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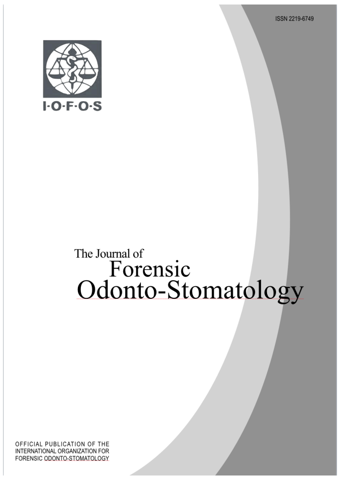

THE JOURNAL OF FORENSIC ODONTO-STOMATOLOGY

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CONTENTS

The role of orthodontics in children identification: a case report of two victims of mass disaster

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KEYWORDS

Mass disaster,
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ABSTRACT

Introduction: Human Identification based on dental evidence cannot be accomplished if antemortem dental records are unavailable or of poor quality. The involvement of the orthodontist in mass disaster victim identification processes may be crucial in relation to the amount and quality of the records which can be obtained before, during, and following the treatment.
Aim: The aim of the study is the description of the contribution of the findings drawn from orthodontic records to the identification of victims of mass disasters who had received an orthodontic treatment, through the presentation of two cases. The first case involves the identification of a child victim of a plane crash and the second case involves the identification of two identical twin girls who died in a fire. In both cases, the identification was based on the findings obtained from the ante-mortem records provided by the orthodontist.
Conclusions: The orthodontists apply customized orthodontic appliances and keep a comprehensive file of images, casts, radiographs, and other records in their practice. As a result, they can make a substantial contribution to the identification of young people or even adult victims of mass disasters in any case in which the authorities make a request.

INTRODUCTION

In recent decades mass disasters became a common global issue of concern. A mass disaster or a mass fatality incident, is an event in which there is a critical relationship between the number of casualties and resources, both human and material, available at the occurrence site, usually unpredictable and abrupt.[1] Environmental (such as tornadoes, hurricanes, earthquakes), transportation, industrial events, or terrorist acts, might all result in mass fatalities .[2]
Depending on the location of the occurrence and the country/countries of origin of the victims, the disaster might be characterized as local, national, or international.[2-4] Mass catastrophes can also be classified as "closed" (an aircraft-related accident) or "open" (an earthquake), based on whether the number of victims and those involved are known details.[2, 5-7]
Human identification is the process to recognize an individual as a unique being. Forensic odontology is the branch of dentistry applied in criminal and civil law cases. The participation of forensic odontology in the human identification

process is fundamental when human remains are found, since the dental arches have particularities that make such a process possible.[8] According to the International Criminal Police Organization (Interpol), given the individuality of the teeth and other anatomical structures of the dentomaxillofacial region, forensic odontology is one of the three primary human identifiers. These are classified as primary or secondary according to their ability to achieve an accurate identification. Primary methods include dental analysis, fingerprinting, and DNA analysis. Considering the accuracy and reliability provided to the process, these are the methods of choice in cases of human identification ('https://www.interpol.int/en/How-we-work/Forensics/Disaster-Victim-Identification-DVI'), equally reliable, trustworthy.[9,10] The dental evidence is reliable thanks to the uniqueness and stability of the dental tissues and treatments and includes dental records, study models, photographs, X-rays.[11-13]

However, for a successful comparison process of ante-mortem and post-mortem dental evidence, it is imperative to overcome several difficulties.[14] The most frequent challenge is when incomplete, ambiguous, or incorrectly documented ante-mortem dental records are avalilable.[14] Other obstacles that may influence the identification procedures are the administrative and collaborative issues with foreign authorities about the collection of the ante-mortem data.[15]

Although the DNA evidence is a powerful tool in identification cases and especially in mass disasters victims identification, there are various limitations to be considered.[16]

Orthodontics is the dental speciality in charge of establishing a functional and aesthetic harmony to the face. Since the treatment lasts a long time and its planning is complicated, the orthodontist takes several records in the pre-treatment, treatment and post treatment phese. Mostly the records consist of patient's history, dental models, extra oral and intraoral photographs, and X-rays (at least an Orthopantomogram and a lateral Cephalogram). All these data taken from the orthodontic records can help in the identification of a patient.[17] Dental evidence is a reliable tool thank to the uniqueness and stability of the dental tissues and treatments.[11]

Two mass disaster cases are presented in this study; the first case can be characterized as closed and international and the second case as open and national. The cases show the valuable contribution of orthodontics in the identification of children when casualties of mass fatality events.

CASE I

On August 14, 2005, a Boeing 737-300 plane crashed in a mountainous area of Attica, Greece. The plane took-off from Larnaca airport with final destination Prague, Czech Republic, and stop over in Athens airport, Greece. While approaching Athens airport the plane lost communication with the air traffic control center and soon crashed. All the people on board, 115 passengers (adults and children) and 6 crew members, lost their lives.

