curvature of the tooth; **s_PCL**, Chamber length: goes from the cemento-enamel junction to the end of the pulp at the level of the crown; **s_IL**, Coronal length: goes from the incisal edge to the beginning of the pulp chamber; **s_TTL**, Total tooth length: is the sum of *s_RL*, *s_PCL* and *s_IL*; **sph_CW**, coronal width at pulpar horn level; t, t-test; p, p-value; * $p < 0.05$; males ($n = 124$), females ($n = 249$).

Table 8 presents the results of anatomical measurements of the upper central incisor on coronal slices, comparing measurements between genders. Measurements include cce_MDTL, cce_MDPL, cph_MDTL, and cph_MDPL. Mean values and standard deviations were calculated for each measurement, and t-tests were conducted to assess gender differences.

For the cce_MDTL parameter, males had a mean measurement of 6.51 mm (SD = 0.55 mm), while females had a slightly lower mean of 6.29 mm (SD = 0.58 mm). The t-test revealed a statistically significant difference between genders ($t = 3.197$, $p = 0.002$), indicating that males tend to have larger cce_MDTL measurements compared to females.

Regarding cce_MDPL, males had a mean measurement of 1.94 mm (SD = 0.45 mm), while females had a slightly lower mean of 1.80 mm (SD = 0.37 mm). The t-test also showed a statistically significant difference between genders ($t = 2.938$, $p = 0.004$), indicating that males tend to have larger cce_MDPL measurements compared to females.

Moving on to cph_MDTL, males had a mean measurement of 7.61 mm (SD = 0.95 mm), and females had a slightly lower mean of 7.55 mm (SD = 0.85 mm). However, the t-test did not indicate a significant difference between males and females in terms of cph_MDTL ($t = 0.588$, $p = 0.557$).

For cph_MDPL, males had a mean measurement of 2.16 mm (SD = 0.60 mm), while females had a slightly lower mean of 2.02 mm (SD = 0.57 mm). The t-test showed a borderline significant difference between genders ($t = 1.934$, $p = 0.054$), suggesting a trend towards larger cph_MDPL measurements in males compared to females.

Table 8. Anatomical measurements of upper central incisor on coronal slices compared by gender.

Measure	Gender	Mean (mm)	Std. Deviation (mm)	t	p
cce_MDTL	Male	6.51	0.55	3.197	0.002*
	Female	6.29	0.58		
cce_MDPL	Male	1.94	0.45	2.938	0.004*
	Female	1.80	0.37		
cph_MDTL	Male	7.61	0.95	0.588	0.557
	Female	7.55	0.85		
cph_MDPL	Male	2.16	0.60	1.934	0.054
	Female	2.02	0.57		

cce_MDTL, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cce_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **cph_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cph_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; t, t-test; p, p-value; * $p < 0.05$; males (n=124), females (n=249).

Table 9 presents the results of the anatomical measurements of the upper central incisor on axial slices, comparing the measurements between genders. The measurements include ace_MDTL, ace_MDPL, ace_PVTL, ace_PVPL, aph_MDTL, aph_MDPL, and aph_PVTL. Mean values and standard deviations were calculated for each measurement, and t-tests were conducted to assess gender differences.

For the ace_MDTL parameter, males had a mean measurement of 6.83 mm (SD = 0.62 mm), while females had a slightly lower mean of 6.45 mm (SD = 0.56 mm). The t-test revealed a statistically significant difference between genders ($t = 5.223$, $p < 0.001$), indicating that males tend to have larger ace_MDTL measurements compared to females.

Regarding ace_MDPL, males had a mean measurement of 2.20 mm (SD = 0.51 mm), while females had a slightly lower mean of 2.04 mm (SD = 0.50 mm). The t-test also showed a statistically significant difference between genders ($t = 2.640$, $p = 0.009$), suggesting that males tend to have larger ace_MDPL measurements compared to females.

Moving on to ace_PVTL, males had a mean measurement of 7.55 mm (SD = 0.65 mm), and females had a slightly lower mean of 7.43 mm (SD = 0.47 mm). However, the t-test did not indicate a significant difference between males and females in terms of ace_PVTL ($t = 1.619$, $p = 0.107$).

For ace_PVPL, males had a mean measurement of 1.68 mm (SD = 0.35 mm), while females had a similar mean of 1.70 mm (SD = 0.36 mm). The t-test showed no significant difference between genders in ace_PVPL measurements ($t = -0.506$, $p = 0.613$).

Regarding aph_MDTL, males had a mean measurement of 6.91 mm (SD = 0.84 mm), while females had a slightly lower mean of 6.46 mm (SD = 0.82 mm). The t-test did not reveal a significant difference between genders in terms of aph_MDTL ($t = 1.597$, $p = 0.111$).

For aph_MDPL, males had a mean measurement of 23.48 mm (SD = 0.78 mm), and females had a similar mean of 22.57 mm (SD = 0.78 mm). The t-test showed no significant difference between genders in aph_MDPL measurements ($t = 0.861$, $p = 0.390$).

Lastly, for aph_PVTL, males had a mean measurement of 6.72 mm (SD = 1.05 mm), while females had a slightly lower mean of 6.51 mm (SD = 0.89 mm). The t-test revealed a statistically significant difference between genders ($t = 2.766$, $p = 0.006$), indicating that males tend to have larger aph_PVTL measurements compared to females.

Table 9. Anatomical measurements of upper central incisor on axial slices compared by gender.

Measure	Gender	Mean (mm)	Std. Deviation (mm)	t	p
ace_MDTL	Male	6.83	0.62	5.223	<0.001*
	Female	6.45	0.56		
ace_MDPL	Male	2.20	0.51	2.640	0.009*
	Female	2.04	0.50		
ace_PVTL	Male	7.55	0.65	1.619	0.107
	Female	7.43	0.47		
ace_PVPL	Male	1.68	0.35	-0.506	0.613
	Female	1.70	0.36		
aph_MDTL	Male	6.91	0.84	1.597	0.111
	Female	6.46	0.82		
aph_MDPL	Male	23.48	0.78	0.861	0.390
	Female	22.57	0.78		
aph_PVTL	Male	6.72	1.05	2.766	0.006*
	Female	6.51	0.89		

ace_MDTL, Mesio-distal length: runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxilar arch; **ace_MDPL**, Internal mesio-distal length: goes from the most mesial point of the pulp to the most distal point of the pulp; **ace_PVTL**, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; **ace_PVPL**, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; **aph_MDTL**, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxilar arch; **aph_MDPL**, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; **aph_PVTL**, Palatal- vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth; t, t-test; p, p-value; * $p < 0.05$; males (n=124), females (n=249).

4.2.2 Anatomical measurements of the right upper first molar on three anatomical planes compared by gender

Table 10 presents anatomical measurements of the right upper first molar on three anatomical planes, comparing measurements between genders.

Measurements included in the table are M.S_TTL, M.CACP, M.aph_MDTL, M.aph_MDPL, and M.aph_PVTL. Mean values and standard deviations were calculated for each measurement, and t-tests were conducted to assess gender differences.

For the M.S_TTL parameter, males had a mean measurement of 6.83 mm (SD = 0.62 mm), while females had a slightly lower mean of 6.45 mm (SD = 0.56 mm). The t-test revealed a statistically significant difference between genders ($t = 5.223$, $p < 0.001$), indicating that males tend to have larger M.S_TTL measurements compared to females.

Regarding M.CACP, males had a mean measurement of 2.20 mm (SD = 0.51 mm), while females had a slightly lower mean of 2.04 mm (SD = 0.50 mm). The t-test also showed a statistically significant difference between genders ($t = 2.640$, $p = 0.009$), suggesting that males tend to have larger M.CACP measurements compared to females.

Considering M.aph_MDTL, males had a mean measurement of 7.55 mm (SD = 0.65 mm), and females had a slightly lower mean of 7.43 mm (SD = 0.47 mm). Nevertheless, the t-test did not indicate a significant difference between males and females in terms of M.aph_MDTL ($t = 1.619$, $p = 0.107$).

For M.aph_MDPL, males had a mean measurement of 1.68 mm (SD = 0.35 mm), while females had a similar mean of 1.70 mm (SD = 0.36 mm). The t-test showed no significant difference between genders in M.aph_MDPL measurements ($t = -0.506$, $p = 0.613$).

Regarding M.aph_PVTL, males had a mean measurement of 6.91 mm (SD = 0.84 mm), while females had a slightly lower mean of 6.46 mm (SD = 0.82 mm). The t-test did not reveal a significant difference between genders in terms of M.aph_PVTL ($t = 1.597$, $p = 0.111$).

Table 10. Anatomical measurements of the right upper first molar on three anatomical planes compared by gender.

Measure	Gender	Mean (mm)	Std. Deviation (mm)	t	p
M.S_TTL	Male	6.83	0.62	5.223	<0.001*
	Female	6.45	0.56		
M.CACP	Male	2.20	0.51	2.640	0.009*
	Female	2.04	0.50		
M.aph_MDTL	Male	7.55	0.65	1.619	0.107
	Female	7.43	0.47		
M.aph_MDPL	Male	1.68	0.35	-0.506	0.613
	Female	1.70	0.36		
M.aph_PVTL	Male	6.91	0.84	1.597	0.111
	Female	6.46	0.82		

M.S_TTL, molar sagittal total tooth length; **M.CACP**, molar pulp chambre height; **M.aph_MDTL**, molar axial mesiodistal tooth length at pulp horn level; **M.aph_MDPL**, molar axial mesiodistal pulp length at pulp horn level; **M.aph_PVTL**, molar axial palatovestibular tooth length at pulp horn level; t, t-test; p, p-value; * $p < 0.05$; males (n=124), females (n=249).

4.2.3 Ratios of the right upper central incisor on three anatomical planes compared by gender

Table 11 presents the ratios of the right upper central incisor on three anatomical planes, comparing the measurements between genders. The table includes various ratios, such as s_{IL}/s_{TTL} , s_{PCL}/s_{TTL} , s_{RL}/s_{TTL} , $s_{IL}+s_{PCL}/s_{TTL}$, sce_{PW}/sce_{TW} , cce_{MDPL}/cce_{MDTL} , cph_{MDPL}/cph_{MDTL} , ace_{MDPL}/ace_{MDTL} , ace_{PVPL}/ace_{PVTTL} , ace_{PVPL}/ace_{MDTL} , aph_{MDPL}/aph_{MDTL} , and aph_{PVTTL}/aph_{MDTL} . Mean values and standard deviations were calculated for each ratio, and t-tests were conducted to assess gender differences.

For the s_{IL}/s_{TTL} ratio, males had a mean ratio of 0.29 (SD = 0.05), while females had a slightly lower mean ratio of 0.28 (SD = 0.05). The t-test did not reveal a significant difference between genders in terms of the s_{IL}/s_{TTL} ratio ($t = 0.906$, $p = 0.365$).

Regarding the s_{PCL}/s_{TTL} ratio, males had a mean ratio of 0.12 (SD = 0.05), while females had a slightly higher mean ratio of 0.14 (SD = 0.05). The t-test showed a statistically significant difference between genders ($t = -2.344$, $p = 0.020$), indicating that females tend to have larger s_{PCL}/s_{TTL} ratios compared to males.

Moving on to the s_{RL}/s_{TTL} ratio, males had a mean ratio of 0.58 (SD = 0.04), while females had a slightly lower mean ratio of 0.57 (SD = 0.05). However, the t-test did not indicate a significant difference between males and females in terms of the s_{RL}/s_{TTL} ratio ($t = 1.680$, $p = 0.094$).

For the $s_{IL}+s_{PCL}/s_{TTL}$ ratio, males had a mean ratio of 3.26 (SD = 1.19), while females had a slightly higher mean ratio of 3.47 (SD = 1.13). The t-test did not reveal a significant difference between genders in terms of the $s_{IL}+s_{PCL}/s_{TTL}$ ratio ($t = -1.464$, $p = 0.144$).

Regarding the SCE_{PW}/SCE_{TW} ratio, males had a mean ratio of 0.21 (SD = 0.05), while females had a slightly higher mean ratio of 0.22 (SD = 0.04). The t-test also did not indicate a significant difference between males and females in terms of the SCE_{PW}/SCE_{TW} ratio ($t = -1.123$, $p = 0.262$).

Considering the cce_{MDPL}/cce_{MDTL} ratio, males had a mean ratio of 0.29 (SD = 0.06), while females had a similar mean ratio of 0.28 (SD = 0.05). The t-test showed no significant difference between genders in cce_{MDPL}/cce_{MDTL} ratios ($t = 1.773$, $p = 0.077$).

For the cph_{MDPL}/cph_{MDTL} ratio, males had a mean ratio of 0.28 (SD = 0.07), while females had a slightly lower mean ratio of 0.26 (SD = 0.06). The t-test revealed a statistically significant difference between genders ($t = 3.392$, $p = 0.001$), indicating that males tend to have larger cph_{MDPL}/cph_{MDTL} ratios compared to females.

Regarding the ace_{MDPL}/ace_{MDTL} ratio, males had a mean ratio of 0.32 (SD = 0.06), while females had a slightly lower mean ratio of 0.31 (SD = 0.06). However, the t-test did not indicate a significant difference between males and females in terms of the ace_{MDPL}/ace_{MDTL} ratio ($t = 0.889$, $p = 0.375$).

Considering the ace_{PVPL}/ace_{PVTTL} ratio, males had a mean ratio of 0.22 (SD = 0.04), while females had a similar mean ratio of 0.22 (SD = 0.04). The t-test also did not reveal a significant difference between genders in terms of the ace_{PVPL}/ace_{PVTTL} ratio ($t = -1.194$, $p = 0.233$).

For the ace_{PVPL}/ace_{MDTL} ratio, males had a mean ratio of 0.24 (SD = 0.05), while females had a slightly higher mean ratio of 0.26 (SD = 0.06). The t-test showed a statistically

significant difference between genders ($t = -2.410$, $p = 0.017$), suggesting that females tend to have larger ace_PVPL/ace_MDTL ratios compared to males.

For the aph_MDPL/aph_MDTL ratio, males had a mean ratio of 0.30 (SD = 0.09), while females had a similar mean ratio of 0.30 (SD = 0.08). The t-test did not indicate a significant difference between genders in aph_MDPL/aph_MDTL ratios ($t = 0.594$, $p = 0.553$).

Lastly, for the aph_PVTL /aph_MDTL ratio, males had a mean ratio of 0.85 (SD = 0.18), while females had a slightly lower mean ratio of 0.83 (SD = 0.17). The t-test also did not reveal a significant difference between males and females in terms of the aph_PVTL /aph_MDTL ratio ($t = 1.199$, $p = 0.231$).

Table 11. Ratios of the right upper central incisive on three anatomical planes compared by gender.

Measure	Gender	Mean	Std. Deviation	t	p
s_IL/s_TTL	Male	0.29	0.05	0.906	0.365
	Female	0.28	0.05		
s_PCL/s_TTL	Male	0.12	0.05	-2.344	0.020*
	Female	0.14	0.05		
s_RL/s_TTL	Male	0.58	0.04	1.680	0.094
	Female	0.57	0.05		
s_IL+s_PCL/s_TTL	Male	3.26	1.19	-1.464	0.144
	Female	3.47	1.13		
sce_PW/sce_TW	Male	0.21	0.05	-1.123	0.262
	Female	0.22	0.04		
cce_MDPL/cce_MDTL	Male	0.29	0.06	1.773	0.077
	Female	0.28	0.05		
cph_MDPL/cph_MDTL	Male	0.28	0.07	3.392	0.001*
	Female	0.26	0.06		
ace_MDPL/ace_MDTL	Male	0.32	0.06	0.889	0.375
	Female	0.31	0.06		
ace_PVPL/ace_PVTL	Male	0.22	0.04	-1.194	0.233
	Female	0.22	0.04		
ace_PVPL/ace_MDTL	Male	0.24	0.05	-2.410	0.017*
	Female	0.26	0.06		
aph_MDPL/aph_MDTL	Male	0.30	0.09	0.594	0.553
	Female	0.30	0.08		
aph_PVTL /aph_MDTL	Male	0.85	0.18	1.199	0.231
	Female	0.83	0.17		

sce_TW, Amelo-cemental length: goes from the most palatine point to the most vestibular point of the tooth; **sce_PW**, Pulpal amelo-cemental length: goes from the most palatine point of the pulp to the most vestibular point of the pulp; **s_RL**, Root length: goes from the apex to the tooth to the cemento-enamel junction respecting the curvature of the tooth; **s_PCL**, Chamber length: goes from the cemento-enamel junction to the end of the pulp at the level of the crown; **s_IL**, Coronal length: goes from the incisal edge to the beginning of the pulp chamber; **s_TTL**, Total tooth length: is the sum of s_RL, s_PCL and s_IL; **sph_CW**, coronal width at pulpar horn level; **cce_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cce_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **ace_MDTL**, Mesio-distal length: runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxillary arch; **ace_MDPL**, Internal mesio-distal length: goes from the most mesial point of the pulp to the most distal point of the pulp; **ace_PVTL**, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; **ace_PVPL**, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; **cph_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cph_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **aph_MDTL**, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxillary arch; **aph_MDPL**, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; **aph_PVTL**, Palatal- vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth; **s_TTL**, Total length of palatine root: measure from the apex to the red line obeying the curvature of the root; t, t-test; p, p-value; * $p < 0.05$; males (n=124), females (n=249).

4.2.4 Ratios of the right upper first molar on three anatomical planes compared by gender

Table 12 presents ratios of the right upper first molar on three anatomical planes, comparing the ratios between genders.

The table includes various ratios, such as M.CACP/M.S_TTL, M.aph_PVTL/M.aph_MDTL, and M.aph_MDPL/M.aph_MDTL. Mean values and standard deviations were calculated for each ratio, and t-tests were conducted to assess gender differences.

For the M.CACP/M.S_TTL ratio, males had a mean ratio of 0.25 (SD = 0.05), while females had a slightly higher mean ratio of 0.26 (SD = 0.05). However, the t-test did not indicate a significant difference between males and females in terms of the M.CACP/M.S_TTL ratio ($t = -0.174$, $p = 0.862$).

Regarding the M.aph_PVTL/M.aph_MDTL ratio, males had a mean ratio of 1.37 (SD = 0.10), while females had a similar mean ratio of 1.35 (SD = 0.10). The t-test also did not reveal a significant difference between genders in terms of the M.aph_PVTL/M.aph_MDTL ratio ($t = 0.812$, $p = 0.418$).

Considering the M.aph_MDPL/M.aph_MDTL ratio, males had a mean ratio of 0.31 (SD = 0.06), while females had a slightly higher mean ratio of 0.32 (SD = 0.05). The t-test did not indicate a significant difference between males and females in terms of the M.aph_MDPL/M.aph_MDTL ratio ($t = -0.727$, $p = 0.468$).

Table 12. Ratios of the right upper first molar on three anatomical planes compared by gender.

Measure	Gender	Mean	Std. Deviation	t	p
M.CACP/M.S_TTL	Male	0.25	0.05	-0.174	0.862
	Female	0.26	0.05		
M.aph_PVTL/M.aph_MDTL	Male	1.37	0.10	0.812	0.418
	Female	1.35	0.10		
M.aph_MDPL/M.aph_MDTL	Male	0.31	0.06	-0.727	0.468
	Female	0.32	0.05		

M.S_TTL, molar sagittal total tooth length; M.CACP, molar pulp chambre height; M.aph_MDTL, molar axial mesiodistal tooth length at pulp horn level; M.aph_MDPL, molar axial mesiodistal pulp length at pulp horn level; M.aph_PVTL, molar axial palatovestibular tooth length at pulp horn level; t, t-test; p, p-value; * $p < 0.05$; males ($n=124$), females ($n=249$).

4.3 ANATOMICAL MEASUREMENTS AND RATIOS OF UPPER CENTRAL INCISIVE AND UPPER FIRST MOLAR COMPARED BY AGE GROUPS

4.3.1 Anatomical measurements of the right upper central incisor on three anatomical planes compared by age groups

Table 13 presents the results of anatomical measurements of upper central incisor on sagittal slices comparisons across different age groups. The measurements included sce_TW, sce_PW, s_RL, s_PCL, s_IL, s_TTL, and sph_CW. The mean values, standard deviations, minimum and maximum values, as well as F-values and p-values from ANOVA tests, were reported for each measurement.

Regarding sce_TW, the mean measurement ranged from 6.93 mm to 7.27 mm across different age groups. The F-test showed a statistically significant difference ($F = 4.479$, $p = 0.002$) among the age groups. Similarly, for sce_PW, the mean measurement ranged from 1.28 mm to 1.78 mm, and the F-test revealed a significant difference ($F = 19.613$, $p < 0.001$) among the age groups.

For s_{RL}, s_{PCL}, s_{IL}, s_{TTL}, and sph_{CW}, the mean measurements and standard deviations varied across age groups. Nevertheless, the F-tests did not indicate significant differences among the age groups for s_{RL} (F = 1.607, p = 0.172), s_{IL} (F = 2.043, p = 0.088), and s_{TTL} (F = 2.206, p = 0.068). In contrast, s_{PCL} and SPH_{CW} showed significant differences among the age groups (s_{PCL}: F = 32.099, p < 0.001; sph_{CW}: F = 12.335, p < 0.001).

Table 13. Anatomical measurements of upper central incisor on sagittal slices compared by age groups.

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
sce _{TW}	≤30	7.26	0.61	5.52	8.80	4.479	0.002*
	31-40	7.24	0.50	6.00	8.25		
	41-50	7.27	0.44	6.00	8.25		
	51-60	7.11	0.50	5.75	8.25		
	>60	6.93	0.48	6.00	8.70		
	Total	7.17	0.53	5.52	8.80		
sce _{PW}	≤30	1.78	0.38	1.00	3.00	19.613	<0.001*
	31-40	1.62	0.38	1.00	3.30		
	41-50	1.67	0.37	1.00	2.75		
	51-60	1.43	0.30	0.50	2.00		
	>60	1.28	0.30	0.75	2.00		
	Total	1.57	0.39	0.50	3.30		
s _{RL}	≤30	12.71	1.75	8.54	16.64	1.607	0.172
	31-40	13.16	2.09	6.00	17.44		
	41-50	13.22	2.03	7.84	17.25		
	51-60	13.39	1.33	10.03	16.61		
	>60	13.43	2.10	7.51	18.06		
	Total	13.16	1.87	6.00	18.06		
s _{PCL}	≤30	3.87	0.95	1.82	5.75	32.099	<0.001*
	31-40	3.57	0.85	1.27	5.41		
	41-50	3.25	1.15	0.60	6.02		
	51-60	2.57	1.02	0.90	6.50		
	>60	2.09	1.06	0.25	5.75		
	Total	3.12	1.19	0.25	6.50		
s _{IL}	≤30	6.26	1.00	3.06	8.49	2.043	0.088
	31-40	6.55	1.16	0.93	8.92		
	41-50	6.79	1.37	3.75	10.61		
	51-60	6.78	1.36	3.51	10.00		
	>60	6.75	1.59	1.25	10.01		
	Total	6.61	1.30	0.93	10.61		
s _{TTL}	≤30	22.90	2.23	17.52	27.80	2.206	0.068
	31-40	23.28	2.23	15.08	28.21		
	41-50	23.26	2.37	15.84	27.71		
	51-60	22.70	2.14	18.14	31.34		
	>60	22.20	2.32	16.76	27.20		
	Total	22.87	2.27	15.08	31.34		
sph _{CW}	≤30	6.09	0.94	4.50	8.75	12.335	<0.001*
	31-40	6.49	0.76	5.10	8.50		
	41-50	6.58	0.83	4.75	8.10		
	51-60	6.92	0.72	5.50	8.75		
	>60	6.94	0.78	5.00	8.70		
	Total	6.58	0.87	4.50	8.75		

sce_{TW}, Amelo-cemental length: goes from the most palatine point to the most vestibular point of the tooth; sce_{PW}, Pulpal amelo-cemental length: goes from the most palatine point of the pulp to the most vestibular point of the pulp; s_{RL}, Root length: goes from the apex to the tooth to cemento-enamel junction respecting the curvature of the tooth; s_{PCL}, Chamber length: goes from the cemento-enamel junction to the end of the pulp at the level of the crown; s_{IL}, Coronal length: goes from the incisal edge to the beginning of the pulp chamber; s_{TTL}, Total tooth length: is the sum of s_{RL}, s_{PCL} and s_{IL}; sph_{CW}, coronal width at pulpar horn level; F, ANOVA test; p, p-value; *p<0.05; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73).

Table 14 presents the results of Bonferroni tests conducted for age group comparisons within specific measurements. The comparisons were made for *sce_TW*, *sce_PW*, *s_PCL*, and *SPH_CW*. The Bonferroni-adjusted p-values were reported for each comparison.

For *SCE_TW*, significant differences were found between the age group ≤ 30 and the age group >60 ($p = 0.005$), between the age group 31-40 and the age group >60 ($p = 0.016$), and between the age group 41-50 and the age group >60 ($p = 0.007$). In terms of *SCE_PW*, significant differences were observed between the age group ≤ 30 and the age group 51-60 ($p < 0.001$), the age group >60 ($p < 0.001$), between the age group 31-40, the age group 51-60 ($p = 0.030$), and the age group >60 ($p < 0.001$), and between the age group 41-50 and the age group 51-60 ($p = 0.003$), and the age group >60 ($p < 0.001$).

Similarly, for *S_PCL*, significant differences were found between the age group ≤ 30 and the age group 41-50 ($p = 0.006$), the age group 51-60 ($p < 0.001$), and the age group >60 ($p < 0.001$), between the age group 31-40 and the age group 51-60 ($p < 0.001$), and the age group >60 ($p < 0.001$), and between the age group 41-50 and the age group 51-60 ($p = 0.003$), and the age group >60 ($p < 0.001$). Lastly, for *SPH_CW*, significant differences were observed between the age group ≤ 30 and the age group 41-50 ($p = 0.009$), the age group 51-60 ($p < 0.001$), and the age group >60 ($p < 0.001$), between the age group 31-40 and the age group 51-60 ($p = 0.032$), and the age group >60 ($p = 0.029$).

Table 14. Significant Bonferroni tests for age group comparisons in *sce_TW*, *sce_PW*, *s_PCL* and *sph_CW*.