Depending on each victim's individual situation, all primary human identification techniques (fingerprinting, DNA, and dental evidence) were used since it was impossible to identify the victims visually. Whenever possible, multiple identification techniques were used in each case.

Post-mortem data:

Both jaws were available for examination. Post-mortem dental examination and charting were completed. The child was undergoing orthodontic treatment, as evidenced by the post-mortem data of his corpse, which demonstrated that fixed orthodontic appliances had been fitted in his maxilla.

In particular, the first upper premolars were missing bilaterally, the first upper permanent molars had orthodontic stainless-steel rings (bands), in which a trans-palatal arch was fixed. Both the upper permanent canines, lateral and central incisors had been erupted and had metallic brackets, with hooks on the canines. Also, the second permanent molars were erupted bilaterally (Fig.1).

In the mandible, the first premolars were missing bilaterally, the first permanent molars had orthodontic rings and all the rest of the permanent teeth had brackets. Moreover, the second permanent molars were erupted bilaterally. Supplementary to the clinical examination, post-mortem photographs were taken (Fig.1). Age estimation based on tooth eruption was between 12.5 and 16.5.

Ante-mortem data:

Among the victims' postmortem dental records obtained by the police there was the orthodontic record of a male child. The record included notes, a panoramic radiograph taken before the orthodontic treatment,1 extraoral photograph, 3 intraoral photographs, and a set of orthodontic models (Fig. 2,3,4,5). The ante-mortem data were collected and charted. The study of the ante-mortem records revealed that the boy had orthodontic stainless-steel rings (bands) in his maxillary first molars in which a trans-palatal arch was fixed, all teeth (from # 15 to # 25) had metallic brackets with hooks on the canines.

Comparison of post-mortem and ante-mortem dental evidence.

The little youngster was positively recognized based on the similarities found from the analysis of the dental records' ante-mortem and post-mortem data. Specifically, there was no difference between the extracted teeth found in the ante-mortem and post-mortem dental records. In both the antemortem and postmortem reports, the fixed trans-palatal arch was precisely the same. And both the dental records, antemortem and postmortem, showed the metal brackets with hooks on the canines.

Figure 1. Post-mortem photographs from both jaws which were available for examination. a) A stainless steel trans-palatal arch was fixed on the palate. b) Fixed orthodontic appliances were placed on the maxilla, first premolars bilaterally were not present, first permanent molars had orthodontic stainless-steel rings (bands). Both permanent canines, lateral and central incisors had erupted and had metallic brackets, with hooks on the canines. c) Right lateral view of the maxilla and mandible, d) Left lateral view of the maxilla and mandible, second permanent molars had erupted bilaterally.