Measure	Age group (i)	Age group (j)	Bonferroni p value
sce_TW	≤ 30	>60	0.005
	31-40	>60	0.016
	41-50	>60	0.007
sce_PW	≤ 30	51-60	<0.001
		>60	<0.001
	31-40	51-60	0.030
		>60	<0.001
	41-50	51-60	0.003
		>60	<0.001
s_PCL	≤ 30	41-50	0.006
		51-60	<0.001
		>60	<0.001
	31-40	51-60	<0.001
		>60	<0.001
	41-50	51-60	0.003
		>60	<0.001
sph_CW	≤ 30	41-50	0.009
		51-60	<0.001
		>60	<0.001
	31-40	51-60	0.032
		>60	0.029

sce_TW, Amelo-cemental length: goes from the most palatine point to the most vestibular point of the tooth; **sce_PW**, Pulpal amelo-cemental length: goes from the most palatine point of the pulp to the most vestibular point of the pulp; **s_PCL**, Chamber length: goes from the cemento- enamel junction to the end of the pulp at the level of the crown; **sph_CW**, coronal width at pulpar horn level

Table 15 presents the results of anatomical measurements of upper central incisor on coronal slices compared by age groups. The measurements included cce_MDTL, cce_MDPL, cph_MDTL, and cph_MDPL. The mean values, standard deviations, minimum and maximum values, as well as F-values and p-values from ANOVA tests, were reported for each measurement.

For cce_MDTL, the mean measurement ranged from 6.23 mm to 6.47 mm across different age groups. The F-test did not show a statistically significant difference ($F = 1.218$, $p = 0.303$) among the age groups. Regarding cce_MDPL, the mean measurement ranged from 1.49 mm to 1.98 mm, and the F-test revealed a significant difference ($F = 15.110$, $p < 0.001$) among the age groups. For cph_MDTL, the mean measurement ranged from 6.89 mm to 8.06 mm, and the F-test indicated a statistically significant difference ($F = 21.773$, $p < 0.001$) among the age groups. Lastly, for cph_MDPL, the mean measurement ranged from 1.49 mm to 2.43 mm, and the F-test showed a significant difference ($F = 33.935$, $p < 0.001$) among the age groups.

Table 15. Anatomical measurements of upper central incisor on coronal slices compared by age groups.

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
cce_MDTL	≤30	6.37	0.68	4.75	7.80	1.218	0.303
	31-40	6.36	0.61	4.50	7.50		
	41-50	6.47	0.49	5.50	7.50		
	51-60	6.40	0.56	5.10	7.80		
	>60	6.23	0.51	5.00	7.20		
	Total	6.367	0.58	4.50	7.80		
cce_MDPL	≤30	1.97	0.36	1.50	2.80	15.110	<0.001*
	31-40	1.98	0.44	1.20	3.00		
	41-50	1.95	0.39	1.00	3.00		
	51-60	1.75	0.36	1.00	2.80		
	>60	1.54	0.30	0.75	2.40		
	Total	1.85	0.41	0.75	3.00		
cph_MDTL	≤30	8.06	0.72	6.00	9.50	21.773	<0.001*
	31-40	7.81	0.73	6.25	9.60		
	41-50	7.74	0.95	4.50	10.25		
	51-60	7.26	0.77	6.00	9.00		
	>60	6.89	0.78	5.25	8.75		
	Total	7.57	0.89	4.50	10.25		
cph_MDPL	≤30	2.43	0.56	1.50	3.60	33.935	<0.001*
	31-40	2.26	0.52	1.50	3.75		
	41-50	2.18	0.44	1.25	3.50		
	51-60	1.82	0.48	0.75	3.25		
	>60	1.49	0.41	0.75	2.50		
	Total	2.07	0.59	0.75	3.75		

cce_MDTL, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cce_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **cph_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cph_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; F, ANOVA test; p, p-value; * $p < 0.05$; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73).

Table 16 presents the results of Bonferroni tests conducted for age group comparisons within specific measurements, namely cce_MDPL, cph_MDTL, and cph_MDPL. Bonferroni-adjusted p-values were reported for each comparison.

For cce_MDPL, significant differences were found between the age group ≤30 and the age group 51-60 ($p = 0.006$), and the age group >60 ($p < 0.001$). Additionally, significant

differences were observed between the age group 31-40 and the age group 51-60 ($p = 0.009$), and the age group >60 ($p < 0.001$). Furthermore, significant differences were found between the age group 41-50 and the age group 51-60 ($p = 0.038$), and the age group >60 ($p < 0.001$). Finally, a significant difference was observed between the age group 51-60 and the age group >60 ($p = 0.022$).

Regarding *cph_MDTL*, significant differences were found between the age group ≤ 30 and the age group 51-60 ($p < 0.001$), and the age group >60 ($p < 0.001$). Furthermore, significant differences were observed between the age group 31-40 and the age group 51-60 ($p = 0.001$), and the age group >60 ($p < 0.001$). Additionally, a significant difference was found between the age group 41-50 and the age group 51-60 ($p = 0.011$), and the age group >60 ($p < 0.001$).

For *cph_MDPL*, significant differences were found between the age group ≤ 30 and the age group 41-50 ($p = 0.047$), the age group 51-60 ($p < 0.001$), and the age group >60 ($p < 0.001$). Furthermore, significant differences were observed between the age group 31-40 and the age group 51-60 ($p < 0.001$), and the age group >60 ($p < 0.001$). Additionally, significant differences were found between the age group 41-50 and the age group 51-60 ($p = 0.002$), and the age group >60 ($p < 0.001$). Finally, a significant difference was observed between the age group 51-60 and the age group >60 ($p = 0.003$).

Table 16. Significant Bonferroni tests for age group comparisons in *cce_MDPL*, *cph_MDTL* and *cph_MDPL*.

Measure	Age group (i)	Age group (j)	Bonferroni p value
cce_MDPL	≤ 30	51-60	0.006
		>60	<0.001
	31-40	51-60	0.009
		>60	<0.001
	41-50	51-60	0.038
		>60	<0.001
cph_MDTL	≤ 30	51-60	<0.001
		>60	<0.001
	31-40	51-60	0.001
		>60	<0.001
	41-50	51-60	0.011
		>60	<0.001
cph_MDPL	≤ 30	41-50	0.047
		51-60	<0.001
		>60	<0.001
	31-40	51-60	<0.001
		>60	<0.001
	41-50	51-60	0.002
		>60	<0.001
	51-60	>60	0.003

cce_MDPL, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **cph_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cph_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; F, ANOVA test; p, p-value; * $p < 0.05$; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73).

Table 17 presents the results of anatomical measurements of upper central incisive on axial slices comparing different age groups. The measurements included *ace_MDTL*, *ace_MDPL*, *ace_PVTL*, *ace_PVPL*, *aph_MDTL*, *aph_MDPL*, and *aph_PVTL*. For each measurement,

the table provides the mean values, standard deviations, minimum and maximum values, as well as F-values and p-values from ANOVA tests. In the measurement ace_MDTL, the mean values ranged from 6.47 mm to 6.72 mm across the age groups. The F-test did not show a statistically significant difference ($F = 1.246$, $p = 0.292$) among the age groups. Regarding ace_MDPL, the mean values ranged from 1.75 mm to 2.23 mm, and the F-test indicated a significant difference ($F = 10.695$, $p < 0.001$) among the age groups. For ace_PVTTL, the mean values ranged from 7.30 mm to 7.59 mm, and the F-test revealed a statistically significant difference ($F = 3.180$, $p = 0.014$) among the age groups.

In the measurement ace_PVPL, the mean values ranged from 1.44 mm to 1.90 mm, and the F-test showed a significant difference ($F = 16.819$, $p < 0.001^*$) among the age groups.

Regarding aph_MDTL, the mean values ranged from 7.09 mm to 8.24 mm, and the F-test indicated a statistically significant difference ($F = 23.602$, $p < 0.001^*$) among the age groups.

For aph_MDPL, the mean values ranged from 1.61 mm to 3.02 mm, and the F-test revealed a significant difference ($F = 50.491$, $p < 0.001^*$) among the age groups.

In the measurement aph_PVTTL, the mean values ranged from 6.25 mm to 6.88 mm, and the F-test showed a significant difference ($F = 14.437$, $p < 0.001^*$) among the age groups.

Table 17. Anatomical measurements of upper central incisive on axial slices compared by age groups.

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
ace_MDTL	≤30	6.57	0.63	4.82	7.90	1.246	0.292
	31-40	6.55	0.66	4.44	8.14		
	41-50	6.72	0.62	5.39	8.25		
	51-60	6.59	0.54	5.44	8.12		
	>60	6.47	0.58	5.19	7.95		
	Total	6.58	0.61	4.44	8.25		
ace_MDPL	≤30	2.21	0.45	1.25	3.22	10.695	<0.001*
	31-40	2.23	0.49	1.25	3.35		
	41-50	2.23	0.51	1.00	3.25		
	51-60	2.02	0.51	0.75	3.30		
	>60	1.75	0.44	0.79	2.85		
	Total	2.10	0.51	0.75	3.35		
ace_PVTTL	≤30	7.59	0.60	6.25	9.20	3.180	0.014*
	31-40	7.50	0.46	6.60	8.71		
	41-50	7.58	0.53	6.50	9.51		
	51-60	7.39	0.52	6.25	8.51		
	>60	7.30	0.54	6.25	8.70		
	Total	7.48	0.54	6.25	9.51		
ace_PVPL	≤30	1.90	0.36	1.00	3.25	16.819	<0.001*
	31-40	1.78	0.32	1.00	2.72		
	41-50	1.71	0.33	1.25	2.50		
	51-60	1.61	0.29	1.00	2.40		
	>60	1.44	0.34	0.75	2.25		
	Total	1.70	0.36	0.75	3.25		
aph_MDTL	≤30	8.24	0.64	6.72	9.70	23.602	<0.001*
	31-40	7.94	0.72	6.18	9.19		
	41-50	7.85	0.86	6.02	10.36		
	51-60	7.43	0.71	5.95	8.83		
	>60	7.09	0.74	5.70	8.48		
	Total	7.73	0.83	5.70	10.36		

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
aph_MDPL	≤30	3.02	0.56	2.00	4.32	50.491	<0.001*
	31-40	2.70	0.67	1.20	3.91		
	41-50	2.28	0.61	0.75	3.40		
	51-60	1.99	0.67	0.50	3.40		
	>60	1.61	0.49	0.50	2.75		
	Total	2.37	0.79	0.50	4.32		
aph_PVTL	≤30	5.85	1.03	4.00	9.20	14.437	<0.001*
	31-40	6.25	0.80	4.50	7.81		
	41-50	6.39	1.01	3.00	8.00		
	51-60	6.78	0.75	5.25	9.01		
	>60	6.88	0.78	4.76	8.50		
	Total	6.41	0.96	3.00	9.20		

ace_MDTL, Mesio-distal length: runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxilar arch; **ace_MDPL**, Internal mesio-distal length: goes from the most mesial point of the pulp to the most distal point of the pulp; **ace_PVTL**, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; **ace_PVPL**, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; **aph_MDTL**, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxilar arch; **aph_MDPL**, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; **aph_PVTL**, Palatal- vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth; F, ANOVA test; p, p-value; *p<0.05; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73).

Table 18 presents the significant Bonferroni tests conducted for age group comparisons within specific measurements, including ace_MDPL, ace_PVTL, ace_PVPL, aph_MDTL, aph_MDPL, and aph_PVTL. The table reports Bonferroni-adjusted p-values for each comparison.

For ace_MDPL, significant differences were found between the age group >60 and the age groups ≤30, 31-40 and 41-50 (p < 0.001). Additionally, a significant difference was observed between the age group 51-60 and the age group >60 (p = 0.022).

Regarding ace_PVTL, a significant difference was found between the age group ≤30 and the age group >60 (p = 0.030). Similarly, a significant difference was observed between the age group >60 and the age group ≤30 (p = 0.030).

In the measurement ace_PVPL, significant differences were found between the age group ≤30, the age group 41-50 (p = 0.021) and the age group 51-60 (p < 0.001). Additionally, significant differences were observed between the age group >60 and the age group 51-60 (p < 0.001). Furthermore, a significant difference was found between the age group 51-60 and the age group ≤30 (p = 0.021).

For aph_MDTL, significant differences were found between the age group ≤30 and the age groups 41-50, 51-60, and >60 (p < 0.001). Similarly, significant differences were observed between the age group 31-40 and the age groups 41-50, 51-60, and >60 (p < 0.001). Moreover, a significant difference was found between the age group 51-60 and the age group >60 (p = 0.001).

In the measurement aph_MDPL, significant differences were found between the age group ≤30 and the age groups 41-50, 51-60, and >60 (p < 0.001). Similarly, significant differences were observed between the age group 31-40 and the age groups 41-50, 51-60, and >60 (p < 0.001). Additionally, a significant difference was found between the age group 41-50 and the age group >60 (p = 0.004). Furthermore, a significant difference was observed between the age group 51-60 and the age group >60 (p < 0.001).

Regarding aph_PVTL, significant differences were found between the age group ≤30 and the age group >60 (p = 0.007). In addition, a significant difference was observed between the age group >60 and the age group ≤30 (p = 0.007).

Table 18. Significant Bonferroni tests for age group comparisons in ace_MDPL, ace_PVTL, ace_PVPL, aph_MDTL, aph_MDPL and ace_PVTL.

Measure	Age group (i)	Age group (j)	Bonferroni p value
ace_MDPL	>60	≤30	<0.001
		31-40	<0.001
		41-50	<0.001
		51-60	0.022
ace_PVTL	≤30	>60	0.030
	>60	≤30	0.030
ace_PVPL	≤30	41-50	0.021
		51-60	<0.001
		>60	<0.001
	31-40	51-60	0.038
		>60	<0.001
	41-50	>60	<0.001
aph_MDTL	≤30	41-50	0.037
		51-60	<0.001
		>60	<0.001
	31-40	51-60	0.001
		>60	<0.001
	41-50	51-60	0.022
aph_MDPL	≤30	>60	<0.001
		31-40	0.030
		41-50	<0.001
		51-60	<0.001
	31-40	41-50	0.004
		51-60	<0.001
		>60	<0.001
	41-50	>60	<0.001
	51-60	>60	<0.001
		>60	0.011
ace_PVTL	≤30	41-50	0.008
		51-60	<0.001
		>60	<0.001
	31-40	51-60	0.009
		>60	0.002
	41-50	>60	0.048

ace_MDPL, Internal mesio-distal length: goes from the most mesial point of the pulp to the most distal point of the pulp; **ace_PVTL**, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; **ace_PVPL**, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; **aph_MDTL**, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxilar arch; **aph_MDPL**, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; **aph_PVTL**, Palatal- vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth.

4.3.2 Anatomical measurements of the right upper first molar on three anatomical planes compared by age groups

Table 19 presents the anatomical measurements of the right upper first molar on three anatomical planes, comparing different age groups. The measurements included M.S_TTL, M.CACP, M.aph_MDTL, M.aph_MDPL, and M.aph_PVTL. The table provides the mean values, standard deviations, minimum and maximum values, as well as F-values and p-values from ANOVA tests.

In the measurement M.S_TTL, the mean values ranged from 13.51 mm to 14.37 mm across the age groups. The F-test did not show a statistically significant difference ($F = 1.255$, $p = 0.288$) among the age groups.

Regarding M.CACP, the mean values ranged from 3.22 mm to 3.96 mm, and the F-test indicated a significant difference ($F = 11.569$, $p < 0.001$) among the age groups.

For M.aph_MDTL, the mean values ranged from 8.31 mm to 8.60 mm, and the F-test did not show a statistically significant difference ($F = 1.433$, $p = 0.223$) among the age groups.

In the measurement M.aph_MDPL, the mean values ranged from 2.61 mm to 2.81 mm, and the F-test did not show a statistically significant difference ($F = 1.376$, $p = 0.243$) among the age groups.

Regarding M.aph_PVTL, the mean values ranged from 11.34 mm to 11.55 mm, and the F-test did not show a statistically significant difference ($F = 0.476$, $p = 0.753$) among the age groups.

Table 19. Anatomical measurements of the right upper first molar on three anatomical planes compared by age groups.

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
M.S_TTL	≤30	14.20	1.98	8.32	17.57	1.255	0.288
	31-40	14.05	1.76	9.26	18.10		
	41-50	14.37	1.69	10.86	17.77		
	51-60	13.51	2.04	8.54	17.02		
	>60	13.89	1.61	9.72	17.42		
	Total	14.05	1.85	8.32	18.10		
M.CACP	≤30	3.96	0.76	2.25	6.00	11.569	<0.001*
	31-40	3.72	0.74	2.10	5.70		
	41-50	3.40	0.70	2.00	4.75		
	51-60	3.27	0.63	1.75	4.25		
	>60	3.22	0.66	1.75	4.50		
	Total	3.62	0.77	1.75	6.00		
M.aph_MDTL	≤30	8.31	0.73	6.87	11.72	1.433	0.223
	31-40	8.55	0.77	7.18	11.18		
	41-50	8.37	0.73	7.04	10.77		
	51-60	8.60	0.74	7.43	10.94		
	>60	8.41	0.79	6.42	10.23		
	Total	8.42	0.75	6.42	11.72		
M.aph_MDPL	≤30	2.74	0.40	1.82	3.75	1.376	0.243
	31-40	2.80	0.58	0.92	4.21		
	41-50	2.62	0.45	1.68	3.61		
	51-60	2.81	0.72	1.50	5.02		
	>60	2.61	0.56	1.50	3.84		
	Total	2.72	0.53	0.92	5.02		
M.aph_PVTL	≤30	11.41	0.81	9.24	13.26	0.476	0.753
	31-40	11.55	0.73	10.24	13.58		
	41-50	11.34	0.73	9.75	12.96		
	51-60	11.47	1.01	9.43	14.14		
	>60	11.39	0.88	9.77	13.73		
	Total	11.43	0.82	9.24	14.14		

M.S_TTL, molar sagittal total tooth length; M.CACP, molar pulp chambre height; M.aph_MDTL, molar axial mesiodistal tooth length at pulp horn level; M.aph_MDPL, molar axial mesiodistal pulp length at pulp horn level; M.aph_PVTL, molar axial palatovestibular tooth length at pulp horn level; F, ANOVA test; p, p-value; * $p < 0.05$; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73).

Table 20 presents the significant Bonferroni tests conducted for age group comparisons within the M.CACP measurement. The table reports Bonferroni-adjusted p-values for each comparison.

Significant differences were found in the M.CACP measurement between the age group ≤ 30 and the age group 41-50 ($p = 0.001$), the age group 51-60 ($p < 0.001$), and the age group > 60 ($p < 0.001$). Additionally, significant differences were observed between the age group 31-40, the age group 51-60 ($p = 0.041$) and the age group > 60 ($p = 0.008$). Furthermore, a significant difference was found between the age group 41-50 and the age group ≤ 30 ($p = 0.001$).

Table 20. Significant Bonferroni tests for age group comparisons in M.CACP.

Measure	Age group (i)	Age group (j)	Bonferroni p value
M.CACP	≤ 30	41-50	0.001
		51-60	< 0.001
		> 60	< 0.001
	31-40	51-60	0.041
		> 60	0.008
	41-50	≤ 30	0.001

M.CACP, molar pulp chambre height.

4.3.3 Ratios of the right upper central incisive on three anatomical planes compared by age groups

Table 21 presents the sagittal ratios of the right upper central incisive, comparing different age groups. The ratios measured include s_{IL}/s_{TTL} , s_{PCL}/s_{TTL} , s_{RL}/s_{TTL} , $s_{IL}+s_{PCL}/s_{TTL}$, and sce_{PW}/sce_{TW} . The table provides the mean values, standard deviations, minimum and maximum values, as well as F-values and p-values from ANOVA tests.

For the measurement s_{IL}/s_{TTL} , the mean values ranged from 0.27 to 0.31 across the age groups. The F-test indicated a significant difference ($F = 2.932$, $p = 0.021$) among the age groups.

Regarding s_{PCL}/s_{TTL} , the mean values ranged from 0.10 to 0.17, and the F-test showed a highly significant difference ($F = 29.477$, $p < 0.001$) among the age groups.

In the measurement s_{RL}/s_{TTL} , the mean values ranged from 0.56 to 0.60, and the F-test indicated a highly significant difference ($F = 11.183$, $p < 0.001$) among the age groups.

For the measurement $s_{IL}+s_{PCL}/s_{TTL}$, the mean values ranged from 2.40 to 4.15, and the F-test showed a highly significant difference ($F = 33.172$, $p < 0.001$) among the age groups.

Regarding the ratio sce_{PW}/sce_{TW} , the mean values ranged from 0.19 to 0.25, and the F-test showed a highly significant difference ($F = 16.439$, $p < 0.001$) among the age groups.

Table 21. Sagittal ratios of upper central incisor compared by age groups.

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
s_IL/s_TTL	≤30	0.27	0.04	0.15	0.38	2.932	0.021*
	31-40	0.28	0.05	0.04	0.41		
	41-50	0.29	0.06	0.18	0.46		
	51-60	0.30	0.05	0.16	0.40		
	>60	0.31	0.08	0.06	0.48		
	Total	0.29	0.06	0.04	0.48		
s_PCL/s_TTL	≤30	0.17	0.04	0.08	0.25	29.477	<0.001*
	31-40	0.15	0.04	0.05	0.24		
	41-50	0.14	0.05	0.03	0.26		
	51-60	0.11	0.04	0.04	0.21		
	>60	0.10	0.05	0.01	0.29		
	Total	0.14	0.05	0.01	0.29		
s_RL/s_TTL	≤30	0.56	0.05	0.42	0.69	11.183	<0.001*
	31-40	0.56	0.05	0.40	0.79		
	41-50	0.57	0.05	0.47	0.68		
	51-60	0.59	0.04	0.49	0.72		
	>60	0.60	0.05	0.45	0.75		
	Total	0.57	0.05	0.40	0.79		
s_IL+s_PCL/s_TTL	≤30	4.15	0.94	2.15	5.96	33.172	<0.001*
	31-40	3.85	0.83	1.62	5.63		
	41-50	3.54	1.10	1.06	6.20		
	51-60	2.87	0.98	1.29	6.81		
	>60	2.40	1.01	0.57	5.81		
	Total	3.40	1.16	0.57	6.81		
sce_PW/sce_TW	≤30	0.25	0.05	0.14	0.41	16.439	<0.001*
	31-40	0.22	0.05	0.14	0.44		
	41-50	0.23	0.05	0.14	0.33		
	51-60	0.20	0.04	0.07	0.30		
	>60	0.19	0.04	0.10	0.27		
	Total	0.22	0.05	0.07	0.44		

sce_TW, Amelo-cemental length: goes from the most palatine point to the most vestibular point of the tooth; sce_PW, Pulpal amelo-cemental length: goes from the most palatine point of the pulp to the most vestibular point of the pulp; s_RL, Root length: goes from the apex to the tooth to the cemento-enamel junction respecting the curvature of the tooth; s_PCL, Chamber length: goes from the cemento-enamel junction to the end of the pulp at the level of the crown; s_IL, Coronal length: goes from the incisal edge to the beginning of the pulp chamber; s_TTL, Total tooth length: is the sum of s_RL, s_PCL and s_IL; sph_CW, coronal width at pulpar horn level; cce_MDTL, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; cce_MDPL, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; ace_MDTL, Mesio-distal length: runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxillary arch; ace_MDPL, Internal mesio-distal length: goes from the most mesial point of the pulp to the most distal point of the pulp; ace_PVTL, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; ace_PVPL, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; cph_MDTL, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; cph_MDPL, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; aph_MDTL, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxillary arch; aph_MDPL, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; aph_PVTL, Palatal-vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth; F, ANOVA test; p, p-value; *p<0.05; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73).

Table 22 presents the significant Bonferroni tests conducted for age group comparisons within the various sagittal ratios measurements. The table reports the Bonferroni-adjusted p-values for each comparison.

Significant differences were found in the s_IL/s_TTL measurement between the age group <30 and the age group >60 (p = 0.031).

For the s_PCL/s_TTL measurement, significant differences were observed between the age group <30 and the age group 41-50 (p = 0.002), 51-60 (p < 0.001), and >60 (p < 0.001). Additionally, significant differences were found between the age group 31-40 and the age group

51-60 ($p < 0.001$) and >60 ($p < 0.001$). Furthermore, significant differences were observed between the age group 41-50 and the age group 51-60 ($p = 0.009$) and >60 ($p < 0.001$).

In the s_{RL}/s_{TTL} measurement, significant differences were found between the age group <30 , the age group 51-60 ($p < 0.001$) and >60 ($p < 0.001$). Additionally, significant differences were observed between the age group 31-40, the age group 51-60 ($p = 0.010$) and >60 ($p < 0.001$). Furthermore, significant differences were found between the age group 41-50 and the age group >60 ($p = 0.001$), as well as between the age group 31-40, the age group <30 ($p < 0.001$) and 41-50 ($p = 0.001$).

For the $s_{IL}+s_{PCL}/s_{TTL}$ measurement, significant differences were observed between the age group <30 , the age group 41-50 ($p = 0.006$), 51-60 ($p < 0.001$), and >60 ($p < 0.001$). Additionally, significant differences were found between the age group 31-40 and the age group 51-60 ($p < 0.001$) and >60 ($p < 0.001$). Moreover, significant differences were observed between the age group 41-50 and the age group 51-60 ($p = 0.002$) and >60 ($p < 0.001$).

In the ratio sce_{PW}/sce_{TW} , significant differences were found between the age group <30 and the age group 51-60 ($p < 0.001$) and >60 ($p < 0.001$). Additionally, significant differences were observed between the age group 31-40 and the age group >60 ($p < 0.001$). Furthermore, a significant difference was found between the age group 41-50, the age group 51-60 ($p = 0.014$) and >60 ($p < 0.001$).

Table 22. Significant Bonferroni tests for age group comparisons in s_{IL}/s_{TTL} , s_{RL}/s_{TTL} , $s_{IL}+s_{PCL}/s_{TTL}$, $s_{IL}+s_{PCL}/s_{TTL}$ and sce_{PW}/sce_{TW} .