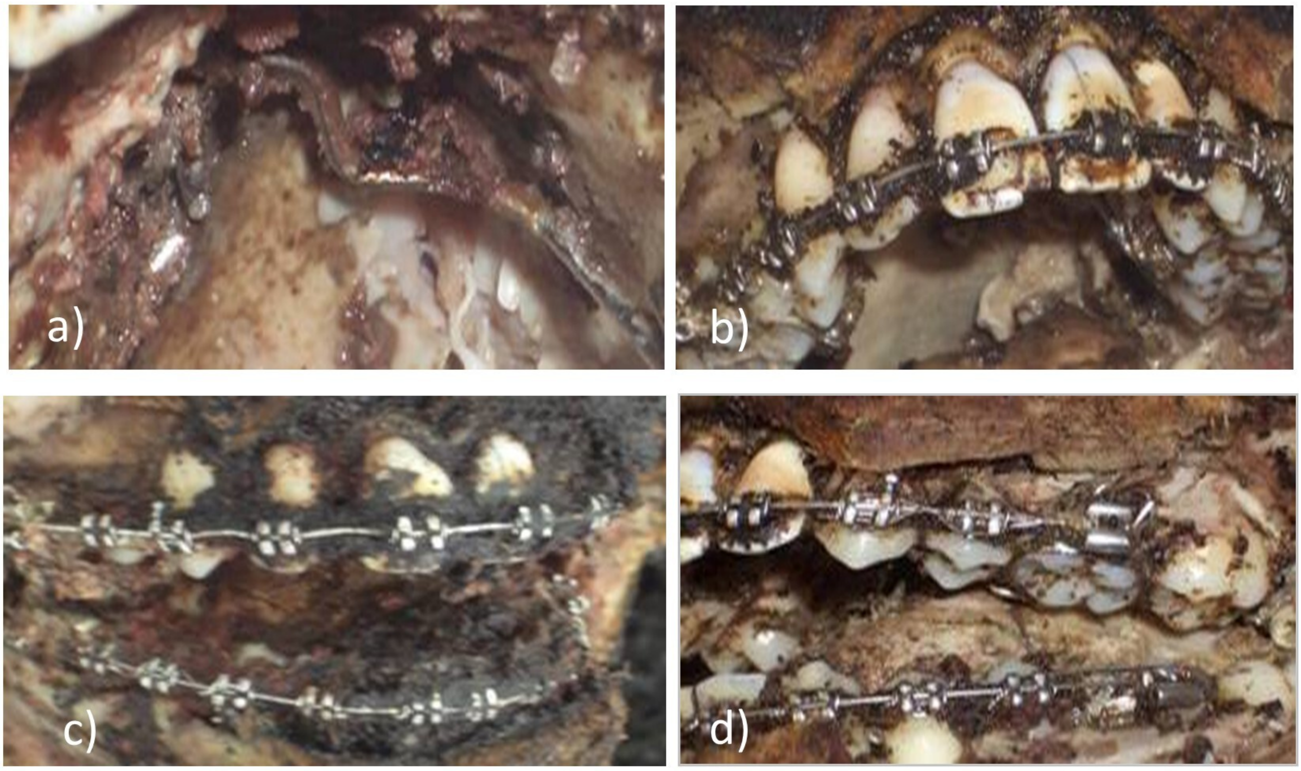

Figure 2. A panoramic radiograph taken by the orthodontist before the orthodontic treatment started

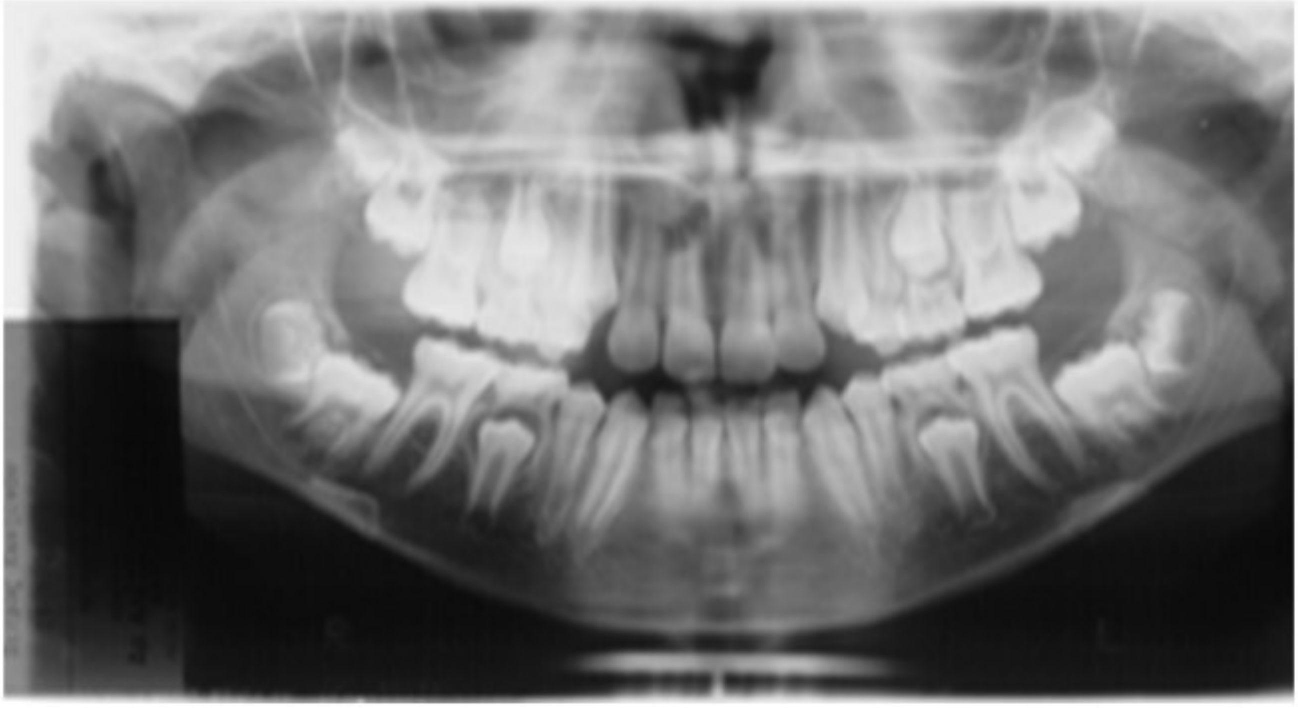

Figure 3. Extraoral photograph taken by the orthodontist. Face frontal lips relaxed

Figure 4. Intra-oral photographs taken by the orthodontist before treatment. a) Frontal in occlusion. b) Upper occlusal a stainless steel trans-palatal arch fixed on the palate. c) Lower occlusal