Measure	Age group (i)	Age group (j)	Bonferroni p value
s_{IL}/s_{TTL}	<30	>60	0.031
s_{PCL}/s_{TTL}	<30	41-50	0.002
		51-60	<0.001
		>60	<0.001
		51-60	<0.001
	31-40	>60	<0.001
		51-60	0.009
s_{RL}/s_{TTL}	<30	>60	<0.001
		51-60	<0.001
		>60	0.010
		51-60	<0.001
	31-40	>60	0.001
		31-40	<0.001
$s_{IL}+s_{PCL}/s_{TTL}$	<30	41-50	0.006
		51-60	<0.001
		>60	<0.001
		51-60	<0.001
	31-40	>60	<0.001
		51-60	0.002
sce_{PW}/sce_{TW}	<30	>60	<0.001
		51-60	<0.001
		>60	<0.001
		51-60	0.014
	31-40	>60	<0.001
		51-60	<0.001

sce_{TW}, Amelo-cemental length: goes from the most palatine point to the most vestibular point of the tooth; **sce_{PW}**, Pulpal amelo-cemental length: goes from the most palatine point of the pulp to the most vestibular point of the pulp; **s_{RL}**, Root length: goes from the apex to the tooth to cemento-enamel junction respecting the curvature of the tooth; **s_{PCL}**, Chamber length: goes from the cemento-enamel junction to the end of the pulp at the level of the crown; **s_{IL}**, Coronal length: goes from the incisal edge to the beginning of the pulp chamber; **s_{TTL}**, Total tooth length: is the sum of s_{RL} , s_{PCL} and s_{IL} ; **sph_{CW}**, coronal width at pulpar horn level; **cce_{MDTL}**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cce_{MDPL}**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **ace_{MDTL}**, Mesio-distal length: runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxilar arch; **ace_{MDPL}**, Internal mesio-distal length: goes from the most mesial

point of the pulp to the most distal point of the pulp; **ace_PVTL**, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; **ace_PVPL**, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; **cph_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cph_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **aph_MDTL**, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxilar arch; **aph_MDPL**, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; **aph_PVTL**, Palatal- vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth; **sTTL**, Total length of palatine root: measure from the apex to the red line obeying the curvature of the root.

Table 23 presents the coronal ratios of the right upper central incisive, comparing different age groups. The ratios measured include cce_MDPL/cce_MDTL and cph_MDPL/cph_MDTL. The table provides the mean values, standard deviations, minimum and maximum values, as well as F-values and p-values from ANOVA tests.

For the cce_MDPL/cce_MDTL measurement, the mean values ranged from 0.25 to 0.31 across the age groups. The F-test indicated a significant difference ($F = 16.38$, $p < 0.001$) among the age groups.

Regarding the cph_MDPL/cph_MDTL measurement, the mean values ranged from 0.22 to 0.30, and the F-test showed a highly significant difference ($F = 18.30$, $p < 0.001$) among the age groups.

Table 23. Coronal ratios of upper central incisive compared by age groups.

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
cce_MDPL/cce_MDTL	≤30	0.31	0.04	0.23	0.42	16.38	<0.001*
	31-40	0.31	0.06	0.19	0.43		
	41-50	0.30	0.05	0.18	0.46		
	51-60	0.27	0.06	0.14	0.44		
	>60	0.25	0.05	0.13	0.33		
	Total	0.29	0.06	0.13	0.46		
cph_MDPL/cph_MDTL	≤30	0.30	0.06	0.17	0.42	18.30	<0.001*
	31-40	0.29	0.06	0.19	0.43		
	41-50	0.29	0.06	0.15	0.44		
	51-60	0.25	0.07	0.11	0.48		
	>60	0.22	0.06	0.11	0.33		
	Total	0.27	0.07	0.11	0.48		

cce_MDTL, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cce_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **cph_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cph_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; F, ANOVA test; p, p-value; * $p < 0.05$; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73).

Table 24 presents the significant Bonferroni tests conducted for age group comparisons within the cce_MDPL/cce_MDTL and cph_MDPL/cph_MDTL ratio measurements. The table reports Bonferroni-adjusted p-values for each comparison.

Significant differences were found in the cce_MDPL/cce_MDTL measurement between the age group <30 and the age group 51-60 ($p = 0.001$), as well as between the age group <30 and the age group >60 ($p < 0.001$). Additionally, significant differences were observed between the age group 31-40, the age group 51-60 ($p = 0.001$) and >60 ($p < 0.001$). Furthermore, significant differences were found between the age group 41-50, the age group 51-60 ($p = 0.053$) and >60 ($p < 0.001$). Moreover, a significant difference was observed between the age group 51-60, the age group 41-50 ($p = 0.053$) and >60 ($p = 0.042$).

In the cph_MDPL/cph_MDTL measurement, significant differences were found between the age group <30 and the age group 51-60 ($p < 0.001$), as well as between the age group <30 and the age group >60 ($p < 0.001$). Additionally, a significant difference was observed between the age group 31-40, the age group 51-60 ($p = 0.018$) and >60 ($p < 0.001$). Furthermore, a significant difference was found between the age group 41-50, the age group 51-60 ($p = 0.059$) and >60 ($p < 0.001$). Moreover, a significant difference was observed between the age group 51-60 and the age group >60 ($p = 0.011$).

Table 24. Significant Bonferroni tests for age group comparisons in cce_MDPL / cce_MDTL and cph_MDPL / cph_MDTL.

Measure	Age group (i)	Age group (j)	Bonferroni p value
cce_MDPL / cce_MDTL	<30	51-60	0.001
		>60	<0.001
	31-40	51-60	0.001
		>60	<0.001
	41-50	51-60	0.053
		>60	<0.001
	51-60	41-50	0.053
		>60	0.042
cph_MDPL / cph_MDTL	<30	51-60	<0.001
		>60	<0.001
	31-40	51-60	0.018
		>60	<0.001
	41-50	51-60	0.059
		>60	<0.001
	51-60	>60	0.011

cce_MDTL, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cce_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp; **cph_MDTL**, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; **cph_MDPL**, Mesio-distal pulp length: goes from the most mesial point to the most distal point of the pulp.

Table 25 presents the axial ratios of the right upper central incisive, comparing different age groups. The ratios measured include ace_MDPL/ace_MDTL, ace_PVPL/ace_PVTl, ace_PVPL/ace_MDTL, aph_MDPL/aph_MDTL, and aph_PVTl/aph_MDTL. The table provides the mean values, standard deviations, minimum and maximum values, as well as F-values and p-values from ANOVA tests.

For the ace_MDPL/ace_MDTL measurement, the mean values ranged from 0.27 to 0.34 across the age groups. The F-test indicated a significant difference ($F = 12.269$, $p < 0.001$) among the age groups.

Regarding the ace_PVPL/ace_PVTl measurement, the mean values ranged from 0.20 to 0.25, and the F-test showed a highly significant difference ($F = 13.323$, $p < 0.001$) among the age groups.

In the ace_PVPL/ace_MDTL measurement, the mean values ranged from 0.23 to 0.29, and the F-test indicated a significant difference ($F = 12.464$, $p < 0.001$) among the age groups.

For the aph_MDPL/aph_MDTL measurement, the mean values ranged from 0.23 to 0.37, and the F-test showed a highly significant difference ($F = 37.342$, $p < 0.001$) among the age groups.

Regarding the aph_PVTl/aph_MDTL measurement, the mean values ranged from 0.71 to 0.98, and the F-test indicated a significant difference ($F = 33.246$, $p < 0.001$) among the age groups.

Table 25. Axial ratios of upper central incisor compared by age groups.

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
ace_MDPL/ace_MDTL	≤30	0.34	0.05	0.19	0.42	12.269	<0.001*
	31-40	0.34	0.06	0.25	0.49		
	41-50	0.33	0.06	0.15	0.44		
	51-60	0.31	0.07	0.10	0.44		
	>60	0.27	0.06	0.12	0.43		
	Total	0.32	0.07	0.10	0.49		
ace_PVPL/ace_PVTL	≤30	0.25	0.05	0.15	0.48	13.323	<0.001*
	31-40	0.24	0.04	0.14	0.36		
	41-50	0.23	0.04	0.16	0.33		
	51-60	0.22	0.04	0.13	0.30		
	>60	0.20	0.04	0.10	0.29		
	Total	0.23	0.05	0.10	0.48		
ace_PVPL /ace_MDTL	≤30	0.29	0.07	0.14	0.60	12.464	<0.001*
	31-40	0.27	0.05	0.13	0.42		
	41-50	0.26	0.05	0.16	0.39		
	51-60	0.25	0.05	0.13	0.38		
	>60	0.23	0.06	0.13	0.37		
	Total	0.26	0.06	0.13	0.60		
aph_MDPL /aph_MDTL	≤30	0.37	0.06	0.23	0.48	37.342	<0.001*
	31-40	0.34	0.07	0.16	0.48		
	41-50	0.29	0.07	0.09	0.41		
	51-60	0.27	0.08	0.07	0.42		
	>60	0.23	0.06	0.08	0.36		
	Total	0.30	0.09	0.07	0.48		
aph_PVTL/aph_MDTL	≤30	0.71	0.13	0.48	1.05	33.246	<0.001*
	31-40	0.80	0.15	0.52	1.25		
	41-50	0.83	0.16	0.30	1.20		
	51-60	0.92	0.14	0.59	1.26		
	>60	0.98	0.15	0.60	1.26		
	Total	0.84	0.17	0.30	1.26		

ace_MDTL, Mesio-distal length: runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxillary arch; **ace_MDPL**, Internal mesio-distal length: goes from the most mesial point of the pulp to the most distal point of the pulp; **ace_PVTL**, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; **ace_PVPL**, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; **aph_MDTL**, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxillary arch; **aph_MDPL**, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; **aph_PVTL**, Palatal- vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth; F, ANOVA test; p, p-value; *p<0.05; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73).

Table 26 presents the significant Bonferroni tests conducted for age group comparisons within each ratio measurement. The table reports Bonferroni-adjusted p-values for each comparison.

Significant differences were found in the ace_MDPL/ace_MDTL measurement between the age group <30 and the age group >60 ($p < 0.001$). Additionally, significant differences were observed between the age group 31-40 and the age group 51-60 ($p = 0.026$) and >60 ($p < 0.001$). Furthermore, significant differences were found between the age group 41-50 and the age group >60 ($p < 0.001$). Moreover, a significant difference was observed between the age group 51-60 and the age group >60 ($p = 0.019$).

In the ace_PVPL/ace_PVTL measurement, significant differences were found between the age group <30, the age group 41-50 ($p = 0.016$), 51-60 ($p < 0.001$), and >60 ($p < 0.001$). Additionally, significant differences were observed between the age group 31-40 and the age group >60 ($p < 0.001$). Furthermore, significant differences were found between the age

group 41-50, the age group <30 ($p = 0.016$) and >60 ($p = 0.008$). Moreover, significant differences were observed between the age group 51-60, the age group <30 ($p < 0.001$) and >60 ($p < 0.001$). Furthermore, a significant difference was found between the age group >60, the age group 31-40 ($p < 0.001$) and 41-50 ($p = 0.008$).

Table 26. Significant Bonferroni tests for age group comparisons in ace_MDPL/ace_MDTL, ace_PVPL/ace_PVTL, ace_PVPL /ace_MDTL, aph_MDPL /aph_MDTL and aph_PVTL/aph_MDTL.

Measure	Age group (i)	Age group (j)	Bonferroni p value
ace_MDPL/ace_MDTL	<30	>60	<0.001
	31-40	51-60	0.026
		>60	<0.001
	41-50	>60	<0.001
	51-60	>60	0.019
ace_PVPL/ace_PVTL	<30	41-50	0.016
		51-60	<0.001
		>60	<0.001
	31-40	>60	<0.001
	41-50	<30	0.016
		>60	0.008
	51-60	<30	<0.001
	>60	<30	<0.001
		31-40	<0.001
		41-50	0.008
ace_PVPL /ace_MDTL	<30	41-50	0.008
		51-60	<0.001
		>60	<0.001
	31-40	>60	<0.001
	41-50	>60	0.042
aph_MDPL /aph_MDTL	<30	41-50	<0.001
		51-60	<0.001
		>60	<0.001
	31-40	41-50	0.008
		51-60	<0.001
		>60	<0.001
	41-50	>60	<0.001
	51-60	31-40	<0.001
aph_PVTL/aph_MDTL	<30	>60	0.024
		31-40	0.008
		41-50	<0.001
		51-60	<0.001
	31-40	>60	<0.001
		51-60	<0.001
		>60	<0.001
	41-50	51-60	0.005
		>60	<0.001

ace_MDPL, Internal mesio-distal length: goes from the most mesial point of the pulp to the most distal point of the pulp; **ace_PVTL**, Palatal-vestibular length: runs from the most vestibular and central point of the tooth to the most palatine and central point of the tooth; **ace_PVPL**, Internal palatal-buccal length: runs from the most vestibular point of the pulp to the most palatine point of the pulp; **aph_MDTL**, Mesio-distal length: goes from the most mesial and central point to the most distal and central point of the tooth, obeying the curvature of the maxilar arch; **aph_MDPL**, Internal mesio-distal length: length-goes from the most mesial point of the pulp to the most distal point of the pulp; **aph_PVTL**, Palatal- vestibular length: runs from the most palatine point of the tooth to the most vestibular point of the tooth.

4.3.4 Ratios of the right upper first molar on three anatomical planes compared by age groups

Table 27 presents the sagittal and axial ratios of the right upper first molar on three anatomical planes, comparing different age groups. The ratios measured include M.CACP/M.S_TTL, M.aph_PVTl/M.aph_MDTL, and M.aph_MDPL/M.aph_MDTL. The table provides the mean values, standard deviations, minimum and maximum values, as well as F-values and p-values from ANOVA tests.

For the M.CACP/M.S_TTL measurement, the mean values ranged from 0.24 to 0.28 across the age groups. The F-test indicated a significant difference ($F = 8.246$, $p < 0.001$) among the age groups.

Regarding the M.aph_PVTl/M.aph_MDTL measurement, the mean values ranged from 1.34 to 1.38, and the F-test did not show a significant difference ($F = 0.839$, $p = 0.501$) among the age groups.

In the M.aph_MDPL/M.aph_MDTL measurement, the mean values ranged from 0.31 to 0.33, and the F-test did not indicate a significant difference ($F = 1.361$, $p = 0.248$) among the age groups.

Table 27. Sagittal and axial ratios of the upper first molar on three anatomical planes compared by age groups.

Measure	Age groups	Mean	Std. Deviation	Min.	Max.	F	p
M.CACP/M.S_TTL	≤30	0.28	0.06	0.14	0.42	8.246	<0.001*
	31-40	0.27	0.05	0.15	0.41		
	41-50	0.24	0.05	0.13	0.34		
	51-60	0.25	0.05	0.14	0.35		
	>60	0.24	0.05	0.14	0.32		
	Total	0.26	0.06	0.13	0.42		
M.aph_PVTl/M.aph_MDTL	≤30	1.38	0.08	1.13	1.63	0.839	0.501
	31-40	1.36	0.11	1.01	1.66		
	41-50	1.36	0.11	1.11	1.56		
	51-60	1.34	0.13	0.92	1.66		
	>60	1.36	0.12	1.18	1.60		
	Total	1.36	0.11	0.92	1.66		
M.aph_MDPL/M.aph_MDTL	≤30	0.33	0.05	0.24	0.44	1.361	0.248
	31-40	0.33	0.06	0.10	0.44		
	41-50	0.31	0.05	0.21	0.45		
	51-60	0.32	0.07	0.20	0.46		
	>60	0.31	0.06	0.19	0.41		
	Total	0.32	0.05	0.10	0.46		

M.S_TTL, molar sagittal total tooth length; M.CACP, molar pulp chambre height; M.aph_MDTL, molar axial mesiodistal tooth length at pulp horn level; M.aph_MDPL, molar axial mesiodistal pulp length at pulp horn level; M.aph_PVTl, molar axial palatovestibular tooth length at pulp horn level; F, ANOVA test; p, p-value; * $p < 0.05$; ≤ 30 (n=96), 31-40 (n=70), 41-50 (n=63), 51-60 (n=71), > 60 (n=73)

Table 28 presents the significant Bonferroni tests conducted for age group comparisons within the M.CACP/M.S_TTL ratio measurement. The table reports the Bonferroni-adjusted p-values for each comparison.

Significant differences were found in the M.CACP/M.S_TTL measurement between the age group <30, the age group 41-50 ($p < 0.001$), 51-60 ($p = 0.008$), and >60 ($p < 0.001$).

Additionally, a significant difference was observed between the age group 31-40 and the age group >60 ($p = 0.057$).

Table 28. Significant Bonferroni tests for age group comparisons in M.CACP / M.S_TTL.

Measure	Age group (i)	Age group (j)	Bonferroni p value
M.CACP / M.S_TTL	<30	41-50	<0.001
		51-60	0.008
		>60	<0.001
	31-40	>60	0.057

M.S_TTL, molar sagittal total tooth length; M.CACP, molar pulp chambre height.

4.4 ASSOCIATION AND PREDICTION BETWEEN VARIABLES: LINEAR REGRESSION MODELS

Considering the outcomes s_PCL, sph_CW, cce_MDTL, cph_MDTL and aph_MDTL, five multiple linear regression models (mLRM) were created. The following equations present final models, each of one represents the solution that has the highest value of explained variance.

s_PCL

The multiple linear regression model (mLRM) was employed to predict s_PCL, and the obtained results revealed significant independent variables ($p < 0.05$). The variables cph_MDTL ($\beta = 0.724$), sph_CW ($\beta = -0.564$), ace_MDTL ($\beta = -0.469$), and ace_PVTL ($\beta = 0.482$) demonstrated significant associations with S_PCL. The findings suggest that higher values of cph_MDTL and ace_PVTL are associated with an increase in S_PCL, while lower values of sph_CW and ace_MDTL are associated with an increase in S_PCL. Collectively, these variables accounted for 60.4% of the variance in S_PCL ($R^2 = 60.4\%$). The global test yielded an F-value of 71.781 ($p < 0.001$), supporting the overall significance of the model. The equation describing the relationship between the predictors and S_PCL is as follows:

$$S_PCL = 0.845 + 0.724 \text{ cph_MDTL} - 0.564 \text{ sph_CW} - 0.469 \text{ ace_MDTL} + 0.482 \text{ ace_PVTL}$$

sph_CW

A linear regression model (LRM) was employed to predict sph_CW using several independent variables. The analysis revealed that the following variables significantly ($p < 0.05$) contributed to the prediction of sph_CW: s_PCL ($B = -0.354$), ace_PVTL ($\beta = 0.552$), s_IL ($B = 0.155$), M.aph_MDTL ($\beta = 0.180$), cph_MDPL ($\beta = -0.263$), and cce_MDTL ($\beta = 0.235$). These variables demonstrated a statistically significant relationship with sph_CW. It was found that the combination of these predictors accounted for 60.1% of the variability observed in sph_CW ($R^2 = 0.601$). The overall significance of the model was confirmed by a significant global test, yielding an F-value of 47.411 ($p < 0.001$). The resulting regression equation for predicting sph_CW is as follows:

$$\text{sph_CW} = 0.045 - 0.354 \text{ s_PCL} + 0.552 \text{ ace_PVTL} + 0.155 \text{ s_IL} + 0.180 \text{ M.aph_MDTL} - 0.263 \text{ cph_MDPL} + 0.235 \text{ cce_MDTL}$$

cce_MDTL

The linear regression model (LRM) was utilized to predict cce_MDTL using a set of independent variables: ace_MDPL ($B = 0.238$), sce_TW ($\beta = 0.165$), sce_PW ($B = -0.354$), cph_MDTL ($\beta = 0.256$), sph_CW ($\beta = 0.239$), and cce_MDPL ($\beta = 0.366$). The analysis revealed that these predictor variables demonstrated significant associations with cce_MDTL ($p < 0.05$).

Specifically, ace_MDPL ($\beta = 0.238$), sce_TW ($\beta = 0.165$), cph_MDTL ($\beta = 0.256$), sph_CW ($\beta = 0.239$), and cce_MDPL ($\beta = 0.366$) displayed positive associations with cce_MDTL, while sce_PW ($\beta = -0.354$) exhibited a negative association.

Collectively, these variables accounted for 62.7% of the variability observed in cce_MDTL ($R^2 = 0.627$). The global test yielded an F-value of 50.474 ($p < 0.001$), indicating the overall significance of the model. Therefore, the equation describing the relationship between the predictors and cce_MDTL is as follows:

$$\text{cce_MDTL} = 1.043 + 0.238 \text{ ace_MDPL} + 0.165 \text{ sce_TW} - 0.354 \text{ sce_PW} + 0.256 \text{ cph_MDTL} + 0.239 \text{ sph_CW} + 0.366 \text{ cce_MDPL}$$

cph_MDTL

The linear regression model (LRM) was employed to predict cph_MDTL using a set of independent variables: s_PCL ($\beta = 0.383$), cce_MDTL ($\beta = 0.689$), and cph_MDTL_p ($\beta = 0.346$). The analysis revealed that these predictor variables exhibited significant associations with cph_MDTL ($p < 0.05$).

Specifically, S_PCL ($\beta = 0.383$), cce_MDTL ($\beta = 0.689$), and cph_MDTL_p ($\beta = 0.346$) demonstrated positive associations with cph_MDTL. Collectively, these variables accounted for 66.9% of the variability observed in cph_MDTL ($R^2 = 0.669$). The global test yielded an F-value of 125.566 ($p < 0.001$), indicating the overall significance of the model. Therefore, the equation describing the relationship between the predictors and cph_MDTL is as follows:

$$\text{cph_MDTL} = 1.326 + 0.383 \text{ S_PCL} + 0.689 \text{ cce_MDTL} + 0.346 \text{ cph_MDTL_p}$$

aph_MDTL

The multiple linear regression model (LRM) was used to predict aph_MDTL, resorting to the following independent variables: s_PCL ($\beta = 0.337$), ace_MDTL ($\beta = 0.622$), and aph_MDPL ($\beta = 0.210$). The analysis revealed that these predictor variables demonstrated significant associations with aph_MDTL ($p < 0.05$).

Specifically, s_PCL ($\beta = 0.337$), ace_MDTL ($\beta = 0.622$), and aph_MDPL ($\beta = 0.210$) exhibited positive associations with aph_MDTL.

Collectively, these variables accounted for 63% of the variance observed in aph_MDTL ($R^2 = 0.630$). The global test yielded an F-value of 106.189 ($p < 0.001$), supporting the overall significance of the model. Thus, the equation describing the relationship between the predictors and aph_MDTL is as follows:

$$\text{aph_MDTL} = 2.130 + 0.337 \text{ s_PCL} + 0.622 \text{ ace_MDTL} + 0.210 \text{ aph_MDPL}$$

4.5 ASSOCIATION AND PREDICTION BETWEEN VARIABLES II: PREDICTION OF GENDER USING BINARY LOGISTIC REGRESSION MODELS

Now, we will present the results of binary logistic regression models for predicting gender based on CBCT measurements. In each model, the included independent/ predictor variables were the ones that were screened as statistically significant ($p < 0.05$) in bivariate associations with independent samples t-tests.

4.5.1 Binary Logistic Regression model for linear variables

Table 29 and Figure 9 present the results of the effect of linear variables on predicting male gender. The analysis focused on identifying the association between the predictors and the likelihood of being male. Four predictors were included: s_RL, cce_MDTL, ace_MDTL, and M.aph_PVTL. The β coefficient represents the standardized regression coefficient, and aOR indicates the adjusted odds ratio.

The findings reveal that s_RL has a significant positive effect on predicting male gender ($\beta = 0.234$, aOR = 1.263, $p = 0.032$), indicating that higher values of s_RL are associated with an increased likelihood of being male. Conversely, cce_MDTL shows a significant negative effect on predicting male gender ($\beta = -1.112$, aOR = 0.329, $p = 0.023$), suggesting that higher values of cce_MDTL are associated with a decreased likelihood of being male.

Furthermore, ace_MDTL demonstrates a significant positive effect for gender, with higher scores associated with males ($\beta = 1.459$, aOR = 4.302, $p = 0.003$). Similarly, M.aph_PVTL shows a significant positive effect on gender, suggesting that higher scores are associated with males ($\beta = 0.563$, aOR = 1.757, $p = 0.01$), and that higher values of M.aph_PVTL are associated with an increased likelihood of being male.

Table 29. Effect of linear variables to predict gender male.

Predictors	β	aOR	Sig.	95% CI for OR	
				LB	UB
s_RL	0.234	1.263	0.032	1.021	1.564
cce_MDTL	-1.112	0.329	0.023	0.126	0.860
ace_MDTL	1.459	4.302	0.003	1.619	11.428
M.aph_PVTL	0.563	1.757	0.014	1.121	2.754

s_RL, Root length: goes from the apex to the tooth to cemento-enamel junction respecting the curvature of the tooth; cce_MDTL, Mesio-distal length: runs from the most mesial point to the most distal point of the tooth; ace_MDTL, Mesio-distal length: runs from the most mesial and central point to the most distal and central point obeying the curvature of the maxillary arch; M.aph_PVTL, molar axial palatovestibular tooth length at pulp horn level; aOR, adjusted odds ratio; CI, confidence interval; LB, lower bound; UB, upper bound.

The model was significant, and it explained between 13.3% (Cox and Snell R^2) and 19.4% (Nagelkerke R^2) of the dependent variable (gender). It also correctly classifies 78.3% ($p < 0.001$) of males and females. This result was obtained mostly at the expense of correct female classifications (95.4%). Proportion of males correct classification was 32.0%. Hence, results suggest that this model is accurate for predicting females, but not so when predicting males. Univariate linear regressions were run to assess the contribute of each variable to correctly classify the dependent variable (gender). s_RL results explained between 3.1% (Cox and Snell R^2) and 4.4% (Nagelkerke R^2) of the dependent variable (gender). cce_MDTL results explained between 3.8% (Cox and Snell R^2) and 5.2% (Nagelkerke R^2) of the dependent variable (gender). ace_MDTL results explained between 7.2% (Cox and Snell R^2) and 10.0%

(Nagelkerke R^2) of the dependent variable (gender). M.aph_PVTL results explained between 6.5% (Cox and Snell R^2) and 9.3% (Nagelkerke R^2) of the dependent variable (gender). This way, results show that ace_MDTL and M.aph_PVTL were the most important variables predicting gender.

Table 30. Classification Table for predicting gender based on linear variables.

	Predicted		Total correct classifications	Cox and Snell R^2	Nagelkerke R^2
Observed	Female	Male			
Female	251	12	251/263 (95.4%)	0.133	0.194
Male	66	31	31/ 97 (32.0%)		
Total	317	43	282/ 373 (78.3%)		

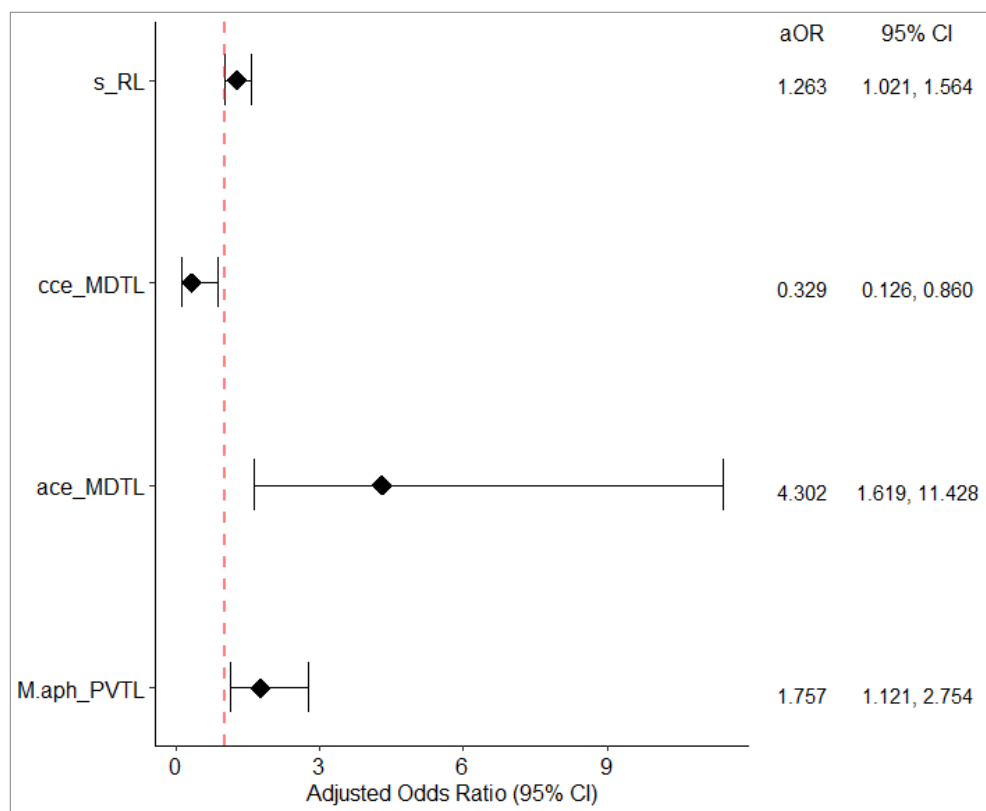


Figure 21. Forest plot for the effect of linear variables to predict gender male.

4.5.2 Binary Logistic Regression model for ratios

Binary logistic regression models for predicting gender based on ratios did not find noteworthy results.

The ratio cce_MDPL / cce_MDTL was the only significant variable for predicting gender. However, only one male was correctly classified by this model. So, odds ratio has not a finite upper bound in its 95% confidence interval. Taking this into consideration, we conclude that, in our study, ratios were not an accurate solution to predict gender male. Despite that, females were 100% correctly classified. Model explained between 2.3% (Cox and Snell R^2) and 3.3% (Nagelkerke R^2) of the dependent variable (gender).

4.6 ASSOCIATION AND PREDICTION BETWEEN VARIABLES III: PREDICTION OF AGE USING LINEAR REGRESSION MODELS

Table 31 presents the results of multiple linear regression models for age estimation based on upper central incisors. The table includes adjusted R^2 values, standard error of estimate (SEE) in years, and p-values for each regression model in different dimensions: sagittal, coronal, axial, and multiplanar measurements.

In the sagittal dimension, both linear measurements and ratios were considered. The linear measurement model suggests that age estimation is influenced by variables such as s_PCL (pulp chamber length), sce_PW (pulp width at cementoenamel junction level), and s_R (root length). As the values of these variables decrease, the estimated age tends to increase, indicating that older individuals may exhibit smaller measurements in these aspects. The adjusted R^2 of 0.364 implies that approximately 36.4% of the variance in age can be explained by these linear measurements. The standard error of estimate (SEE) of 12.495 years indicates the average deviation between the predicted age and the actual age.

Similarly, the ratios model indicates that the ratio of s_PCL plus/s_IL s_TTL, sce_PW/sce_TW, and s_RL/s_TT contributes to age estimation. The adjusted R^2 of 0.372 suggests that around 37.2% of the variance in age can be explained by these ratios. The SEE of 12.417 years implies the average difference between the predicted age and the actual age.

Moving to the coronal dimension, the linear measurement model includes variables such as cph_MDPL (mesiodistal pulp length at pulp horn level), cph_MDTL (mesiodistal tooth length at pulp horn level), cce_MDTL (mesiodistal tooth length at cementoenamel junction level), and cce_MDPL (mesiodistal pulp length at cementoenamel junction level). The negative coefficients for cph_MDPL and cph_MDTL suggest that as these measurements decrease, the estimated age tends to increase. Conversely, the positive coefficients for cce_MDTL and cce_MDPL indicate that as these measurements increase, the estimated age also increases. The adjusted R^2 of 0.373 suggests that approximately 37.3% of the variability in age can be explained by these linear measurements.

The ratios model in the coronal dimension reveals that the ratios of cph_MDPL/cph_MDTL and cce_MDPL/cce_MDTL contribute to age estimation. The negative coefficients for these ratios indicate that as the ratios decrease, the estimated age tends to increase. The adjusted R^2 of 0.225 implies that approximately 22.5% of the variance in age can be explained by these ratios.

In the axial dimension, the linear measurement model considers variables such as aph_MDPL (mesiodistal pulp length at pulp horn level), ace_PVPL (palatovestibular pulp length at cementoenamel junction level), and aph_PVTL (palatovestibular tooth length at cementoenamel junction level). The coefficients suggest that as aph_MDPL and ace_PVPL decrease, while aph_PVTL increases, the estimated age tends to increase. The adjusted R^2 of 0.498 indicates that approximately 49.8% of the variability in age can be explained by these linear measurements.

The ratios model in the axial dimension involves ratios such as aph_MDPL/aph_MDTL, aph_PVTL/aph_MDTL, ace_PVPL/ace_MDTL, and ace_MDPL/ace_MDTL. The coefficients indicate that as these ratios decrease, the estimated age tends to increase. The adjusted R^2 of 0.509 suggests that approximately 50.9% of the variance in age can be explained by these ratios.

Lastly, in the multiplanar measurements, both linear measurements and ratios were considered. The linear measurement model includes variables such as aph_MDPL, ace_PVPL, s_PCL, and s_RL. The coefficients suggest that as these measurements decrease, the estimated age tends to increase. The adjusted R^2 of 0.520 indicates that approximately 52% of the variability in age can be explained by these linear measurements.

The ratios model in the multiplanar measurements involves ratios such as aph_MDPL/aph_MDTL, s_PCL/s_IL s_TTL, ace_PVPL_p/ace_PVTTL, and ace_MDPL/ace_MDT. The coefficients indicate that as these ratios decrease, the estimated age tends to increase. The adjusted R^2 of 0.517 implies that approximately 51.7% of the variance in age can be explained by these ratios.

Univariate linear regressions were run to assess the contribute of each variable to explain the variance of age. For sagittal linear measurements, s_PCL added the most important contribute to predict age, with a total of 31.0% explained variance. For sagittal ratios sce_PW/sce_TW added the most important contribute to predict age, with a total of 17.2% explained variance. For coronal linear measurements, cph_MDPL, added the most important contribute to predict age, with a total of 26.3% explained variance. For coronal ratios, cce_MDPL/cce_MDTL, added the most important contribute to predict age, with a total of 15.6% explained variance. For axial linear measurements, aph_MDPL added the most important contribute to predict age, with a total of 34.3% explained variance. For axial ratios, aph_MDPL/aph_MDTL added the most important contribute to predict age, with a total of 30.0% explained variance. For multiplanar linear measurements, aph_MDPL added the most important contribute to predict age, with a total of 34.3% explained variance. For multiplanar ratios, aph_MDPL/aph_MDTL added the most important contribute to predict age, with a total of 30.0% explained variance.

Overall, these regression models provide insights into the relationship between various linear measurements and ratios of upper central incisors with age estimation. The interpretation of the coefficients reveals the direction and magnitude of the influence of these variables on age estimation. Additionally, the adjusted R^2 values quantify the proportion of the variability in age that can be explained by the models, while the SEE provides an estimate of the average deviation between the predicted and actual ages. Figure 22 shows that multiplanar and axial measurements and ratios are the models with a better predictive capacity.

Table 31. Multiple linear regression models for age estimation based on upper central incisors.

		Adjusted R ²	SEE (±year)	p*
Sagittal				
Linear measurements	Age = 68.050 – 5.828 s_PCL – 11.509 sce_PW + 0.987 s_RL Univariate R ² = 0.310 (s_PCL), 0.190 (sce_PW) and 0.012 (s_RL)	0.364	12.495	0.011
Ratios	Age = 55.463 – 5.685 s_PCL plus/s_IL s_TTL – 80.909 sce_PW/sce_TW + 46.024 s_RL/s_TTL Univariate R ² = 0.108 (s_PCL plus/s_IL s_TTL), 0.172 (sce_PW/sce_TW) and 0.108 (s_RL/s_TTL)	0.372	12.417	0.003
Coronal				
Linear measurements	Age = 75.844 – 8.630 cph_MDPL – 5.863 cph_MDTL + 6.953 cce_MDTL – 7.250 cce_MDPL Univariate R ² = 0.263 (cph_MDPL), 0.224 (cph_MDTL), 0.001 (cce_MDTL) and 0.135 (cce_MDPL)	0.373	12.320	0.001
Ratios	Age = 86.030 – 72.205 cph_MDPL/cph_MDTL – 75.696 cce_MDPL/cce_MDTL Univariate R ² = 0.144 (cph_MDPL/cph_MDTL) and 0.156 (cce_MDPL/cce_MDTL)	0.225	13.701	<0.001
Axial				
Linear measurements	Age = 72.963 – 10.084 aph_MDPL – 12.017 ace_PVPL + 2.477 aph_PVTL Univariate R ² = 0.343 (aph_MDPL), 0.211 (ace_PVPL) and 0.163 (aph_PVTL)	0.498	10.957	0.001
Ratios	Age = 68.762 – 68.668 aph_MDPL/aph_MDTL + 26.912 aph_PVTL/aph_MDTL – 61.559 ace_PVPL/ace_MDTL – 31.265 ace_MDPL/ace_MDTL Univariate R ² = 0.300 (aph_MDPL/aph_MDTL), 0.291 (aph_PVTL/aph_MDTL), 0.163 (ace_PVPL/ace_MDTL) and 0.100 (ace_MDPL/ace_MDTL)	0.509	10.839	0.003
Multiplanar Measurements (homonyms excluded)				
Linear measurements	Age = 80.608 – 9.197 aph_MDPL – 10.310 ace_PVPL – 2.765 s_PCL + 0.901 s_RL Univariate R ² = 0.343 (aph_MDPL), 0.211 (ace_PVPL), 0.310 (s_PCL) and 0.012 (s_RL)	0.520	10.717	<0.001
Ratios	Age = 107.129 – 69.226 aph_MDPL/aph_MDTL – 4.195 s_PCL plus/s_IL s_TTL – 73.910 ace_PVPL _p/ace_PVTL – 32.828 ace_MDPL/ace_MDTL Univariate R ² = 0.300 (aph_MDPL/aph_MDTL), 0.108 (s_PCL plus/s_IL s_TTL), 0.177 (ace_PVPL _p/ace_PVTL) and 0.100 (ace_MDPL/ace_MDTL)	0.517	10.757	<0.001

SEE, Standard error of estimate, * Multivariate linear regression analysis. sce_TW: tooth width at cemento-enamel junction level, sce_PW: pulp width at cemento-enamel junction level, s_RL: root length, s_PCL: pulp chamber length, s_TTL: total tooth length, cce_MDTL: mesiodistal tooth length, cce_MDPL: mesiodistal pulp length at cemento-enamel junction level, cph_MDTL: mesiodistal tooth length at pulp horn level, cph_MDPL: mesiodistal pulp length at pulp horn level, ace_MDTL: mesiodistal tooth length at cemento-enamel junction level, ace_MDPL: mesiodistal pulp length at cemento-enamel junction level, ace_PVTL: palatovestibular tooth length at cemento-enamel junction level, ace_PVPL: palatovestibular pulp length at cemento-enamel junction level, aph_MDTL: mesiodistal tooth length at pulp horn level, aph_MDPL: mesiodistal pulp length at pulp horn level, aph_PVTL: palatovestibular tooth length at pulp horn level.

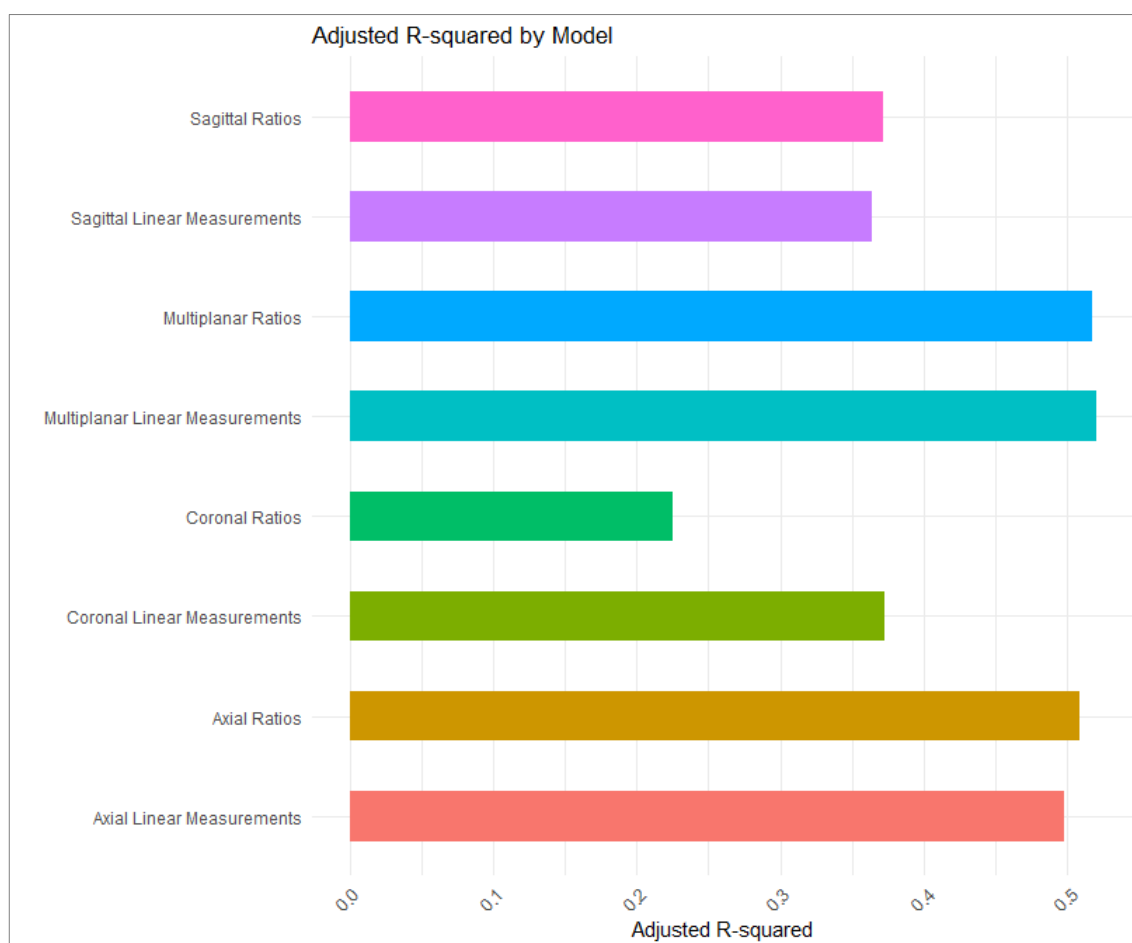


Figure 22. Adjusted r-squared for multiple linear regressions predicting age.

5 DISCUSSION

This section has been partially adapted/extracted from our published manuscript titled “**Age Estimation Using Maxillary Central Incisor Analysis on Cone Beam Computed Tomography Human Images**” Santos et al (2022)

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5.1 AGE ESTIMATION THROUGH THE CBCT METHOD

In the present study, CBCT method was chosen to estimate age equations clinically and statistically acceptable for forensic dental medicine. Several 3D analyses were carried out in the right upper central incisors (including sagittal, coronal and axial linear measurements) and the right upper first molar (include sagittal linear measurements) so as to derive these equations. Most of them were mainly built on axial measurements and ratios. Ours results demonstrated that the horizontal dimensions, especially pulp dimensions, can provide more accurate age estimation.

The indirect quantification of the secondary dentin deposition was first determined by several methods. The first methods with 2D imaging use the Kvaal et al. method (Kvaal et al., 1995), the Ikeda et al. tooth coronal index (Ikeda et al., 1985), and the Cameriere et al. (2007) pulp to tooth area ratio. With the evolution to 3D radiology, micro-CT was a very precise meter with several advantages, such as providing a high spatial resolution and a precise segmentation of dental structures (Ge et al., 2015). Nevertheless, it also had some disadvantages, such as the long waiting time for image acquisition and the fact that it can only be applied to one tooth at a time in postmortem individuals (Vandervoort et al., 2004). On the other hand, CBCT can be used on multiple teeth simultaneously in living people with a wide range of accuracy, with less costs and lower radiation exposure (Aboshi et al., 2010; Afify et al., 2014; Agematsu et al., 2010; Elgazzar et al., 2020; Ludlow & Ivanovic, 2008; Sakuma et al., 2013; Salemi et al., 2020; Someda et al., 2009; Tardivo et al., 2014; Vandervoort et al.,

2004;). This way, CBCT is widely used in several areas of dental medicine and allows for 3D information in living people, in an easy and cheaper way, and without losing accuracy.

In this study, 360 CBCTs were assessed and it was possible to conclude that anatomical measurements of the right upper central incisor and of the right upper first molar vary according to the age groups, with mean measurements ranging between different values. However, not all anatomical measurement parameters present a significant difference among age groups. The identified correlation between the anatomical measurements parameters and an individual's age is the following: as the former decreases, the latter increases. Hence, when these parameter measurements decrease, the age of the individual tends to increase, indicating that older individuals may exhibit smaller measurements in certain tooth parameters.

Since 2006 (Yang et al., 2006), several authors have been used CBCT for age estimation with a large range of results (Andrade et al., 2019; De Angelis et al., 2015; Farhadian et al., 2019; Gulsahi et al., 2018; Haghaniifar et al., 2019; Lee et al., 2017; Pinchi et al., 2015; Porto et al., 2015; Rai et al., 2016; Yang et al., 2006). Some authors found a low capacity for age estimations (Al-Omouh et al., 2021; Alsoleihat et al., 2017; De Angelis et al., 2015; Kazmi et al., 2019; Porto et al., 2015; Yang et al., 2006), but, on the other hand, other authors determined age estimation equations with good R^2 and SEE values (Andrade et al., 2019; Farhadian et al., 2019; Haghaniifar et al., 2019; Lee et al., 2017), demonstrating that CBCT can be as useful as CT (Afify et al., 2014; Elgazzar et al., 2020; Sakuma et al., 2013; Salemi et al., 2020; Tardivo et al., 2014), or micro-CT (Aboshi et al., 2010; Agematsu et al., 2010; Someda et al., 2009; Vandevoort et al., 2004). For age estimation through CBCT, several effective and accurate methods with ratios of dental linear measurements were applied, such as Kvaal's method (Akay et al., 2019; Kvaal et al., 1995; Penaloza et al., 2016), Cameriere's pulp tooth area ratio (Farhadian et al., 2019; Haghaniifar et al., 2019; Lee et al., 2017; Salemi et al., 2020), pulp to tooth volume ratio (Aboshi et al., 2010; Kazmi et al., 2022; Molina et al., 2021; Zhan et al., 2020; Zheng et al., 2021), pulp volume (Andrade et al., 2019; Kazmi et al., 2019), and chamber volume (Ge et al., 2015, 2016; Helmy et al., 2020; Oscandar et al., 2018). The equations obtained in the present study using linear measurements and ratios yield acceptable R^2 and SEE values. In the literature, the regression equations of R^2 are from 0.15 to 0.91 (Afify et al., 2014; Alsoleihat et al., 2017; Andrade et al., 2019; Farhadian et al., 2019; Ge et al., 2015, 2016; Gulsahi et al., 2018; Haghaniifar et al., 2019; Kazmi et al., 2019; Lee et al., 2017; Rai et al., 2016; Yang et al., 2006) and SEE values are from 4.2 to 11.45 years (Andrade et al., 2019; Ge et al., 2015, 2016; Haghaniifar et al., 2019; Lee et al., 2017; Pinchi et al., 2015; Yang et al., 2006). The variability in these results is due to differences in measurement methods and in tooth type: different methods and/or difference teeth produce difference results. Through CBCT, a great age estimation has been reported to different teeth: maxillary canines (Afify et al., 2014; Andrade et al., 2019; Elgazzar et al., 2020; Farhadian et al., 2019; Lee et al., 2017), mandibular canines (Afify et al., 2014; Elgazzar et al., 2020), maxillary lateral incisors (Zhan et al., 2020), maxillary second premolars (Akay et al., 2019), maxillary and mandibular first molars (Ge et al., 2015; Sue et al., 2018), and maxillary and mandibular second molars (Helmy et al., 2020) in spite of the fact that uniradicular teeth have been used in most research (Andrade et al., 2019; Biuki et al., 2017; Farhadian et al., 2019; Gulsahi et al., 2018; Haghaniifar et al., 2019; Jagannathan et al., 2011; Kazmi et al., 2019; Lee et al., 2017; Pinchi et al., 2015; Rai et al., 2016; Yang et al., 2006), specifically upper central incisors (Andrade et al., 2019; Asif et al., 2018, 2019; Haghaniifar et al., 2019; Pinchi et al., 2015; Porto et al., 2015; Soundarajan & Dharman, 2020) and canines (Afify et al., 2014; De

Angelis et al., 2015; Farhadian et al., 2019; Jagannathan et al., 2011; Kazmi et al., 2019, 2022; Lee et al., 2017; Rai et al., 2016; Salemi et al., 2020; Tardivo et al., 2014).

In this study, the upper central incisor was chosen because its pulp has a simple anatomy, considerable size, and few anatomic variations, making it easier to measure than posterior teeth (Kvaal et al., 1995). It is harder to analyze the secondary dentinal deposition in teeth with smaller pulp dimensions, such as mandibular incisors (Biuki et al., 2017; Cameriere et al., 2007; Gulsahi et al., 2018; Jagannathan et al., 2011; Tardivo et al., 2014). The upper central incisors are one of the most frequent remnants teeth in older patients, which is another important reason for our choice (Kvaal et al., 1995). Most research that compares tooth groups found the highest correlation with maxillary central incisors for age estimation (Andrade et al., 2019; Asif et al., 2019; Biuki et al., 2017; Gulsahi et al., 2018; Haghaniifar et al., 2019; Molina et al., 2021; Penaloza et al., 2016; Star et al., 2011). Regarding volume methods, this study used incisor linear measurements produced an R^2 within the previously observed range (Pinchi et al., 2015; Soundarajan & Dharman, 2020), and a slightly higher SEE (Ge et al., 2016; Haghaniifar et al., 2019). On the other hand, the method chosen for this study is easier and faster than other volumetric methods (pulp/tooth volume and pulp/crown volume) that may take from 30 min to several hours (Asif et al., 2018). Our equations are also less complex than those involving several teeth and measurements, while generating similar R^2 and SEE values (Penaloza et al., 2016).

The results of our study are in agreement with previous research found in the literature, which successfully used root canal diameter as an indirect quantification method for secondary dentin deposition (Aboshi et al., 2010). As we found in this study, several authors have reported that, with the aging process, dentinal thickness increased more along the pulp walls than along the pulp roof (Kanchan-Talreja et al., 2012; Prapanpoch et al., 1992). Although several authors have found that pulp cavity's height significantly correlated with chronological age on 2D imaging (Drusini et al., 1997; Kvaal et al., 1995), our study found horizontal measurements to have better R^2 and SEE values than vertical measurements. Our results were similar to most CBCT research (Akay et al., 2019; Haghaniifar et al., 2019; Nemsi et al., 2017; Penaloza et al., 2016), except for the study of Lee et al. (2017). In that regard, we found that horizontal dimensions are more precise for age estimation.

Vertical measurements are not very useful for age estimation due to the effects of external factors, like attrition, occlusion type and behavior habits. The results found in this study indicate that attrition is not sufficiently related to age to be used as a tool for age estimation. These results are in agreement with the study of Kvaal et al. (1995). Other research also described that attrition has a stronger relation to diet and habits (Molnar, 1971). This shows how low harshness of the current diet may explain the lack of association with age. Beside the secondary dentin deposition, pulp cavity dimensions may also be modified by other local and systemic factors, such as tertiary dentin deposition at the chamber roof due to decay or to restorations (Paewinsky et al., 2005). To avoid this problem, we only used healthy teeth, according to Kvaal's method (Kvaal et al., 1995).