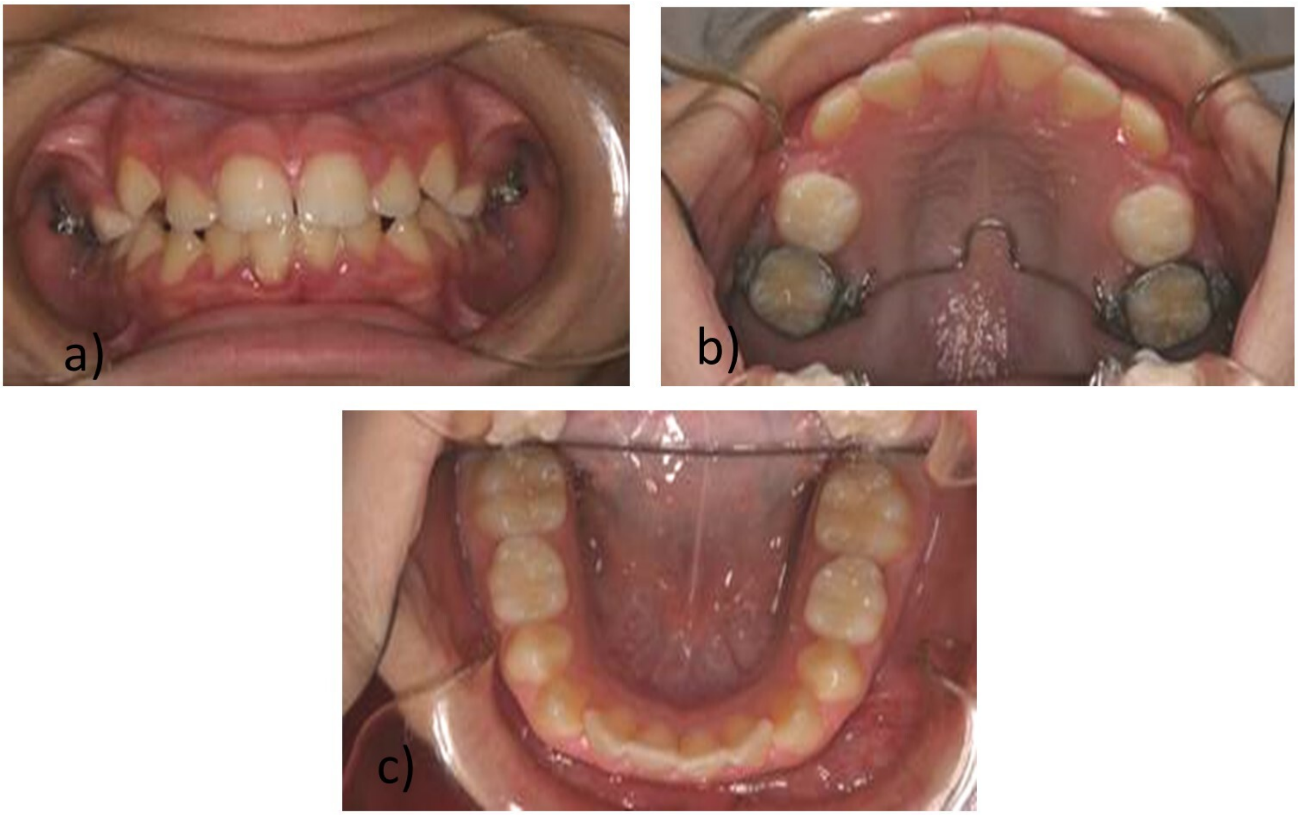

Figure 5. Orthodontic plaster models

CASE II

Two homozygous twin girls were among the 102 people that died in a fire which broke out in a village in Attica in July 2018. Visual identification was impossible. Moreover, the identification of the children's corpses could not be based on the DNA analysis process since the individuals were homozygous twins and shared exactly the same DNA.Therefore, the only suitable process to establish the identity of the victims was the evaluation of dental evidence.

Post-mortem data:

The maxilla and the mandible were available for post-mortem examination in both cases. The children were both in the phase of mixed dentition (Fig. 6).

In the maxilla of both children, the first permanent molars were erupted bilaterally, first premolars were erupted bilaterally, both upper incisors were erupted, as well as the second deciduous molars bilaterally.
The different finding among the post-mortem dental findings of the children was that in the maxilla of one of them, the left central and lateral incisors had erupted labially, while the right lateral incisor had not been erupted yet since it seemed that there was not enough space for its eruption. On the contrary, the maxillary teeth of the second child had been erupted normally (Fig. 6). The dentition of both children did not present any kind of dental intervention.