Pulp dimensions could be influenced by other factors, such as race, nutritional and hormonal changes, and certain systemic diseases, as suggested by some authors (*e.g.* Bang, 1989). In this study, the patients were chosen without analyzing their clinical histories and this may be considered a gap. However, our aim was to find an equation for age estimation in the general population and not to analyze the influence of systemic diseases on secondary dentin deposition. Besides, secondary dentin deposition is considered to vary according to tooth type, sex and population (Kvaal et al., 1995; Prapanpoch et al., 1992). This is one of the

reasons why regression-specific equations are necessary to validate age estimation methods in different populations (Babshet et al., 2010; Cunha et al., 2009; Li et al., 2019; Patil et al., 2014). Specific equations could produce different age estimates for different populations (Jagannathan et al., 2011; Patil et al., 2014), in spite of Cameriere et al. (2009) were able to adequately determine age for both Italian and Portuguese samples with the same regression equation. That way, our method should be used in future research in other populations.

Forensic dentistry's constant search for the ideal age estimation method leads to several methods, each one of them with strengths and weaknesses. On the one hand, to maximize age estimation accuracy, more than one method could be applied with repeat measurements (Afify et al., 2014; Biuki et al., 2017; Cameriere et al., 2012; Ge et al., 2016; Kvaal et al., 1995), with multiple tooth types (Cameriere et al., 2012), which could be a limitation of our study, which only used upper central incisors. On the other hand, there is a disagreement among authors about multicollinearity problems when using multiple tooth types in a single model (Cameriere et al., 2012; Kazmi et al., 2019).

5.2 GENDER ESTIMATION THROUGH THE CBCT METHOD

CBCT method was also chosen to estimate gender equations clinically and statistically acceptable for forensic dental medicine. We used the 3D analyses previously described in section 4.1.

In the 360 CBCTs carried out in this study, right upper incisors (both the incisive and the first molar) tend to present higher dimensions in males rather than in females (sce_TW, sph_CW), s_TTL, s_RL, s_IL, cce_MDTL and cph_MDTL), with only a few dimensions being similar between both (cce_MDPL and cph_MDPL) or even lower in males (sce_PW and s_PCL). Thus, this study suggests that, in general, right upper incisors with larger dimensions refer to males.

Andrade et al. (2019) developed a study to assess both age and sex estimation based on pulp cavity volume, using CBCT through a sample of 116 CT scans from Brazilian individuals of both genders, ranging in age from 13 to 70 years. They evaluated a total of 232 teeth, especially upper central incisors and canines. Their results demonstrated that the age estimation in females produced best results, and highlighted that gender estimation is only accurate when a person's age is actually known. Their sex estimation formulas presented a high accuracy during the validation process, being higher for females using one or both types of teeth. For males, when the sex estimation formula was applied without the information of age, the use of canine volumetric measurements alone resulted in a low accuracy. Therefore, these authors do not recommend the use of the pulp volume of the upper canines without some other pieces of information about the biological profile for sex/gender estimation.

However, previous research has demonstrated different results. For instance, Tardivo et al. (2011) aimed at proposing a new method for sex and age estimation, based on the use of 3D models to obtain more precise predictions when using tooth volumes. Their sample comprised 58 dental CT scans of patients aged 14-74, with a well-balanced sex ratio. Briefly, after applying the equations to the validation sample, Tardivo et al. (2011) found no significant difference between the real and the predicted age, with 100% of sex predictions being correct. Thus, their 3D-based model seems to be very accurate in gender estimation, comprising the evaluation of tooth volumes.

The study conducted by Santosh et al. (2022) is congruent with the results obtained in our research. In their innovative research, the authors developed a fully automated system in order

to identify the gender and age of humans based on digital images of teeth, using 1142 X-ray images of the latter to conduct both estimations. The proposed system can be widely applied in the forensic dentistry to predict results quickly and accurately, considering that it achieved 96% of accuracy when predicting both age and gender of individuals. Moreover, another important contribution of the study conducted by these authors refers to the values of different teeth parameters, corroborating our own findings, namely related to the fact that males often present higher values in several tooth dimensions when compared to females.

Badran et al. (2015) examined 419 orthopantomographic images, 126 of males and 293 of females. They all referred to young adults with an average age of 19.3 years (13–26 years). The assessment comprised verifying the presence of a flexure on the posterior margin of the ramus at the occlusal plane. The posterior margin of the ramus was then graphically traced, and the occlusal plane level was delineated as guided by the height of cusp tips at the occlusal surfaces of the mandibular molars. Badran et al. (2015) showed that the accuracy of predicting females was higher than the accuracy of predicting males. In addition, by using two raters (doubled-blind), authors found that agreement, measured with Cohen's kappa, was moderate ($k=0.546$). So, not only females were more accurately predicted, with accuracies of 85.4% vs. 75.0% for rater 1 and 86.7% vs. 66.7% for rater 2, but also results were fairly consistent between the two raters. Despite the differences between methods, results of Badran et al. (2015) are in line with ours. In our study, s_{RL} , higher for males, cce_MDTL , higher for females, ace_MDTL , higher for males, and $M.aph_PVTl$, higher for males, were included in a multivariate logistic model attempting to predict gender. The proportion of females correctly classified was much higher for females (95.4%) than for males (32.0%). This way, despite the differences between the two approaches, results found in both studies followed the same trend.

Results are also in line with findings from Galdames et al. (2008b), where 188 ortopantomography images were assessed according to Loth & Henneberg's method. Patients were 188 Chilean adults, with a mean age of 21.13 ($SD=1.25$), 108 females and 80 males. Two raters (double-blind) classified the ortopantomography images by gender. Accuracy of rater 1 was 62.0% for females and 46.5% for males. As for rater 2, accuracy for females' classification was 64.5% and accuracy for male classification was 50.0%. Cohen's kappa of 0.457 was lower than in Badran et al. (2015) study, but still falling in the moderate threshold. In the study of Tamer (2012), ortopantomography images of 100 patients, equally distributed by gender, were randomly selected. Accuracy for predicting females in Loth & Henneberg method was 66.0%, when compared to an accuracy of 62.0% for predicting males.

Galdames et al. (2008a) conducted a study to assess mandibles of Brazilian subadults, in a total of 33 Brazilian children between 0 and 1 year of age. A blind test with two sessions was performed. Using Loth & Henneberg's method, accuracy for males was 70% in the first session and 70% in the second session. As for females, accuracy was 38.0% in the first session and 46.0% in the second one. These results are not in line with the ones described by Galdames et al. (2008b), Galdames et al. (2008a) and with our study, which found higher proportions of correction classifications for females. So, we can hypothesize that age plays an important role in detecting gender when using these methods.

Mughal et al. (2010) examined data from 200 students, equally distributed by gender, between the age group of 18-25 years, randomly sampled with informed consent. Assessment comprised mandibular canine width and intercanine distance. The observed mandibular canine index (MCI) was compared with the standard MCI value. MCI was calculated as: Mesio-distal crown width of mandibular canine/ Mandibular canine width. Standard MCI was

calculated as: $[(\text{Mean male MCI} - \text{SD}) + (\text{Mean female MCI} + \text{SD})] / 2$. Results showed accurate predictions for 75.97% overall, 78.72% females and 71.67% males, again in line with the results of our study.

In other study, Reddy et al. (2008) assessed 200 patients, equally distributed by gender, between 17-25 years old. Impressions were made with alginate and study models prepared with dental stone. Maximum mesiodistal diameter of mandibular canines and the linear distance between tips of mandibular canines were measured using a Vernier caliper. Resorting to standard MCI, Reddy et al. (2008) were able to detect greater sexual dimorphism in the left canine when compared to the right canine. About 70% of the cases were correctly predicted in terms of gender.

Patel et al. (2017) studied 400 patients (200 males and 200 females), aged between 20 and 40 years old. In their study, they assessed the mesiodistal width of the right and left canine and the intercanine distance. MCI was calculated to establish the amount of sexual dimorphism exhibited by the mandibular canine. Sexual dimorphism in right and left mandibular canines was calculated using $(X_m \div X_f - 1) \times 100$, where X_m = Mean male canine width and X_f = Mean female canine width as Garn et al. (1967). Patel et al. (2017) did not find significant differences between in vivo and in vitro measurements of mesiodistal width of the right and left canines and intercanine distance. Results of this study showed 80.0% of correct classifications for males and 77.5% for females, which is a slight difference, but still in the opposite direction.

Vishwakarma and Guha (2011) studied sexual dimorphism in permanent mandibular canines. They analyzed data from 90 males and 90 females aged between 17-23 years. Measures were the mesiodistal width for right and left mandibular canines and intercanine distance. The mesiodistal width for right and left mandibular canines and intercanine distance were measured. The canine index was calculated for both sides. Significant sexual dimorphism was found for mesiodistal width for right and left mandibular canines, and intercanine and for right and left mandibular canine index. No significant differences were found for intercanine distance. These results follow the line of the ones found in our study. We found that higher dimension parameters were more likely to be found in males than females. In Vishwakarma and Guha's (2011) study, mesiodistal width for right and left mandibular canines and intercanine and for right and left mandibular canines index were significantly higher in males when compared to females.

Other studies such as Hashim & Murshid (1993) or Zakirulla et al. (2019) have found statistically significant differences between males and females regarding canines but not in other teeth. In Hashim and Murshid's (1993) study, a total of 720 teeth were measured from a pre-treatment orthodontic study, 360 from male patients and 360 from female patients, aged from 13 to 20 years. By using an electronic digital caliper authors concluded that mesiodistal tooth width of canines in both jaws is higher in males, while no differences were found in other teeth. In Zakirulla et al.'s (2019) study, 90 patients were included, equally distributed by gender, with a mean age of 26.9 years. Measurements were made directly on the models, with the aid of the digital caliper, establishing the largest mesiodistal measure of incisors, canines, premolars, and molars, in both sides. When compared by gender, mesiodistal tooth width of premolars were significantly higher in females. No other differences were found. Hashim and Murshid's (1993) study results corroborate the ones found in our study by reporting higher dimension parameters for males. On the other hand, Zakirulla et al.'s (2019) study found a

single significant difference for mesiodistal tooth width of premolars, which were larger for females, a result that goes in the opposite direction.

In another approach, Singh et al. (2021) evaluated 20 teeth samples, obtained from 10 males and 10 females. Samples were placed in 10% neutral buffered formalin solution and sections were ground on Arkansas stone, mounted on a slide using DPX, and then visualized through a microscope. Results showed that the mean thickness of secondary dentin was higher in male samples when compared to female samples. This result corroborates previous findings, like ours, demonstrating that male teeth specimens tend to have higher dimension parameters when compared to female teeth specimens. However, in this study, Singh et al. (2021) highlight the need to collect more data to achieve more robust conclusions.

Tardivo et al. (2011) assessed 58 dental CT scans of patients aged between 14 and 74 years old and modeled with Mimics 12.0 (Materialise NV, Leuven, Belgium) a total of 133 healthy canines. A cross-validation procedure was performed by dividing the sample into a training and validation sample. Gender predictions were based on total volumes, and 100% of the predictions were accurate for males and females. Cut-off for canine total volume was ≥ 0.395 ($c = 0.733$). Although the results were promising, Tardivo et al. (2011) recommend more research in larger datasets.

Vila-Blanco et al. (2020a) assessed 3400 dental panoramic images and results and detailed predictive accuracies by age, finding that gender prediction increases with age.

Several others studies were performed to estimate human genders. Singh et al. (2021) aimed to use the secondary dentin as a diagnostic tool in gender predilection/estimation using 20 samples (10 males and 10 females). The extracted teeth were collected and placed in 10% neutral buffered formalin solution until they reached the appropriate thickness. With these results, the authors concluded that the mean thickness of secondary dentin was higher in male samples than in female ones. Therefore, these findings corroborate ours, namely the fact that males present higher values in several tooth parameters and domains when compared to females. These results contribute to the literature because they indicate that the secondary dentin can be used for gender estimation by measuring its thickness. Rao et al. (1989) concluded that the mesiodistal width of mandibular canines was remarkably greater in males when compared to females.

Vila-Blanco et al. (2020a) discussed different methods to estimate the gender of a subject from dental panoramic images, focusing on the influence of the person's age in the prediction accuracy. They obtained several conclusions from the information available in the literature that corroborates the accuracy of gender estimation by assessing dental panoramic images (Acharya & Mainali, 2008; Alias et al., 2018; Badran et al., 2015; Franklin et al., 2006; Marinescu et al., 2013; Milošević et al., 2019; Mughal et al., 2010; Silva et al., 2016; Vila-Blanco et al., 2020b). All this information is important for the constant evolution of forensic dentistry and its search for the ideal gender estimation method.

Our study has a significant limitation. In fact, we were unable to calculate the volume of either the pulp or the tooth, criteria that has been extensively studied and with results of great statistical significance for determining age and gender.

However, the added value of our study is the fact that we used a fairly large sample and a large number of variables that allowed us to make several comparisons between them and thus be able to obtain results with great statistical significance for the determination of gender and, in particular, of age.

6 CONCLUSIONS

1. Linear measurements on CBCT of the upper central incisor and upper first molar are higher in males than in females.
2. These higher male values of measurements related to males occur across all anatomic planes on CBCT, for both the upper central incisor and the upper first molar, with no apparent difference.
3. Ratios were not better at establishing differences between males and females than the other measurements.
4. Predictions concerning gender are useful to detect females, but not as much to detect males.
5. The most suitable characteristic for forensic gender estimation is axial mesiodistal tooth length at cemento-enamel junction level (ace_MDTL).
6. Regarding age estimation, CBCT multiplanar measurements, axial measurements and ratios are the methods that have better predictive capacity.
7. It was not possible to establish a direct overall association between age and higher or lower measurement parameters. Nevertheless, there seems to be a reduction in the parameters over the years, mainly for variables that affect the pulp. Thus, for the sagittal plane, we should consider the sagittal pulp width at cemento-enamel junction level (sce_PW) and the sagittal pulp chamber length (s_PCL). For coronal plane, we should consider the coronal mesiodistal pulp length at pulp horn level (cph_MDPL) and the molar pulp chamber height (M.CACP). For axial plane, we should take into consideration the axial palatovestibular pulp length at cemento-enamel junction level (ace_PVPL) and the axial mesiodistal pulp length at pulp horn level (aph_MDPL).
8. The most suitable characteristic for forensic age estimation is axial mesiodistal pulp length at pulp horn level (aph_MDPL).
9. Although CBCT could be an important tool for forensic dentistry, future research should determine whether combining several CBCT age and gender estimation methods could improve results. Automatic software development is likely to make integrating measurement methods faster and more efficient.

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APPENDIX

APPENDIX 1 - ANATOMICAL MEASUREMENTS OF THE RIGHT UPPER CENTRAL INCISIVE ON THREE ANATOMICAL PLANES

1.1. Sagittal linear measurements of the right upper central incisor

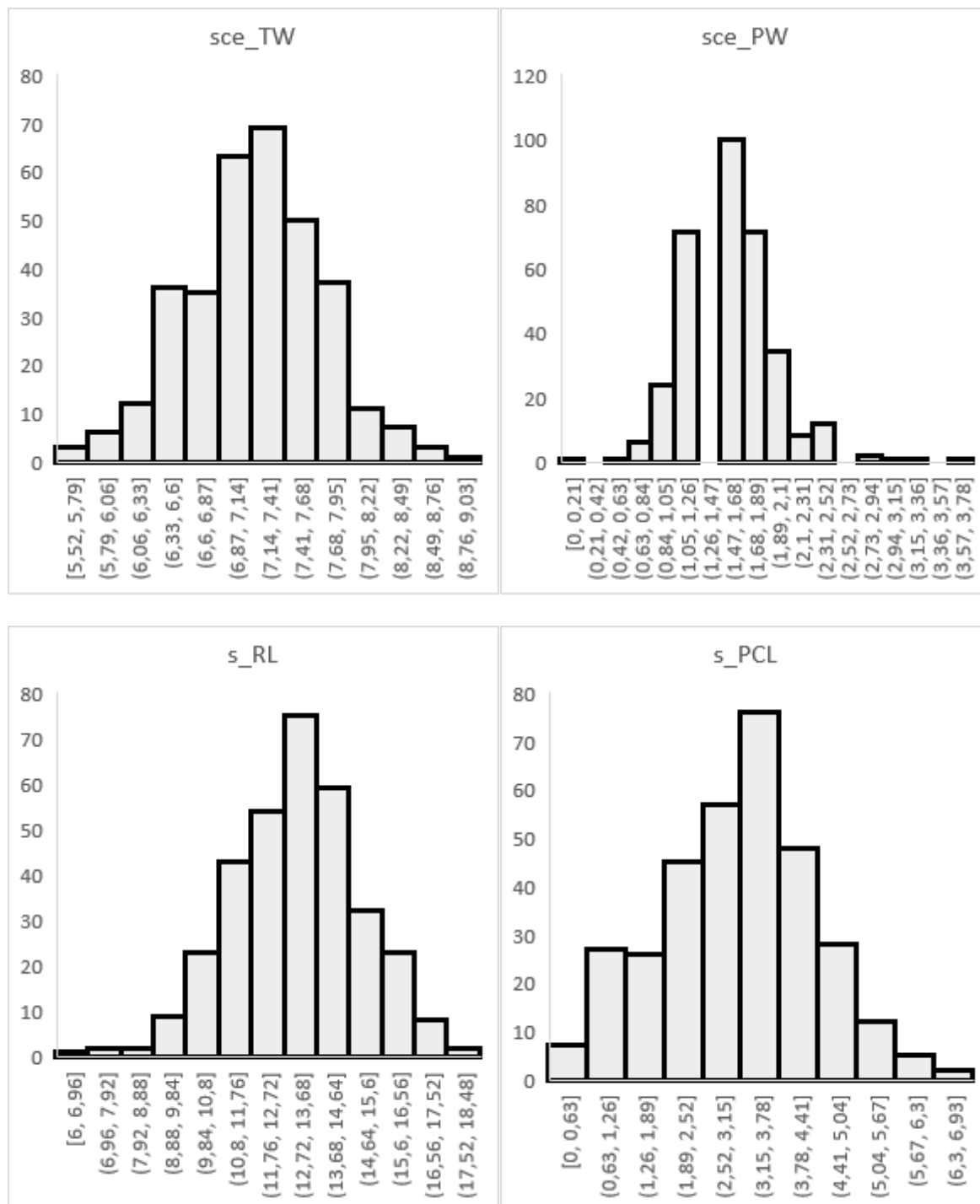


Figure 23. Histograms showing normal distribution, mean and standard deviation for variables of right upper central incisor on sagittal slices: sce_TW, anteroposterior incisive width at cementoenamel junction level; sce_PW, anteroposterior pulpar width at cementoenamel junction level; s_RL, root length; s_PCL, chamber length.

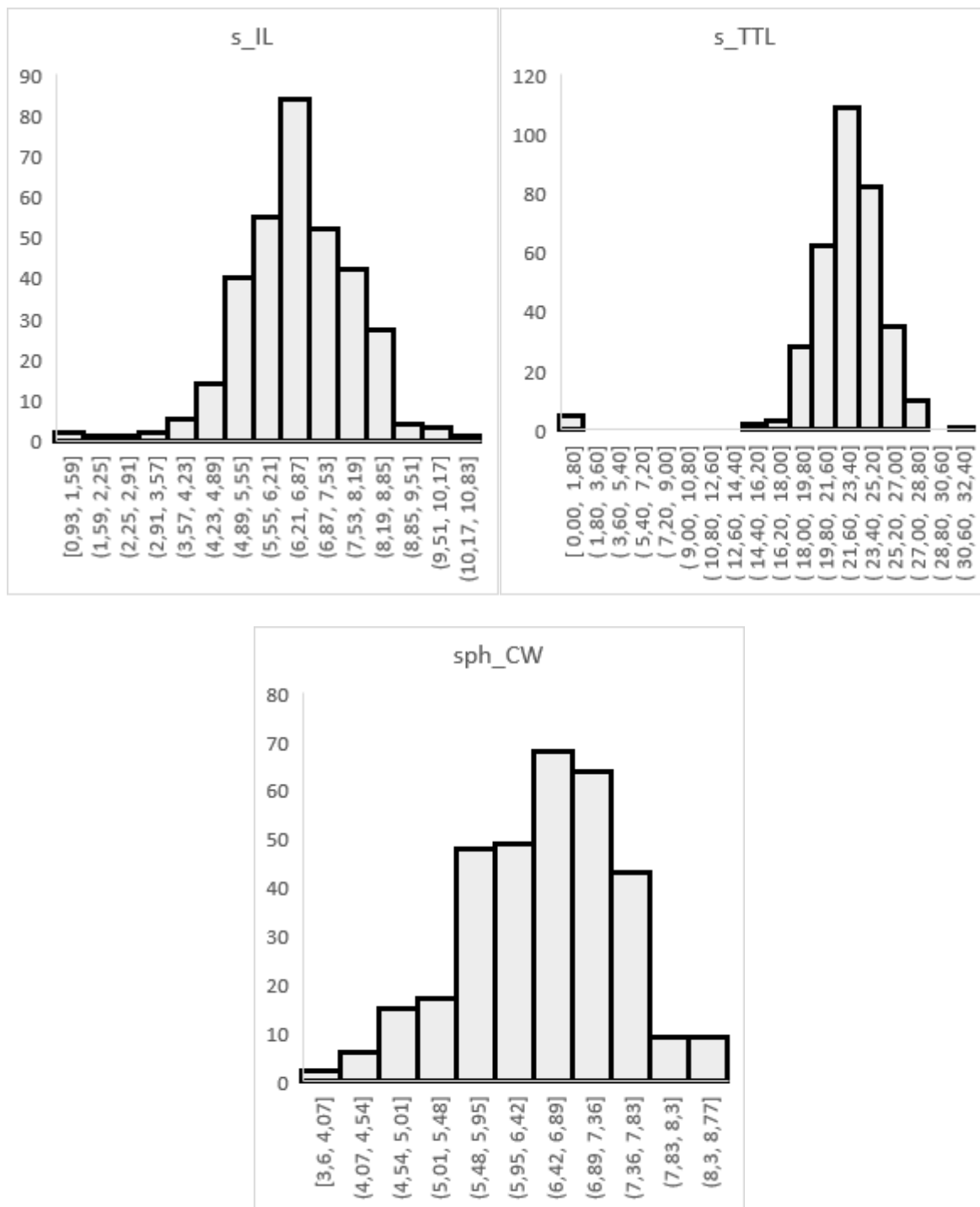


Figure 24. Histograms showing normal distribution, mean and standard deviation for variables of right upper central incisor on sagittal slices: s_IL, coronal length; s_TTL, total length and sph_CW, coronal width at pulpar horn level.

1.2. Coronal linear measurements of the right upper central incisor

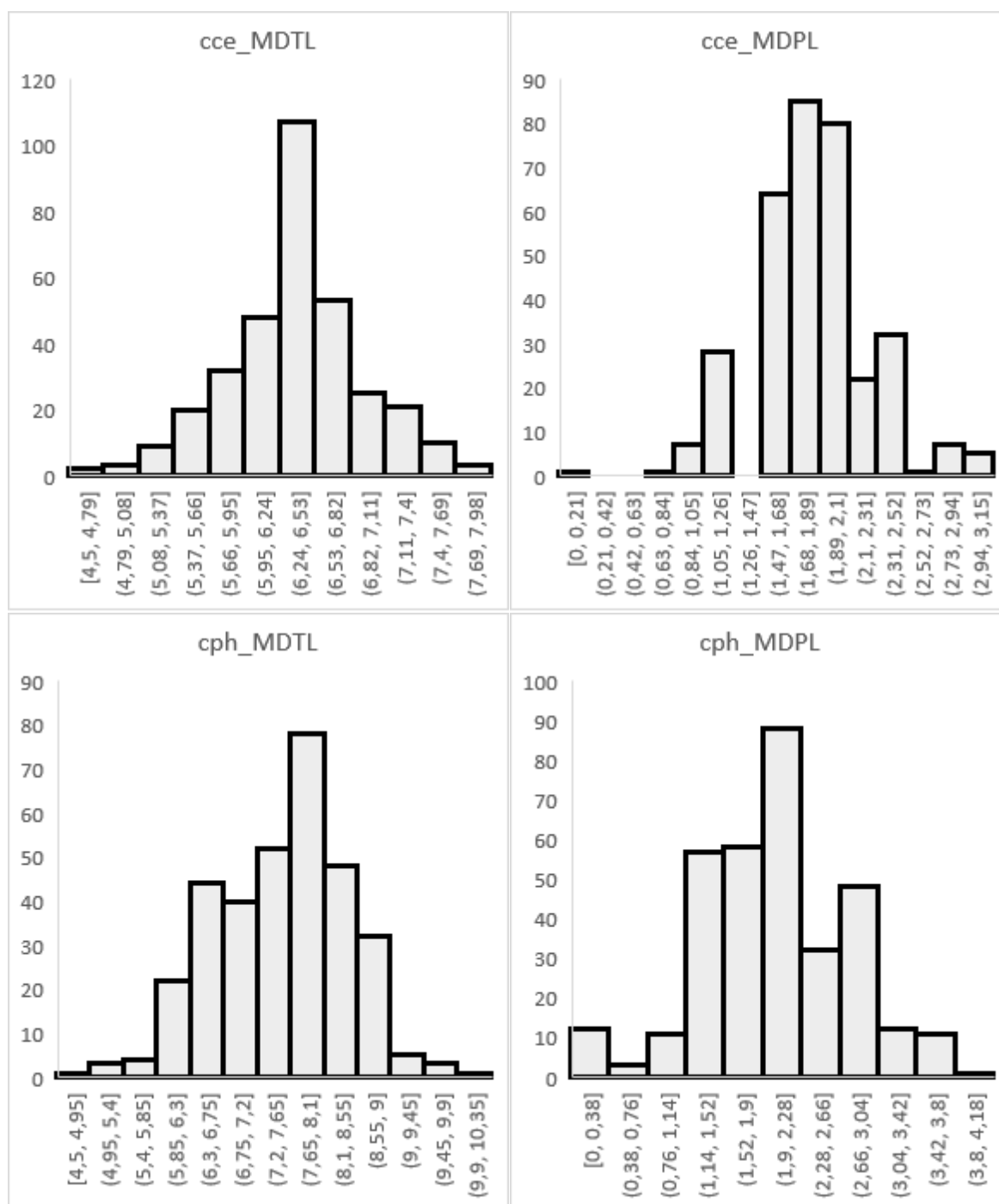


Figure 25. Histograms showing normal distribution, mean and standard deviation for variables of right upper central incisor on coronal slices: cce_MDTL, mesiodistal width at cemento-enamel junction level; cce_MDPL, mesiodistal pulpar width at cemento-enamel junction level; cph_MDTL, mesiodistal width at chamber level and cph_MDPL mesiodistal pulpar width at chamber level.