Ante-mortem data.
The information the family members gave the police authorities indicated that the youngsters had attended a private orthodontist office recently. The orthodontist had the initial models. We obtained the orthodontic models by the orthodontist once the police found him.
The study of the two orthodontic plaster models that belonged to the homozygous twin girls revealed that both children did not present any kind of dental intervention in their teeth. However, we found differences in the arrangement of the anterior maxillary teeth. According to the first plaster model, the left central and lateral incisors had erupted labially, while the right lateral incisor had not yet been erupted since there was not enough space for its eruption (Fig 7 and Fig. 8). On the contrary, the maxillary teeth of the second child's orthodontic plaster model seemed to have been erupted normally (Fig. 9).

Comparison of post-mortem and ante-mortem dental evidence
It was possible to identify the homozygous twins based on the maxillary tooth eruption pattern, which was documented post-mortem and with the comparison of the ante-mortem dental plaster models (Fig.8 and Fig. 10). One orthodontic plaster model's eruption pattern matched the eruption pattern of the first girl's left central and lateral incisors in the maxilla. One other consistent finding between the postmortem and ante mortem dental records was the right lateral incisor not yet erupted due to limited space. The second homozygous twin girl's maxillary incisors had all erupted.

Figure 6. Post-mortem dental records included photographs of the maxillae and mandibles of both children's corpses, that were taken during the post-mortem examination. Both children were in the phase of mixed dentition. Photographs a, and b belonged to one child. Photographs c and d belonged to the other

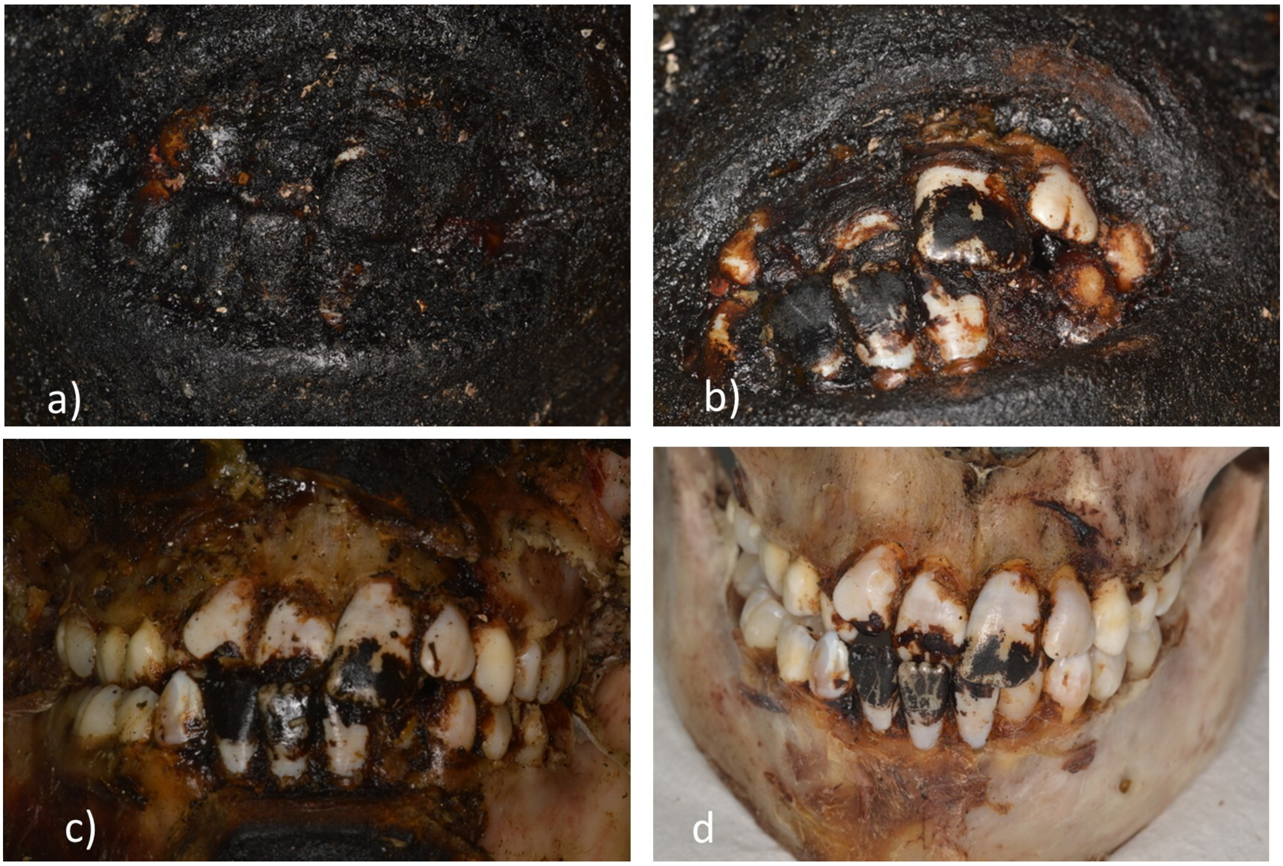

Figure 7. Ante-mortem dental records included plaster models (a and b) taken by the orthodontist for one of the homozygous twin girls. The left central and lateral incisors in the maxilla had erupted labially, while the right lateral incisor had not yet erupted, since there was insufficient space available for its eruption