1.3. Axial linear measurements of the right upper central incise

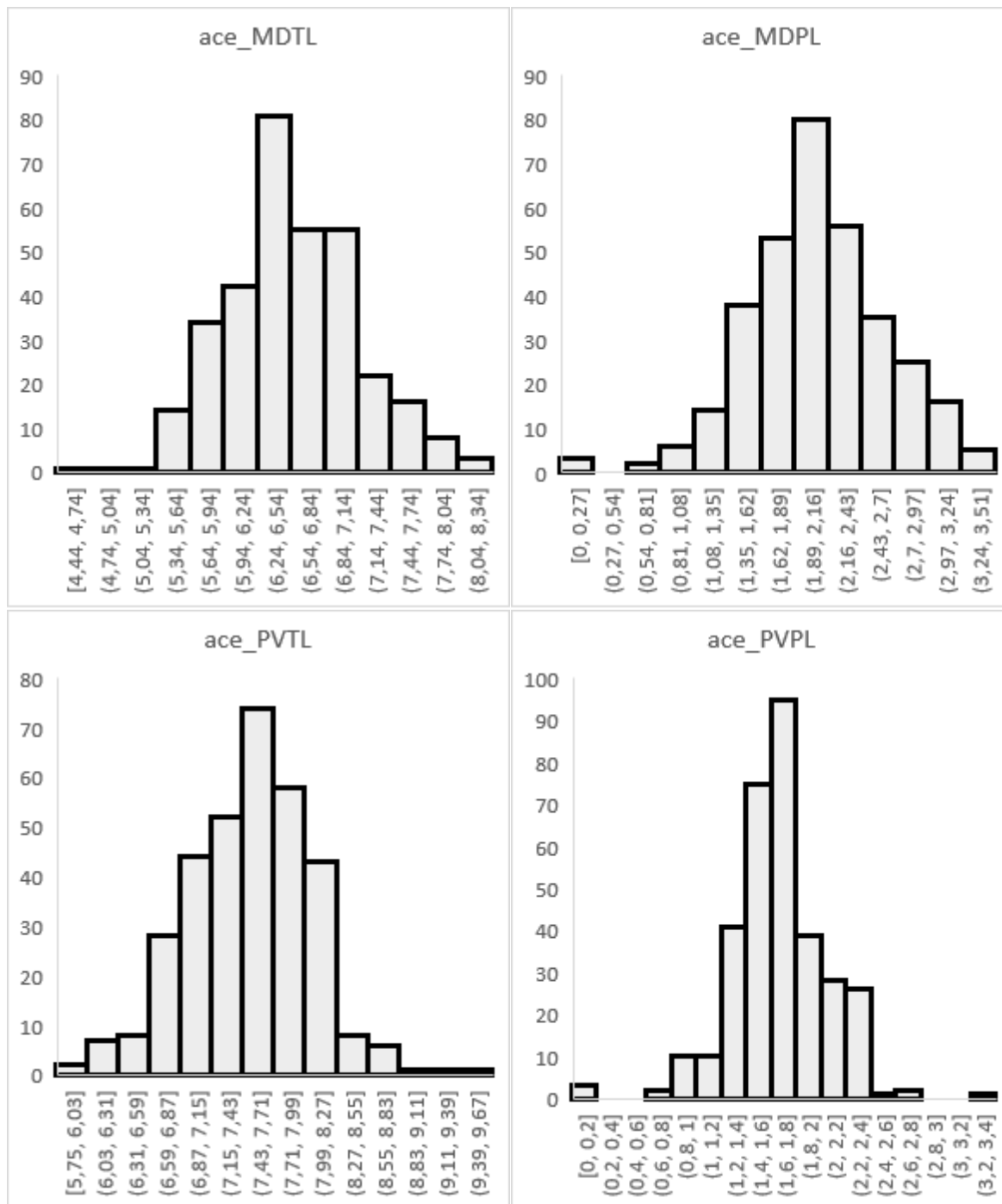


Figure 26. Histograms showing normal distribution, mean and standard deviation for variables of right upper central incise on axial slices: ace_MDTL, mesiodistal length at cementoenamel junction level; ace_MDPL, mesiodistal pulpar length at cementoenamel junction level; ace_PVTL, palatovestibular width at cementoenamel junction level; ace_PVPL, palatovestibular pulpar width at cementoenamel level.

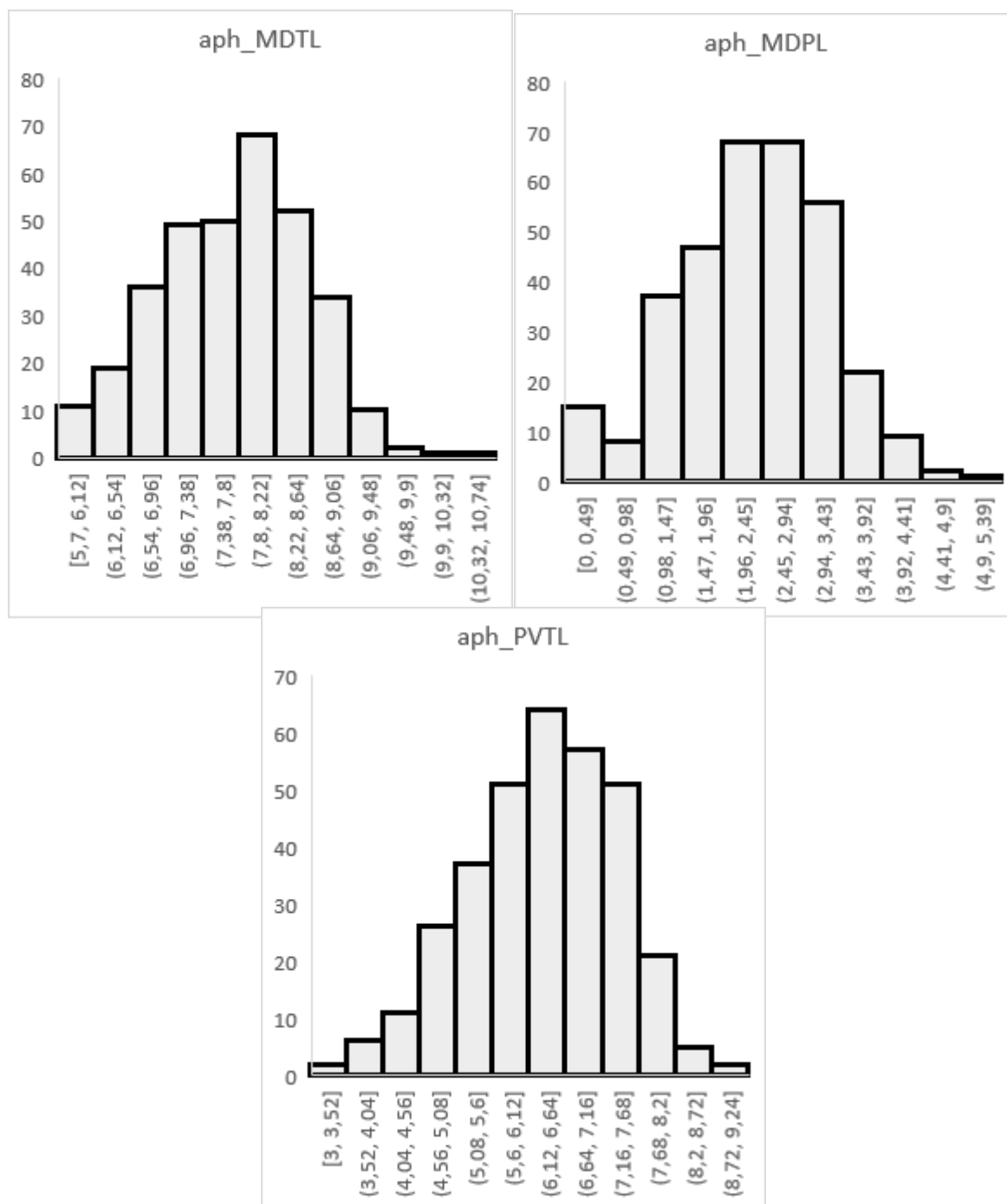


Figure 27. Histograms showing normal distribution, mean and standard deviation for variables of right upper central incisor on axial slices: aph_MDTL, mesiodistal length at pulp horn level; aph_MDPL, mesiodistal pulpar length at pulp horn level and aph_PVTl, palatovestibular length at pulp horn level.

1.4. Sagittal and axial linear measurements of the right upper first molar

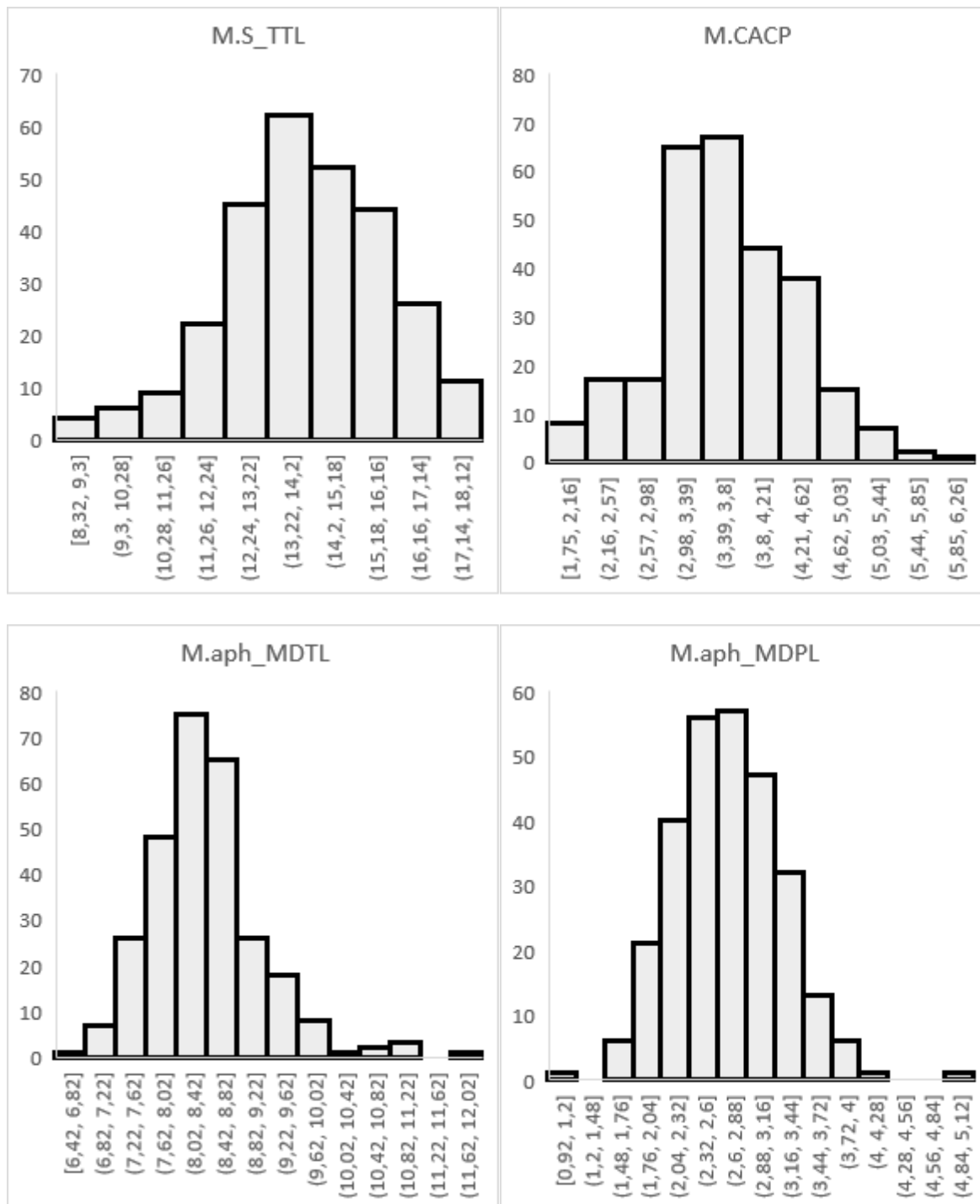


Figure 28. Histograms showing normal distribution, mean and standard deviation for variables of right upper first molar on sagittal slices: M.S_TTL, root length; M.CACP, chamber length; M.ap_h_MDTL, mesiodistal length and M.ap_h_MDPL, mesiodistal pulpar length.

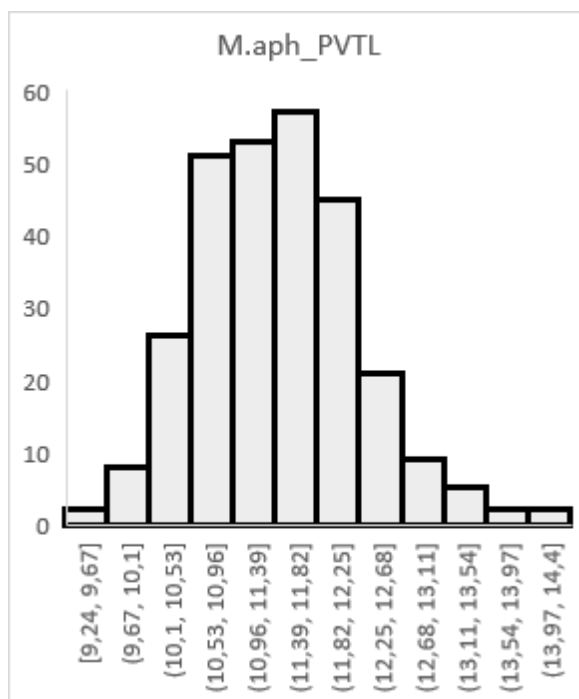


Figure 29. Histograms showing normal distribution, mean and standard deviation for variables of right upper first molar on sagittal slices: M.aph_PVTL, palatovestibular width.

1.5. Sagittal ratios of the right upper central incisive

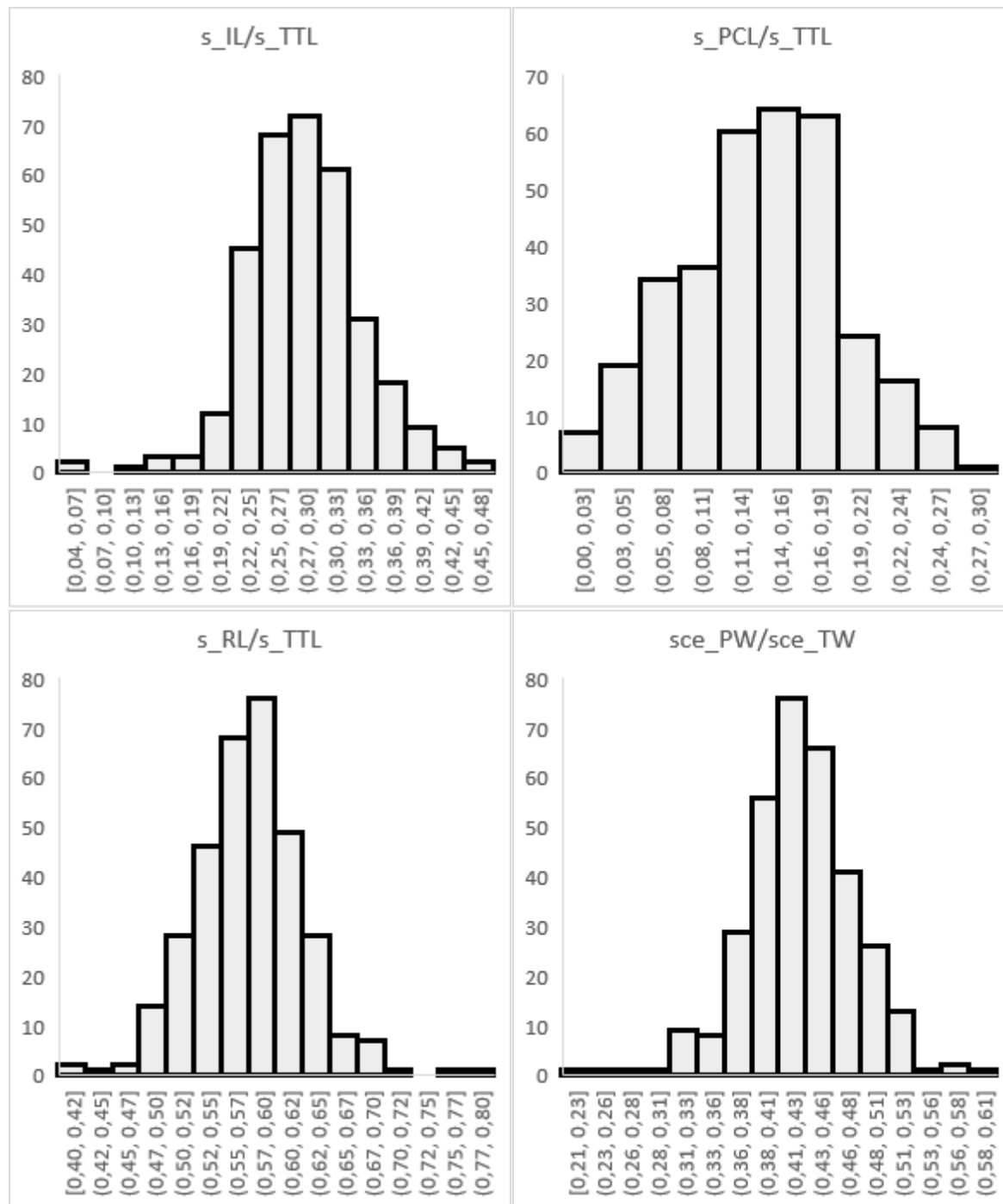


Figure 30. Histograms showing normal distribution, mean and standard deviation for ratios of linear measurements of right upper central incisive on sagittal slices: s_{IL}/s_{TTL} , ratio between coronal length and total incisive length on sagittal slices; s_{RL}/s_{TTL} , ratio between root length and total incisive length on sagittal slices; s_{PCL}/s_{TTL} , ratio between chamber length and total incisive length on sagittal slices and $s_{PCL}+s_{IL}/s_{TTL}$, ratio between total coronal length and total incisive length on sagittal slices.

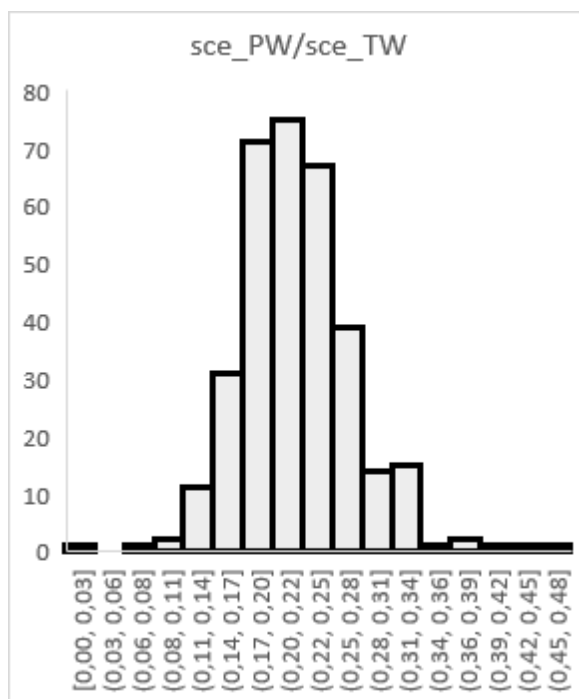


Figure 31. sce_PW/sce_TW , ratio between anteroposterior incisive width at cementoenamel junction level and anteroposterior pulpar width at cementoenamel junction level on sagittal slices.

1.6. Coronal ratios of the right upper central incisive

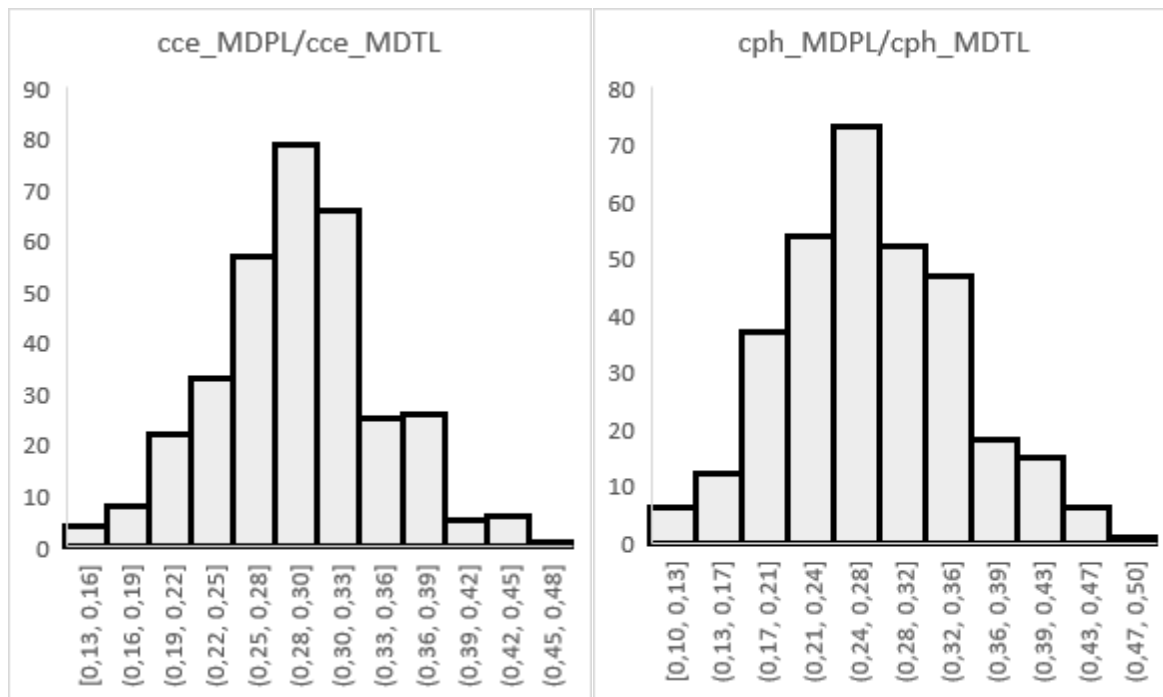


Figure 32. Histograms showing normal distribution, mean and standard deviation for ratios of linear measurements of right upper central incisive on sagittal slices: cce_MDPL/cce_MDTL, ratio between mesiodistal width and mesiodistal pulpar width at cementoenamel junction level on coronal slices; cph_MDPL/cph_MDTL, ratio between mesiodistal width and mesiodistal pulpar width at chamber level on coronal slices.

1.7. Axial ratios of the right upper central incisive

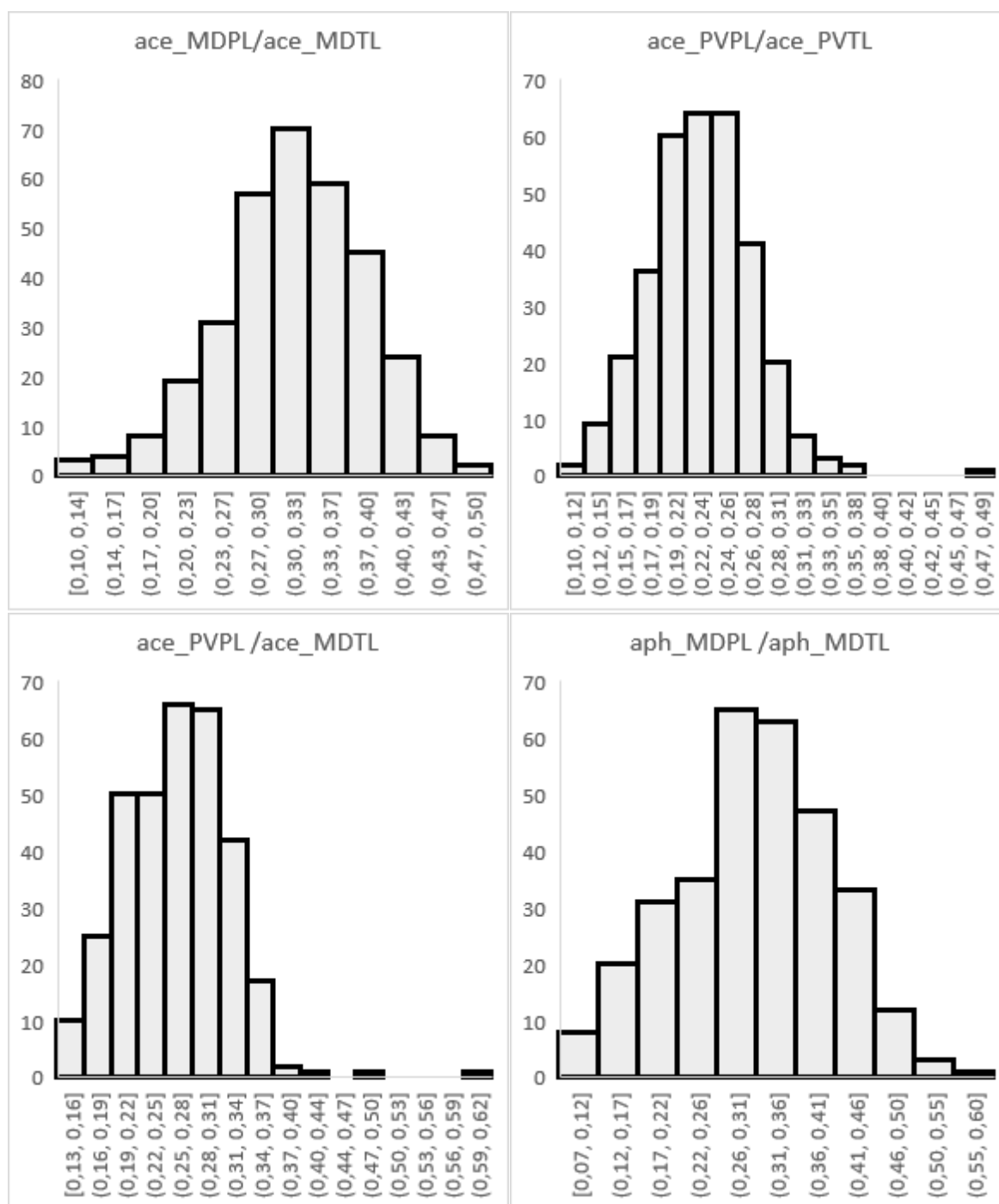


Figure 33. Histograms showing normal distribution, mean and standard deviation for ratios of linear measurements of right upper central incisive on axial slices: ace_MDPL/ace_MDTL, ratio between mesiodistal pulpar length and mesiodistal length at cementoenamel junction level on axial slices; ace_PVPL/ace_PVTL, ratio between palatovestibular pulpar width and palatovestibular width at cementoenamel junction level on axial slices; ace_PVPL/ace_MDTL, ratio between palatovestibular pulpar width and mesiodistal length at cementoenamel junction level on axial slices and aph_MDPL/aph_MDTL, ratio between mesiodistal pulpar length and mesiodistal length at pulpar horn level on axial slices.