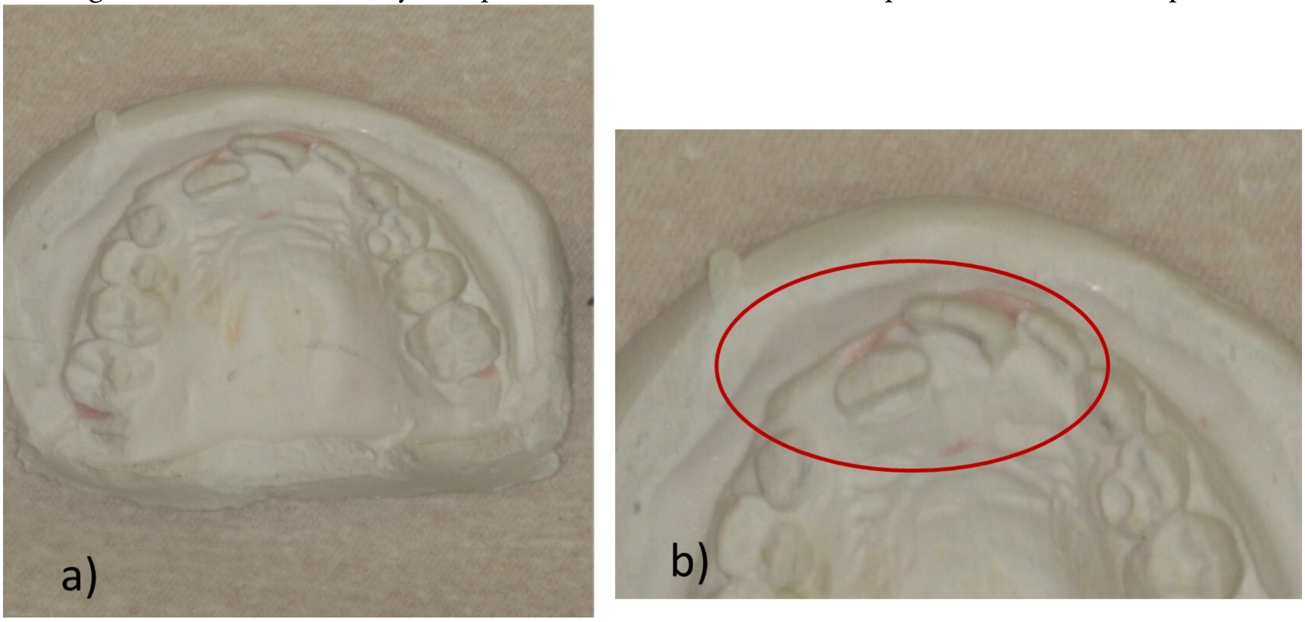

Figure 8. a) Plaster model of the maxilla of one child taken by the orthodontist, ante-mortem records, in the maxilla the left central and lateral incisors had erupted labially, while the right lateral incisor had not been erupted yet since it seems that there was not enough space for its eruption. b) Post-mortem dental records of the same child

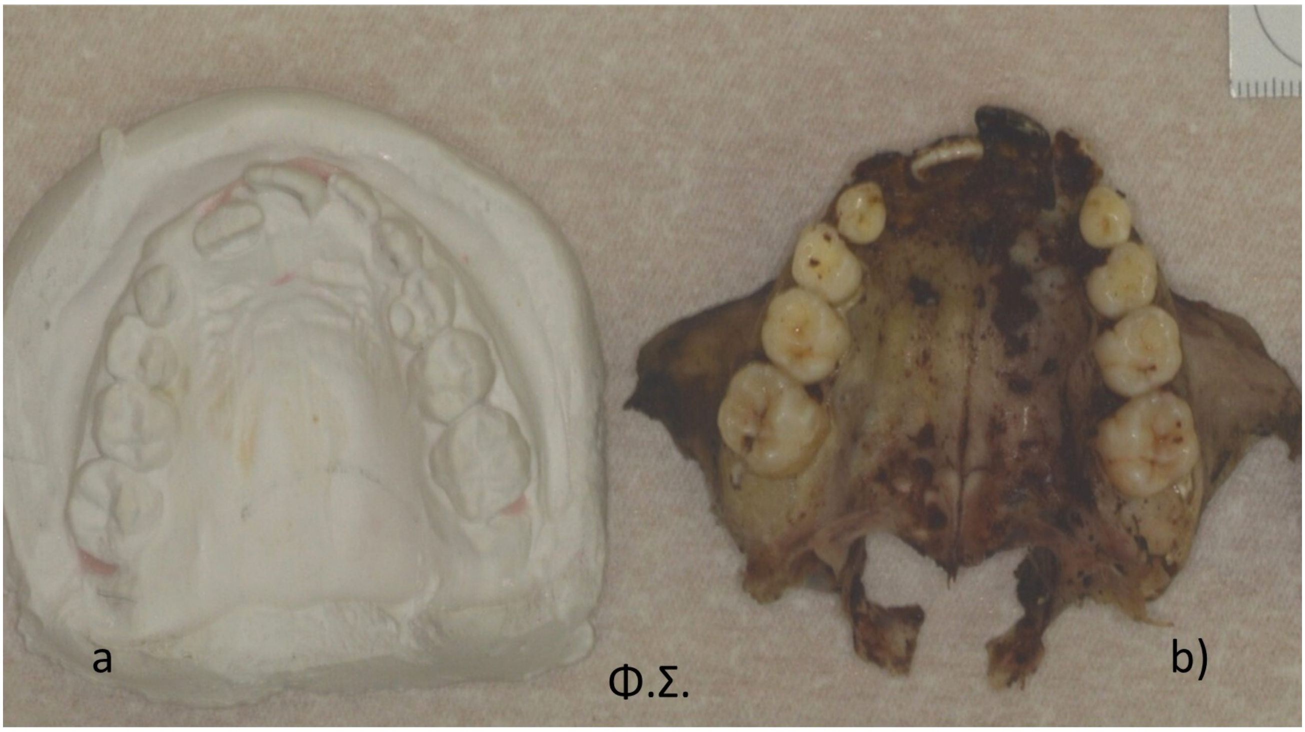

Figure 9. Ante-mortem dental records for the second of the homozygous twin girls from the orthodontist included plaster models (a and b). As can be observed, the maxillary incisors had erupted

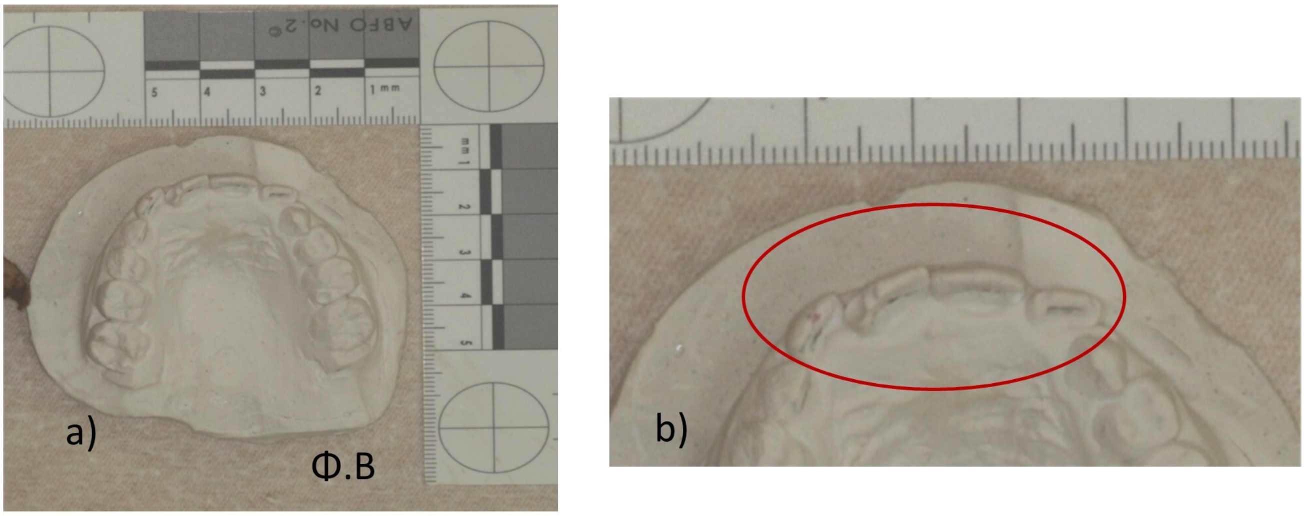

Figure 10. a) Post-mortem dental records of the second homozygous twin girl. b) Plaster model of the maxilla of the same child taken by the orthodontist, in ante-mortem records, the maxillary teeth of the second homozygous twin girl had erupted