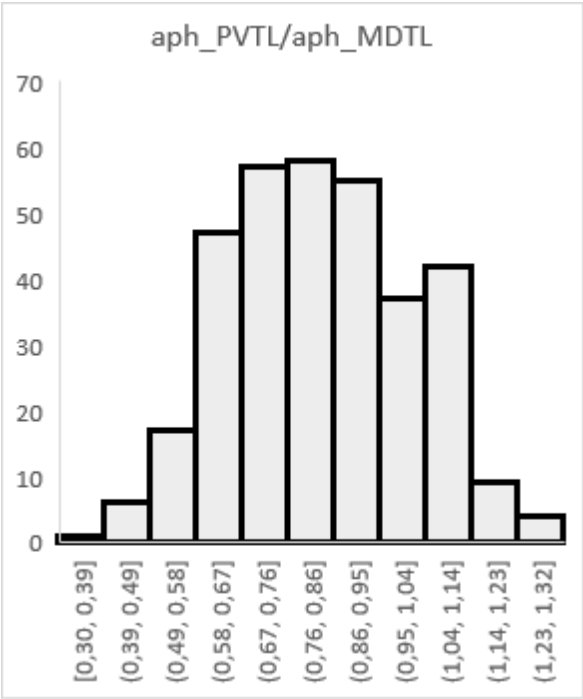


Figure 34. $\text{aph_PVTL}/\text{aph_MDTL}$, ratio between palatovestibular length and mesiodistal length at pulpar horn level on axial slices.

1.8. Sagittal and axial ratios of the right upper first molar

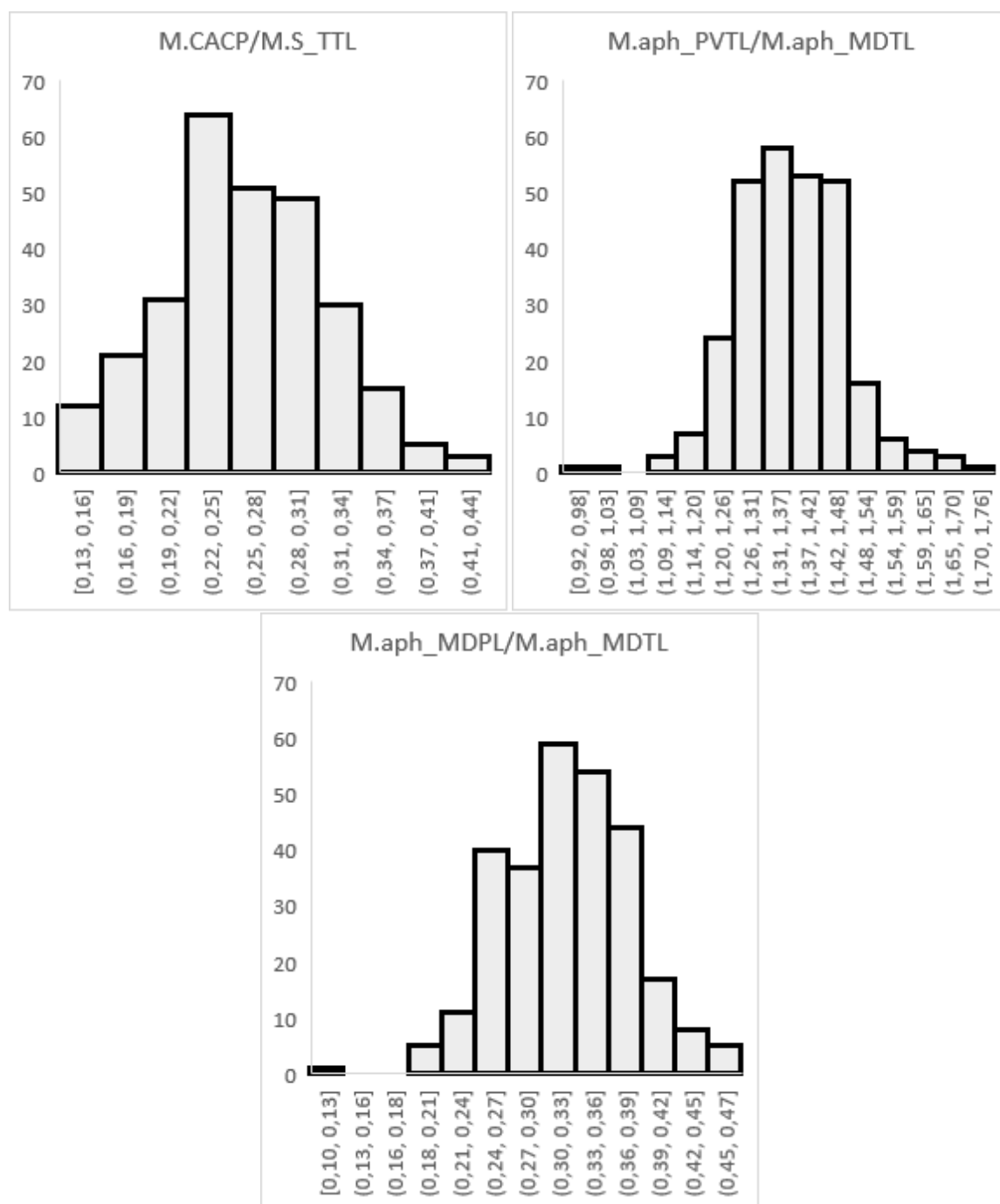


Figure 35. Histogram showing normal distribution, mean and standard deviation for ratios of linear measurements of right upper first molar on sagittal slices: M.CACP/M.S_TTL, ratio between chamber length and root length; M.aph_MDPL/M.aph_MDTL, ratio between mesiodistal pulpar length and mesiodistal length at cemento-enamel junction level on axial slices and aph_PVTL/M.aph_MDTL, ratio between palatovestibular width and mesiodistal length at cemento-enamel junction level on axial slices.

APPENDIX 2 - ETHICS COMMITTEE



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DICTAMEN DEL COMITÉ ÉTICO DE INVESTIGACIÓN CLÍNICA DE GALICIA

Juan M. Vázquez Lago, Secretario Suplente del Comité Ético de Investigación Clínica de Galicia

CERTIFICA:

Que este Comité evaluó en su reunión del día 13/09/2012 el estudio:

Título: Caracterización de osteoporosis en imágenes maxilares de tomografía computerizada CONE BEAM. Proyecto OSTEO-DENT ALNERV-Cone Beam

Promotor: María Mercedes Suárez Cunqueiro

Tipo de estudio: No-EPA

Código de Registro CEIC de Galicia: 2012/272

Y que este Comité de conformidad con sus Procedimientos Normalizados de Trabajo y tomando en cuenta los requisitos éticos, metodológicos y legales exigibles a los estudios de investigación con seres humanos, sus muestras o registros, emite un **DICTAMEN FAVORABLE** al estudio propuesto y que se llevará a cabo en:

Centros	Investigadores principales
Universidade de Santiago (Facultade de Medicina e Odontoloxía) C.H. Universitario de A Coruña C.S. Fontiñas	María Mercedes Suárez Cunqueiro Francisco Javier de Toro Santos Juan Antonio Suárez Quintanilla

En Santiago de Compostela a 17 de septiembre de 2012
El Secretario

Juan M. Vázquez Lago



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MARIA DEL MAR YLLERA FERNÁNDEZ, PROFESORA TITULAR Y PRESIDENTA DEL COMITÉ DE
BIOÉTICA DE LA UNIVERSIDAD DE SANTIAGO DE COMPOSTELA,

INFORMA:

Que el estudio titulado: **“Caracterización de estructuras anatómicas y calidad ósea en imágenes maxilares de tomografía computerizada CONE BEAM”** y del que es Investigadora Principal Dña. **María Mercedes Suárez Cunqueiro**, ha sido examinado por el Comité de Bioética de esta Universidad, reunido el doce de febrero del presente año, cumpliendo en su protocolo experimental los requisitos exigidos.

Este estudio había recibido previamente el dictamen favorable del Comité Ético de Investigación Clínica de Galicia (código 2012/272).

Este documento no exime de la obtención de permisos o autorizaciones y el cumplimiento de otras normativas de aplicación.

Y para que así conste se expide el presente documento en Santiago de Compostela a veintiséis de febrero del año dos mil catorce.

Ms del Mar Yllera



APPENDIX 3- MANUSCRIPT PUBLISHED



International Journal of
Environmental Research
and Public Health



Article

Age Estimation Using Maxillary Central Incisor Analysis on Cone Beam Computed Tomography Human Images

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Abstract: Forensic dentistry plays an important role in human identification, and dental age estimation is an important part of the process. Secondary dentin deposition throughout an individual's lifetime and consequent modification in teeth anatomy is an important parameter for age estimation procedures. The aim of the present study was to develop regression equations to determine age in adults by means of linear measurements and ratios on sagittal, coronal and axial slices of maxillary central incisors using cone beam computed tomography (CBCT). Multiplanar measurements of upper central incisors were taken for a sample of 373 CBCTs. Subsequently, one-way analysis of variance (ANOVA) and multivariate linear regressions were performed for age estimation. The equations obtained from axial linear measurements and ratios presented a standard error of the estimate (SEE) of ± 10.9 years ($R^2 = 0.49$), and a SEE of ± 10.8 years ($R^2 = 0.50$), respectively. The equation obtained for multiplanar linear measurements presented a SEE of ± 10.9 years ($R^2 = 0.52$), while the equation for multiplanar ratios presented a SEE of ± 10.7 years ($R^2 = 0.51$). Thus, CBCT measurements on upper central incisors were found to be an acceptable method for age estimation. Horizontal measurements, especially pulp measurements, improve the accuracy of age estimate equations.

Keywords: dentistry; forensic; age estimation; cone beam computed tomography; CBCT

1. Introduction

Age estimation is an important aspect of forensic investigations and legal issues. Forensic techniques based on bone structures cease to be useful in the face of serious structural damage. However, seeing as they are very difficult to destroy, teeth are one of the main forensic tools for age estimation. Moreover, the literature suggests that dental indicators provide high accuracy for age estimation [1,2]. For these reasons, forensic dentistry is playing an increasingly relevant role. Laccasagne was the first to attempt age determination using dentition in 1889, and in 1925, Bodecker pointed out that certain morphological changes in teeth could be related to increased age [3,4]. Since then, a number of tooth characteristics have been used to determine age: (i) tooth wear, (ii) root dentin transparency, (iii) secondary dentin deposition, (iv) cementum annuli measurement, (v) Retzius striae count, (vi) aspartic acid racemization of dentin, (vii) radio carbon analysis, (viii) mineralization of third molars, and (ix)—with the development of 3D imaging techniques—pulp volume [5–12]. Methods based on biochemical and histological techniques which require



tooth extraction are difficult to apply, time consuming and very expensive when there are many specimens to identify. Dental imaging techniques such as cone beam computed tomography (CBCT) can overcome many of these drawbacks. In addition, the fact that they enable long-term record storage and easy portability make these imaging techniques an unavoidable, valuable adjunct to forensic investigations [13].

Secondary dentin deposition is an important parameter for age estimation because it continues throughout life [14], and it can be indirectly measured with non-destructive imaging techniques [2,15,16]. Over one's lifetime, secondary dentin deposition causes a decrease in the size of the pulp cavity. Based on this fact, various authors have estimated chronological age with imaging techniques [2,15,17]. Two-dimensional imaging systems are insufficient because they produce dimensional variations, are limited to mesiodistal dimensions, and analysis is hindered by factors such as malpositions and superpositions [13]. Thus, 3D imaging is essential for accurate forensic identification. Vanderwoort et al. were the first to apply 3D measurement methods to estimate age based on secondary dentin deposition [18]. Subsequent research analyzing linear measurements [19], areas [19–21] and volumes [11,18,22–30] have been performed using either micro-CT [22,31,32], CT [26,27], or CBCT [11,19–21,23–25,29,30]. Unlike previous research on the topic, the present study has included a much more thorough analysis involving multiple linear measurements and ratios in all three CBCT slices. We hypothesized that CBCT analysis of secondary dentin deposition by means of multiplanar linear measurements could yield convenient and useful methods for age estimation. The aim was to obtain regression equations for estimating age in adults through linear measurements and ratios on sagittal, coronal and axial slices of maxillary central incisors using CBCT.

2. Materials and Methods

2.1. Sample

A total of 373 randomly selected CBCTs were included in this cross-sectional study. The sample size was determined by means of the Slovin's formula. These CBCTs were performed from 2012 to 2017 for treatment planning of various oral surgical procedures in the Radiology Unit of the Medicine and Dentistry School at the Santiago de Compostela University.

2.2. Inclusion and Exclusion Criteria

The inclusion criteria were the following: (1) patients older than 18 years, (2) maxillary with at least one upper central incisor, and (3) CBCT with a 0.3 mm minimum voxel size image quality. The exclusion criteria were as follows: (1) CBCT images which were impossible to rotate, blurred or incomplete, (2) decay, restoration or endodontic treatment, (3) ceramic/metal crowns or orthodontic elements, and (4) calcified root canal or root resorption.

2.3. Ethics Statement

Written informed consent was obtained from all patients. In compliance with ethical, methodological and legal requirements, this study was approved by the Galician Ethics Committee of Clinical Research (Ref: 2012/272). The methods were performed in accordance with relevant guidelines and regulations.

2.4. Image Evaluation

CBCT was carried out using i-CAT® Model 17–19 (Imaging Sciences International Inc., Hatfield, PA, USA) with a flat-panel detector of amorphous silicon, an exposure protocol of 120 kVp and a current of 5 mA for 14.7 s. Patient occlusal plane was set parallel to the floor base by means of ear rods and a chin rest. DICOM files were reconstructed on computer (Samsung R522, Samsung Electronics, Seoul, Korea) using the 3D visualization software iCAT Vision® v. 1.9. CBCT slice thickness was set at 0.25 mm.

2.5. Standardized Incisor Measurement Protocol

Multiplanar measurements (sagittal, coronal and axial) were performed by researcher 1 as follows:

2.5.1. Sagittal Slice

- Sagittal measurements at cementoenamel junction level. Linear measurements were obtained in the “incisor neutral position” which was achieved by placing the horizontal red line of the CBCT program at the level of cementoenamel junction of the upper central incisor (Figure 1a): (a) tooth width: from the most palatine point to the most vestibular point of the incisor (sce_TW, Figure 1b); (b) pulp width: from the most palatine point to the most vestibular point of the pulp (sce_PW, Figure 1b).

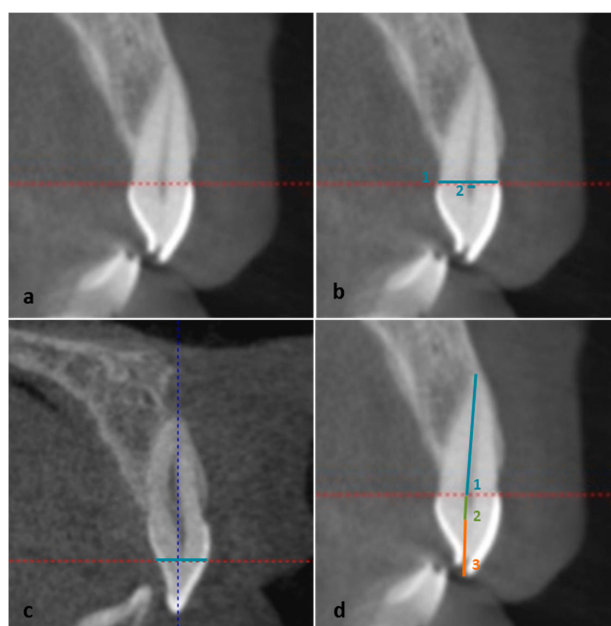


Figure 1. (a) Incisor in neutral position; (b) sagittal measurements at cementoenamel junction: (1) sagittal tooth width (sce_TW), (2) pulp width (sce_PW); (c) sagittal measurement at pulp horn: incisor crown width (sph_CW); and (d) sagittal vertical measurements: (1) root length: (s_RL), (2) pulp chamber length (s_PCL) and (3) incisal length: (s_IL).

- Sagittal measurement at pulp horn level. In order to locate this level, the red horizontal line was moved from the cementoenamel junction to the pulp horn. After the pulp horn level was located, the incisor crown width was measured (sph_CW, Figure 1c).
- Sagittal vertical measurements: (a) root length: from the apex to the cementoenamel junction following the curvature of the tooth (s_RL, Figure 1d); (b) pulp chamber length: from the cementoenamel junction to the end of the pulp at crown level (s_PCL) (c) incisal length: from the incisal edge to the beginning of the pulp chamber (s_IL); (d) total tooth length: the sum of (a), (b) and (c) (s_TTL, sum of values 4 to 8, Figure 1d).

2.5.2. Coronal Slice

- Coronal measurements at cementoenamel junction level: (a) mesiodistal tooth length: from the most mesial point to the most distal point of the incisor (cce_MDTL, sum of the values 1+2+3); (b) mesiodistal pulp length: from the most mesial point to the most distal point of the pulp (cce_MDPL, Figure 2a).

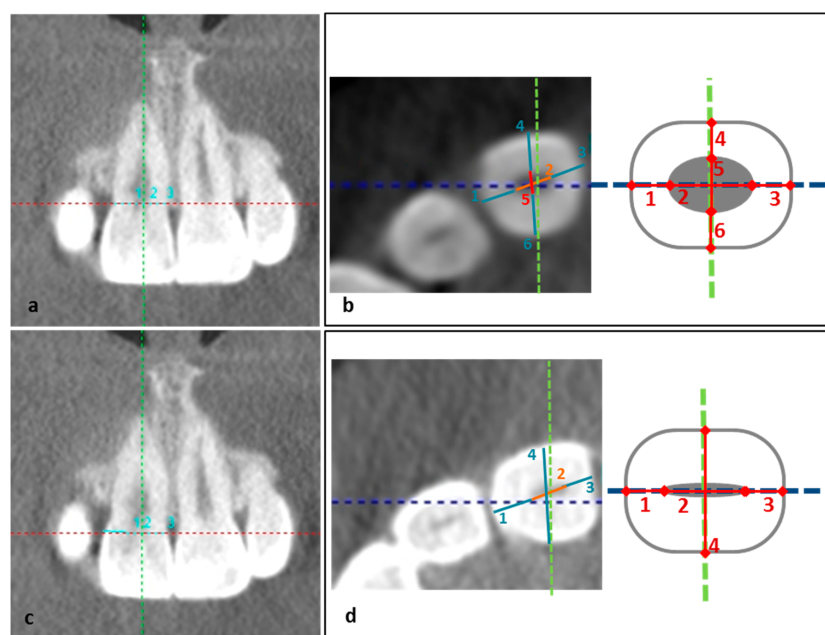


Figure 2. (a) Coronal measurements at cemento-enamel junction level: mesiodistal tooth length (cce_MDTL, sum of the values 1+2+3), mesiodistal pulp length (cce_MDPL, value 2); (b) axial measurements at cemento-enamel junction level: mesiodistal tooth length (ace_MDTL, sum of the values 1+2+3); (c) coronal measurements at pulp horn level: mesiodistal pulp length (cph_MDPL, value 2), palatovestibular tooth length (ace_PVTL, sum of values 4+5+6), palatovestibular pulp length (ace_PVPL, value 5) and (d) axial measurements at pulp horn level: mesiodistal tooth length (aph_MDTL, sum of the values 1+2+3), mesiodistal pulp length (aph_MDPL, value 2), palatovestibular tooth length (aph_PVTL, value 4).

- Coronal measurements at pulp horn level: (a) mesiodistal tooth length: from the most mesial point to the most distal point of the incisor (cph_MDTL, sum of the values 1+2+3, Figure 2c); (b) mesiodistal pulp length: from the most mesial point to the most distal point of the pulp (cph_MDPL, Figure 2c).

2.5.3. Axial Slice

- Axial measurements at cemento-enamel junction level: (a) mesiodistal tooth length: from the most mesial and central point to the most distal and central point (ace_MDTL, sum of the values 1+2+3, Figure 2b); (b) mesiodistal pulp length: from the most mesial point to the most distal point of the pulp (ace_MDPL, Figure 2b); (c) palatovestibular tooth length: from the most vestibular-central point of the tooth to the most palatine-central point of the incisor (ace_PVTL, sum of the values 4+5+6, Figure 2b); (d) palatovestibular pulp length: from the most vestibular point to the most palatine point of the pulp (ace_PVPL, Figure 2b).
- Axial measurements at pulp horn level: (a) mesiodistal tooth length: from the most mesial point to the most distal point of the incisor (aph_MDTL, sum of the values 1+2+3, Figure 2d); (b) mesiodistal pulp length: from the most mesial point to the most distal point of the pulp (aph_MDPL, Figure 2d); (c) palatovestibular tooth length; from the most palatine point to the most vestibular point of the incisor (aph_PVTL, Figure 2d).

Finally, for further analysis, ratios were calculated from the linear measurements obtained on the different slices and levels.

2.6. Intraobserver and Interobserver Variability

To check intraobserver variability, twenty randomly selected CBCTs were remeasured one month later by researcher 1. To check interobserver variability, researcher 3 measured the same twenty CBCTs and the results were compared with measurements made by researcher 1.

2.7. Statistical Analysis

Statistical analysis was performed using SPSS® v. 26.0 for Windows (IBM Corporation, Armond, NY, USA). Intraobserver and interobserver variability were assessed using intraclass correlation coefficient. Descriptive statistics were performed. The Kolmogorov–Smirnov test and the Levene test were applied to check for normality and the homogeneity distribution of the sample. One-way analysis of variance (ANOVA) with post hoc Bonferroni multiple comparison tests were used to compare linear measurements and ratios between age groups. Multivariate linear regression analyses were performed for age estimation based on sagittal, coronal and axial linear measurements and ratios. Statistical significance was set at $p \leq 0.05$.

3. Results

From the initial 373 CBCTs, a total of 360 satisfied the inclusion criteria. Regarding the exclusion criteria, twenty-eight CBCTs were excluded because images were impossible to rotate, blurred or incomplete; twelve CBCTs presented incisors with decay, restoration or endodontic treatment; ten CBCTs showed crowns or orthodontic treatments; and four presented calcified root canal or root resorption. A total of 306 CBCTs remained, of which 208 corresponded to males (67.97%) and 98 corresponded to females (32.03%). Mean age was 44.95 ± 15.74 years, ranging from 18 to 85. The age groups were as follows: 72 subjects (23.53%) were under 30 years of age, 61 (19.93%) between 31 and 40 years, 53 (17.32%) between 41 and 50 years, 65 (21.24%) between 51 and 60 years, and 55 (17.97%) were older than 60 years (Table 1). Intraobserver variability ranged between 0.478 and 0.887, and interobserver variability ranged between 0.403 and 0.865.

Table 1. Differences in sagittal linear measurements and ratios between age groups.

	Age Groups	Mean ¹	Min.	Max.	F	p *
sce_TW	≤30	7.26 ± 0.61 ^a	5.52	8.80	4.479	0.002 *
	31–40	7.24 ± 0.50 ^b	6.00	8.25		
	41–50	7.27 ± 0.44 ^c	6.00	8.25		
	51–60	7.11 ± 0.50	5.75	8.25		
	>60	6.93 ± 0.48 ^{a,b,c}	6.00	8.70		
	Total	7.17 ± 0.53	5.52	8.80		
sce_PW	≤30	1.78 ± 0.38 ^a	1.00	3.00	19.613	<0.001 *
	31–40	1.62 ± 0.38 ^b	1.00	3.30		
	41–50	1.67 ± 0.37 ^c	1.00	2.75		
	51–60	1.43 ± 0.30 ^{a,b,c}	0.50	2.00		
	>60	1.28 ± 0.30 ^{a,b,c}	0.75	2.00		
	Total	1.57 ± 0.39	0.50	3.30		
sph_CW	≤30	6.09 ± 0.94 ^a	4.50	8.75	12.335	<0.001 *
	31–40	6.49 ± 0.76 ^b	5.10	8.50		
	41–50	6.58 ± 0.83 ^a	4.75	8.10		
	51–60	6.92 ± 0.72 ^{a,b}	5.50	8.75		
	>60	6.94 ± 0.78 ^{a,b}	5.00	8.70		
	Total	6.58 ± 0.87	4.50	8.75		
s_RL	≤30	12.71 ± 1.75	8.54	16.64	1.607	0.172
	31–40	13.16 ± 2.09	6.00	17.44		
	41–50	13.22 ± 2.03	7.84	17.25		
	51–60	13.39 ± 1.33	10.03	16.61		
	>60	13.43 ± 2.10	7.51	18.06		
	Total	13.16 ± 1.87	6.00	18.06		

Table 1. Cont.

	Age Groups	Mean ¹	Min.	Max.	F	p *
s_PCL	≤30	3.87 ± 0.95 ^a	1.82	5.75	32.099	<0.001 *
	31–40	3.57 ± 0.85 ^b	1.27	5.41		
	41–50	3.25 ± 1.15 ^{a,c}	0.60	6.02		
	51–60	2.57 ± 1.02 ^{a,b,c}	0.90	6.50		
	>60	2.09 ± 1.06 ^{a,b,c}	0.25	5.75		
	Total	3.12 ± 1.19	0.25	6.50		
s_IL	≤30	6.26 ± 1.00	3.06	8.49	2.043	0.088
	31–40	6.55 ± 1.16	0.93	8.92		
	41–50	6.79 ± 1.37	3.75	10.61		
	51–60	6.78 ± 1.36	3.51	10.00		
	>60	6.75 ± 1.59	1.25	10.01		
	Total	6.61 ± 1.30	0.93	10.61		
s_TTL	≤30	22.90 ± 2.23	17.52	27.80	2.206	0.068
	31–40	23.28 ± 2.23	15.08	28.21		
	41–50	23.26 ± 2.37	15.84	27.71		
	51–60	22.70 ± 2.14	18.14	31.34		
	>60	22.20 ± 2.32	16.76	27.20		
	Total	22.87 ± 2.27	15.08	31.34		
sce_PW/sce_TW	<30	0.25 ± 0.05 ^a	0.14	0.41	16.439	<0.001 *
	31–40	0.22 ± 0.05 ^b	0.14	0.44		
	41–50	0.23 ± 0.05 ^c	0.14	0.33		
	51–60	0.20 ± 0.04 ^{a,c}	0.07	0.30		
	>60	0.19 ± 0.04 ^{a,b,c}	0.10	0.27		
	Total	0.22 ± 0.05	0.07	0.44		
s_IL/s_TTL	<30	0.27 ± 0.04 ^a	0.15	0.38	2.932	0.021 *
	31–40	0.28 ± 0.05	0.04	0.41		
	41–50	0.29 ± 0.06	0.18	0.46		
	51–60	0.30 ± 0.05	0.16	0.40		
	>60	0.31 ± 0.08 ^a	0.06	0.48		
	Total	0.29 ± 0.06	0.04	0.48		
s_PCL/s_TTL	<30	0.17 ± 0.04 ^a	0.08	0.25	29.477	<0.001 *
	31–40	0.15 ± 0.04 ^b	0.05	0.24		
	41–50	0.14 ± 0.05 ^{a,c}	0.03	0.26		
	51–60	0.11 ± 0.04 ^{a,b,c}	0.04	0.21		
	>60	0.10 ± 0.05 ^{a,b,c}	0.01	0.29		
	Total	0.14 ± 0.05	0.01	0.29		
s_RL/s_TTL	<30	0.56 ± 0.05 ^a	0.42	0.69	11.183	<0.001 *
	31–40	0.56 ± 0.05 ^b	0.40	0.79		
	41–50	0.57 ± 0.05 ^c	0.47	0.68		
	51–60	0.59 ± 0.04 ^{a,b}	0.49	0.72		
	>60	0.60 ± 0.05 ^{a,b,c}	0.45	0.75		
	Total	0.57 ± 0.05	0.40	0.79		
(s_PCL plus s_IL)/s_TTL	<30	4.15 ± 0.94 ^a	2.15	5.96	33.172	<0.001 *
	31–40	3.85 ± 0.83 ^b	1.62	5.63		
	41–50	3.54 ± 1.10 ^{a,c}	1.06	6.20		
	51–60	2.87 ± 0.98 ^{a,b,c}	1.29	6.81		
	>60	2.40 ± 1.01 ^{a,b,c}	0.57	5.81		
	Total	3.40 ± 1.16	0.57	6.81		

¹ Values expressed as mean ± SD; * ANOVA test; ^{a,b,c} Bonferroni post hoc test (paired letters showed statistical significance). Sce_TW: tooth width at cemento-enamel junction level, sce_PW: pulp width at cemento-enamel junction level, sph_CW: incisor crown at pulp horn level, s_RL: root length, s_PCL: pulp chamber length, s_IL: incisal length, s_TTL: total tooth length.

3.1. Sagittal Linear Measurements and Ratios

All sagittal horizontal measurements (sce_TW, sce_PW, and sph_CW), and chamber length (s_PCL) showed statistically significant differences between age groups ($p \leq 0.050$). sce_TW, sce_PW, and s_PCL decreased while sph_CW increased with age (Table 1).

All ratios showed statistically significant differences between age groups ($p \leq 0.050$). s_IL/s_TTL and s_RL/s_TTL increased, while s_PCL/s_TTL, s_PCL plus s_IL/s_TTL and sce_PW/sce_TW decreased with age (Table 1).

3.2. Coronal Linear Measurements and Ratios

Mesiodistal pulp length at cementoenamel junction level (cce_MDPL) and all the mesiodistal measurements at pulp horn level (cph_MDTL and cph_MDPL) showed statistically significant differences between age groups ($p \leq 0.050$). All these measurements decreased with age (Table 2).

Table 2. Differences in coronal linear measurements and ratios between age groups.

	Age Groups	Mean ¹	Min.	Max.	F	p *
cce_MDTL	≤30	6.37 ± 0.68	4.75	7.80	1.218	0.303
	31–40	6.36 ± 0.61	4.50	7.50		
	41–50	6.47 ± 0.49	5.50	7.50		
	51–60	6.40 ± 0.56	5.10	7.80		
	>60	6.23 ± 0.51	5.00	7.20		
	Total	6.36 ± 0.58	4.50	7.80		
cce_MDPL	≤30	1.97 ± 0.36 ^a	1.50	2.80	15.110	<0.001 *
	31–40	1.98 ± 0.44 ^b	1.20	3.00		
	41–50	1.95 ± 0.39 ^c	1.00	3.00		
	51–60	1.75 ± 0.36 ^{a,b,c,d}	1.00	2.80		
	>60	1.54 ± 0.30 ^{a,b,c,d}	0.75	2.40		
	Total	1.85 ± 0.41	0.75	3.00		
cph_MDTL	≤30	8.06 ± 0.72 ^a	6.00	9.50	21.773	<0.001 *
	31–40	7.81 ± 0.73 ^b	6.25	9.60		
	41–50	7.74 ± 0.95 ^c	4.50	10.25		
	51–60	7.26 ± 0.77 ^{a,b,c}	6.00	9.00		
	>60	6.89 ± 0.78 ^{a,b,c}	5.25	8.75		
	Total	7.57 ± 0.89	4.50	10.25		
cph_MDPL	≤30	2.43 ± 0.56 ^a	1.50	3.60	33.935	<0.001 *
	31–40	2.26 ± 0.52 ^b	1.50	3.75		
	41–50	2.18 ± 0.44 ^{a,c}	1.25	3.50		
	51–60	1.82 ± 0.48 ^{a,b,c,d}	0.75	3.25		
	>60	1.49 ± 0.41 ^{a,b,c,d}	0.75	2.50		
	Total	2.07 ± 0.59	0.75	3.75		
cce_MDPL/cce_MDTL	<30	0.31 ± 0.04 ^a	0.23	0.42	16.38	<0.001 *
	31–40	0.31 ± 0.06 ^b	0.19	0.43		
	41–50	0.30 ± 0.05 ^c	0.18	0.46		
	51–60	0.27 ± 0.06 ^{a,b,d}	0.14	0.44		
	>60	0.25 ± 0.05 ^{a,b,c,d}	0.13	0.33		
	Total	0.29 ± 0.06	0.13	0.46		
cph_MDPL/cph_MDTL	<30	0.30 ± 0.06 ^a	0.17	0.42	18.30	<0.001 *
	31–40	0.29 ± 0.06 ^b	0.19	0.43		
	41–50	0.29 ± 0.06 ^c	0.15	0.44		
	51–60	0.25 ± 0.07 ^{a,b,d}	0.11	0.48		
	>60	0.22 ± 0.06 ^{a,b,c,d}	0.11	0.33		
	Total	0.27 ± 0.07	0.11	0.48		

¹ Values expressed as mean ± SD, * ANOVA test; ^{a,b,c,d} Bonferroni post hoc test (paired letters showed statistical significance). Cce_MDTL: mesiodistal tooth length, cce_MDPL: mesiodistal pulp length at cementoenamel junction level, cph_MDTL: mesiodistal tooth length at pulp horn level, cph_MDPL: mesiodistal pulp length at pulp horn level.

The two mesiodistal coronal ratios (cce_MDPL/cce_MDTL and cph_MDPL/cph_MDTL) showed statistically significant differences between age groups ($p \leq 0.050$). These measurements also decreased with age (Table 2).

3.3. Axial Linear Measurements and Ratios

Three axial mesiodistal measurements (ace_MDPL, aph_MDTL, and aph_MDPL) and all palatovestibular measurements (ace_PVTL, ace_PVPL, and aph_PVTL) showed

statistically significant differences between age groups ($p \leq 0.050$). These measurements decreased with age (Table 3).

Table 3. Differences in axial linear measurements and ratios between age groups.

	Age Groups	Mean ¹	Min.	Max.	F	p *
ace_MDTL	≤30	6.57 ± 0.63	4.82	7.90	1.246	0.292
	31–40	6.55 ± 0.66	4.44	8.14		
	41–50	6.72 ± 0.62	5.39	8.25		
	51–60	6.59 ± 0.54	5.44	8.12		
	>60	6.47 ± 0.58	5.19	7.95		
	Total	6.58 ± 0.61	4.44	8.25		
ace_MDPL	≤30	2.21 ± 0.45 ^a	1.25	3.22	10.695	<0.001 *
	31–40	2.23 ± 0.49 ^b	1.25	3.35		
	41–50	2.23 ± 0.51 ^c	1.00	3.25		
	51–60	2.02 ± 0.51 ^d	0.75	3.30		
	>60	1.75 ± 0.44 ^{a,b,c,d}	0.79	2.85		
	Total	2.10 ± 0.51	0.75	3.35		
ace_PVTL	≤30	7.59 ± 0.60 ^a	6.25	9.20	3.180	0.014 *
	31–40	7.50 ± 0.46	6.60	8.71		
	41–50	7.58 ± 0.53	6.50	9.51		
	51–60	7.39 ± 0.52	6.25	8.51		
	>60	7.30 ± 0.54 ^a	6.25	8.70		
	Total	7.48 ± 0.54	6.25	9.51		
ace_PVPL	≤30	1.90 ± 0.36 ^a	1.00	3.25	16.819	<0.001 *
	31–40	1.78 ± 0.32 ^b	1.00	2.72		
	41–50	1.71 ± 0.33 ^c	1.25	2.50		
	51–60	1.61 ± 0.29 ^{a,b}	1.00	2.40		
	>60	1.44 ± 0.34 ^{a,b,c}	0.75	2.25		
	Total	1.70 ± 0.36	0.75	3.25		
aph_MDTL	≤30	8.24 ± 0.64 ^a	6.72	9.70	23.602	<0.001 *
	31–40	7.94 ± 0.72 ^b	6.18	9.19		
	41–50	7.85 ± 0.86 ^{a,c}	6.02	10.36		
	51–60	7.43 ± 0.71 ^{a,b,c}	5.95	8.83		
	>60	7.09 ± 0.74 ^{a,b,c}	5.70	8.48		
	Total	7.73 ± 0.83	5.70	10.36		
aph_MDPL	≤30	3.02 ± 0.56 ^a	2.00	4.32	50.491	<0.001 *
	31–40	2.70 ± 0.67 ^{a,b}	1.20	3.91		
	41–50	2.28 ± 0.61 ^{a,b,c}	0.75	3.40		
	51–60	1.99 ± 0.67 ^{a,b,d}	0.50	3.40		
	>60	1.61 ± 0.49 ^{a,b,c,d}	0.50	2.75		
	Total	2.37 ± 0.79	0.50	4.32		
aph_PVTL	≤30	5.85 ± 1.03 ^a	4.00	9.20	14.437	<0.001 *
	31–40	6.25 ± 0.80 ^b	4.50	7.81		
	41–50	6.39 ± 1.01 ^{a,c}	3.00	8.00		
	51–60	6.78 ± 0.75 ^{a,b}	5.25	9.01		
	>60	6.88 ± 0.78 ^{a,b,c}	4.76	8.50		
	Total	6.41 ± 0.96	3.00	9.20		
ace_MDPL/ace_MDTL	<30	0.34 ± 0.05 ^a	0.19	0.42	12.269	<0.001 *
	31–40	0.34 ± 0.06 ^b	0.25	0.49		
	41–50	0.33 ± 0.06 ^c	0.15	0.44		
	51–60	0.31 ± 0.07 ^{b,d}	0.10	0.44		
	>60	0.27 ± 0.06 ^{a,b,c,d}	0.12	0.43		
	Total	0.32 ± 0.07	0.10	0.49		
ace_PVPL/ace_PVTL	<30	0.25 ± 0.05 ^a	0.15	0.48	13.323	<0.001 *
	31–40	0.24 ± 0.04 ^b	0.14	0.36		
	41–50	0.23 ± 0.04 ^a	0.16	0.33		
	51–60	0.22 ± 0.04 ^a	0.13	0.30		
	>60	0.20 ± 0.04 ^{a,b,c}	0.10	0.29		
	Total	0.23 ± 0.05	0.10	0.48		
ace_PVPL/ace_MDTL	<30	0.29 ± 0.07 ^a	0.14	0.60	12.464	<0.001 *
	31–40	0.27 ± 0.05 ^b	0.13	0.42		
	41–50	0.26 ± 0.05 ^{a,c}	0.16	0.39		
	51–60	0.25 ± 0.05 ^a	0.13	0.38		
	>60	0.23 ± 0.06 ^{a,b,c}	0.13	0.37		
	Total	0.26 ± 0.06	0.13	0.60		
aph_MDPL/aph_MDTL	<30	0.37 ± 0.06 ^a	0.23	0.48	37.342	<0.001 *
	31–40	0.34 ± 0.07 ^b	0.16	0.48		
	41–50	0.29 ± 0.07 ^{a,b,c}	0.09	0.41		
	51–60	0.27 ± 0.08 ^{a,b,d}	0.07	0.42		
	>60	0.23 ± 0.06 ^{a,b,c,d}	0.08	0.36		
	Total	0.30 ± 0.09	0.07	0.48		

Table 3. Cont.

	Age Groups	Mean ¹	Min.	Max.	F	p *
aph_PVTL/aph_MDTL	<30	0.71 ± 0.13 ^a	0.48	1.05	33.246	<0.001 *
	31–40	0.80 ± 0.15 ^{a,b}	0.52	1.25		
	41–50	0.83 ± 0.16 ^{a,c}	0.30	1.20		
	51–60	0.92 ± 0.14 ^{a,b,c}	0.59	1.26		
	>60	0.98 ± 0.15 ^{a,b,c}	0.60	1.26		
	Total	0.84 ± 0.17	0.30	1.26		

¹ Values expressed as mean ± SD, * ANOVA test; ^{a,b,c,d} Bonferroni post hoc test (paired letters showed statistical significance). Ace_MDTL: mesiodistal tooth length at cemento-enamel junction level, ace_MDPL: mesiodistal pulp length at cemento-enamel junction level, ace_PVTL: palatovestibular tooth length at cemento-enamel junction level, ace_PVPL: palatovestibular pulp length at cemento-enamel junction level, aph_MDTL: mesiodistal tooth length at pulp horn level, aph_MDPL: mesiodistal pulp length at pulp horn level, aph_PVTL: palatovestibular tooth length at pulp horn level.

All ratios showed statistically significant differences between the different age groups ($p \leq 0.050$). ace_MDPL/ace_MDTL, ace_PVPL/ace_PVTL, ace_PVPL/ace_MDTL, and aph_MDPL/aph_MDTL decreased, while aph_PVTL/aph_MDTL increased with age (Table 3).

3.4. Age Estimation Based on Multiplanar Measurements and Ratios

Multiple linear regressions based on sagittal, coronal and axial linear measurements and ratios were independently performed. The equations obtained from sagittal linear measurements and ratios presented a standard error of the estimate (SEE) of ± 12.4 years ($R^2 = 0.36$), and a SEE of ± 12.4 years ($R^2 = 0.37$), respectively. The equations obtained from coronal linear measurements and ratios presented a SEE of ± 12.3 years ($R^2 = 0.37$), and a SEE of ± 13.7 years ($R^2 = 0.22$), respectively. The equations obtained from axial linear measurements and ratios presented a SEE of ± 10.9 years ($R^2 = 0.49$), and a SEE of ± 10.8 years ($R^2 = 0.50$), respectively (Table 4).

Table 4. Multiple linear regression models for age estimation based on upper central incisors.

	Adjusted R ²	SEE ¹ (±year)	p *
SAGITTAL			
Linear measurements			
Age = 68.050 – 5.828 s_PCL – 11.509 sce_PW + 0.987 s_RL	0.364	12.495	0.011 *
Ratios			
Age = 55.463 – 5.685 $\frac{s_PCL \text{ plus } s_IL}{s_TTL}$ – 80.909 $\frac{sce_PW}{sce_TW}$ + 46.024 $\frac{s_RL}{s_TTL}$	0.372	12.417	0.003 *
CORONAL			
Linear measurements			
Age = 75.844 – 8.630 cph_MDPL – 5.863 cph_MDTL + 6.953 cce_MDTL – 7.250 cce_MDPL	0.373	12.320	0.001 *
Ratios			
Age = 86.030 – 72.205 $\frac{cph_MDPL}{cph_MDTL}$ – 75.696 $\frac{cce_MDPL}{cce_MDTL}$	0.225	13.701	0.000 *
AXIAL			
Linear measurements			
Age = 72.963 – 10.084 aph_MDPL – 12.017 ace_PVPL + 2.477 aph_PVTL	0.498	10.957	0.001 *
Ratios			
Age = 68.762 – 68.668 $\frac{aph_MDPL}{aph_MDTL}$ + 26.912 $\frac{aph_PVTL}{aph_MDTL}$ – 61.559 $\frac{ace_PVPL}{ace_MDTL}$ – 31.265 $\frac{ace_MDPL}{ace_MDTL}$	0.509	10.839	0.003 *
MULTIPLANAR MEASUREMENTS (homonyms excluded)			
Linear measurements			
Age = 80.608 – 9.197 aph_MDPL – 10.310 ace_PVPL – 2.765 s_PCL + 0.901 s_RL	0.520	10.717	0.000 *
Ratios			
Age = 107.129 – 69.226 $\frac{aph_MDPL}{aph_MDTL}$ – 4.195 $\frac{s_PCL \text{ plus } s_IL}{s_TTL}$ – 73.910 $\frac{ace_PVPL}{ace_PVTL}$ – 32.828 $\frac{ace_MDPL}{ace_MDTL}$	0.517	10.757	0.000 *

¹ Standard error of estimate, * Multivariate linear regression analysis. Sce_TW: tooth width at cemento-enamel junction level, sce_PW: pulp width at cemento-enamel junction level, s_RL: root length, s_PCL: pulp chamber length, s_TTL: total tooth length, cce_MDTL: mesiodistal tooth length, cce_MDPL: mesiodistal pulp length at cemento-enamel junction level, cph_MDTL: mesiodistal tooth length at pulp horn level, cph_MDPL: mesiodistal pulp length at pulp horn level, ace_MDTL: mesiodistal tooth length at cemento-enamel junction level, ace_MDPL: mesiodistal pulp length at cemento-enamel junction level, ace_PVTL: palatovestibular tooth length at cemento-enamel junction level, ace_PVPL: palatovestibular pulp length at cemento-enamel junction level, aph_MDTL: mesiodistal tooth length at pulp horn level, aph_MDPL: mesiodistal pulp length at pulp horn level, aph_PVTL: palatovestibular tooth length at pulp horn level.

Multiple linear regressions considering all the linear measurements and ratios, excluding homonym variables in different slices, were independently performed. The equation obtained from linear measurements presented a SEE of ± 10.9 years ($R^2 = 0.52$), and the equation from ratios presented a SEE of ± 10.7 years ($R^2 = 0.51$), (Table 4).

4. Discussion

The present study has identified CBCT linear variables which are clinically and statistically acceptable for making age estimation equations for forensic purposes. These equations were derived after 3D analysis of upper central incisors. The most predictable equations were mainly built on axial measurements and ratios. Our findings reveal that horizontal dimensions, mainly pulp dimensions, allow for more accurate age estimation.

Various methods have been employed to indirectly quantify secondary dentin deposition. Early methods using 2D imaging techniques include the Kvaal et al. method [2], the Ikeda et al. tooth coronal index [17], and the Cameriere et al. pulp to tooth area ratio [15]. With respect to 3D radiology, micro-CT is the gold standard in terms of measurement accuracy because it provides higher spatial resolution and, thus, precise segmentation of dental structures [29]. However, micro-CT presents certain drawbacks. It can only be applied on a single tooth in postmortem specimens and image acquisition is time consuming [18]. Conversely, CBCT can be used in multiple teeth in vivo, is less expensive and minimizes radiation exposure [33]. Therefore, CBCT is widely used in dentistry, enabling 3D information on living individuals to be easily acquired.

Starting with Yang et al. [28], various authors have used CBCT for age estimation and reported a wide range of accuracy [19–21,24,28,34–38]. While some authors report a low capacity for age estimation [11,28,34,36,39,40], others report equations with good R^2 and SEE values [19,20,37,38], showing that CBCT can be as useful as CT [26,41–44], or micro-CT [18,22,31,32]. Various methods involving ratios of dental linear measurements have been employed on CBCT for age estimation, e.g., Kwaal's method [45,46], Cameriere's pulp tooth area ratio [19,20,37,43], pulp to tooth volume ratio [31,47–50], pulp volume [11,38], and chamber volume [29,30,51,52]. The equations obtained in the present study using linear measurements and ratios yield acceptable R^2 and SEE values. Regression equations in the literature yield R^2 values ranging from 0.15 to 0.91 [11,19–21,24,28–30,37–39,42] and SEE values ranging from 4.2 to 11.45 years [20,28–30,35,37,38]. Apart from differences in measurement method, variability is also due to differences in tooth type. Good age estimation has been reported using CBCT for different teeth such as maxillary canines [19,20,38,42,44], mandibular canines [42,44], maxillary lateral incisors [49], maxillary second premolars [45], maxillary and mandibular first molars [29,53], and maxillary and mandibular second molars [51]. However, most research has been based on uniradicular teeth [11,19–21,23–25,28,35,37,38], specifically upper central incisors [35–38,54–56] and canines [11,19–21,25,34,41–43,47]. We have chosen to use the upper central incisor because its pulp has a simple anatomy, considerable size, and few anatomic variations, making it easier to measure than posterior teeth [2]. Secondary dentinal deposition is harder to analyze in teeth with smaller pulp dimensions such as mandibular incisors [15,23–25,27]. Another reason for analyzing upper central incisors was that they are one of the most frequent remanent teeth in older patients [2]. Most CBCT research comparing tooth groups found the highest correlation with age for maxillary central incisors [23,24,37,38,46,48,54,57]. As compared to volume methods, the present research based on incisor linear measurements yielded an R^2 within the previously observed range [35,56], and a slightly higher SEE [30,37]. However, our method is easier and less time consuming than certain volumetric methods (pulp/tooth volume and pulp/crown volume) that may take from 30 min to several hours [55]. Furthermore, our equations are less complex than those involving several teeth and measurements, while yielding similar R^2 and SEE values [46].

Our results are in line with previous research that successfully used root canal diameter as an indirect quantification method for secondary dentin deposition [31]. A number of authors have reported that dentinal thickness increased with age more along the pulp walls

than along the pulp roof [58,59], and our findings concur. Some authors have found that pulp cavity height significantly correlated with chronological age on 2D imaging [2,60], however, the present study found horizontal measurements to have better R^2 and SEE values than vertical measurements. Our results were consistent with the vast majority of CBCT research [37,45,46,61], except for Lee et al. [20]. Thus, we determined that horizontal dimensions are more accurate for age estimation.

The fact that vertical measurements are scarcely useful for age estimation may be due to the confounding effect of external factors such as attrition, occlusion type, or behavioral habits. Our results support the idea that attrition is not sufficiently related to age to be used for age estimation, which is in line with other authors [2]. Previous reports have already described that attrition bears stronger relation to diet and habits [62], and, thus, the low harshness of the current diet may explain the lack of association with age.

Apart from secondary dentin deposition, pulp cavity dimensions may also be modified by other local and systemic factors, such as tertiary dentin deposition at the chamber roof due to decay or to restorations [6]. To avoid this problem, we have used only sound teeth following Kvaal's instructions [2].

Some authors have argued that pulp dimensions may be influenced by other factors such as race, nutritional and hormonal changes and certain systemic diseases [63]. The inclusion of patients without analyzing their clinical histories could be considered a shortcoming of the present study. However, this is not the case because our aim was not to analyze the influence of systemic diseases on secondary dentin deposition but to find an equation for age estimation in the general population. Furthermore, secondary dentin deposition is considered to vary by tooth type, sex and population [2,59]. This is one of the reasons why regression-specific equations are necessary to validate age estimation methods in different populations [64–67]. Although Cameriere et al. [68] were able to adequately determine age for both Italian and Portuguese samples with the same regression equation, specific equations may well yield different age estimates for different populations [25,65]. Thus, future research should consider evaluating our method in other populations.

Forensic dentistry is constantly searching for the ideal age estimation method. Each method presents strengths and weaknesses. Therefore, in order to maximize age estimation accuracy, it may be advisable to apply more than one method and to repeat measurements [2,23,30,42,69]. It may also be advisable to include multiple tooth types [69], which may be seen as a limitation of the present study focusing only on upper central incisors. Nevertheless, there is disagreement among authors regarding multicollinearity problems when using multiple tooth types in a single model [11,69].

5. Conclusions

The present study shows that CBCT linear measurements on upper central incisors are an acceptable method for age estimation. Horizontal measurements, mainly pulp measurements, are preferable for improving accuracy. Although CBCT has become an important tool for forensic dentistry, future research should determine whether combining several CBCT age estimation methods could improve results. Automatic software development is likely to make integrating measurement methods faster and more efficient.

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The aim of this research was to obtain regression equations for estimating age and gender determination in three slices of maxillary central incisors and molars using CBCT. Material and Methods. A total of 360 randomly selected CBCTs were included in this cross-sectional study. The sample size was determined by means of the Slovin's formula. Results. The equations obtained from sagittal linear measurements and ratios presented a standard error of the estimate (SEE) of 12.4 years. The binary logistic regression models for predicting gender indicated that ace_MDTL demonstrates a significant positive effect on predicting male gender. Conclusion. The present study shows that CBCT linear measurements on upper central incisors and upper first molar are an acceptable method for age and gender estimation.