DISCUSSION

The orthodontist, from the very first days of his post graduate training, is used to take routinely a set of diagnostic records pre-treatment, during it and at its end. These records are essential for planning and carrying out the appropriate therapies. Written information, dental radiographs, photographs, plaster casts, digital impressions, and any other document included in a patient's dental record are the evidence the orthodontist relies on to make initial diagnoses, assess prognoses and progress of the treatment outcome.[18] These include case history recording, a full set of intra and extra oral photographs, with complete clinical and a thorough medical examination. Moreover, the orthodontist has extensive knowledge about the various aspects of teeth position, craniofacial growth, age assessment and can deal with the skeletal and dental remains. A well-detailed, accurate, and updated dental record is an indicator of the excellence of the orthodontic services provided. Excellent documentation is directly related to the orthodontist's clinical competence and contributes to the increase of his prestige and trustworthiness. General dentists are more likely to keep incomplete, insufficient, and out-of-date records.[19]

Furthermore, orthodontic appliances are generally manufactured of commercially pure titanium, titanium-aluminum-vanadium alloys, or nickel, molybdenum, copper, and stainless-steel elements. The metals and alloys mentioned above have unique physical and mechanical properties, as well as corrosion resistance.[20-23] Fixed as well as removable orthodontic appliances are valuable dental identification tools due to the aforementioned properties of the orthodontic materials and their resistance to extremely unfriendly circumstances.[24-26] Therefore, all the data an orthodontist collects can be a significant source of information in cases where identification with soft tissue is impossible due to the putrefaction of the bodies.

Creating and maintaining detailed, accurate updated and well organized dental records is essential for a variety of reasons.[27-29] Concerning forensic odontology, detailed and accurate dental records, may help not only with the identification of unidentified corpses or human remains by comparing antemortem and post-mortem dental evidence, but also to the reconstruction of an individual's biological profile and additionally with the resolve of other criminal and civil law cases.[22,30]

The unavailability of dental records or the availability of insufficient dental records are major concerns which complicates the identification procedures in isolated cases and in mass disasters. In this case scenario the collection of all available ante mortem medical data of missing people such as radiographic images out of the dentomaxillofacial area could be considered an useful identification tool.[31] Furthermore, when there is an extreme lack of antemortem medical records, the analysis of images from other sources (like social media) might be suitable for human identification.[32]

In order to use dental records for mass disaster human identification, a number of requirements should be satisfied: trained personnel must collect and evaluate pre- and post-mortem dental records; a uniform dental notation and coding system should be adopted; the necessary equipment must be available; and the personnel must submit to media pressure. Human remains must be adequately stored and recorded in order to safeguard the dentomaxillofacial evidence. The process for identifying teeth should adhere to quality control guidelines. Since various DNA tests that require specific expertise are available, the DNA analysis should be used when dental evidence or fingerprint analysis are inconclusive.[15,16]

Given the complexities of orthodontic cases and long-term treatment plans, orthodontists should always update the patient records on a regular basis. As a consequence, orthodontic records are valuable in forensic cases.[27-29]

The success of an identification process based on forensic dental evidence depends on the availability, accuracy and good quality of the ante-mortem and post-mortem dental records.[20] Due to their excellent quality, orthodontic dental records are extremely valuable tools and when they are available the human identification procedures are greatly facilitated.[33,34]

The present study highlights the contribution of orthodontics to establish the identity of mass catastrophes victims. In the two cases presented the identification was based exclusively on the excellent quality and accuracy of the orthodontic records. The contribution of orthodontics records was even more prominent for the case of the identical twins where all the other primary forensic methods (DNA and finger prints) failed to reach a definite result.

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Canine sexual dimorphism in crown and root dimensions: a cone-beam computed tomographic study

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KEYWORDS

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ABSTRACT

The primary step in forensic odontological analysis is sex determination. The present study is one of the few studies that evaluated the accuracy of the combination of canine tooth root length and crown measurements for sex determination. The study sample comprised 196 cone-beam computed tomographic scans of individuals aged 20-80 years distributed in five age categories: 20-29, 30-39, 40-49, 50-59, and 60+ years old. Different parameters, such as width, length, and ratio measurements for the crown and root of each maxillary and mandibular canine tooth, were examined and recorded. The findings indicated that maxillary canines had greater sex dimorphism ability (87.3%) than mandibular canines (80.6%). Total tooth length and root length of maxillary canine were the most pronounced variables in the differentiation of sex groups. When the combination of the mandibular and maxillary measurements was considered, the accuracy for sex dimorphism was 85.7%. By using ratio variables, the accuracy was reduced to 68.9%. According to the findings of this study, total tooth length and root length are the most discriminant variables of canine teeth. These variables are more reliable sex indicators than crown measurements.

INTRODUCTION

Forensic odontology is a subspecialty of forensic medicine that assists in establishing a post-mortem biologic profile,[1] which primarily includes verifying age, sex, stature, and ancestry.[2-4] The primary step in this context is sex determination. Although sex can be most accurately assessed by DNA analysis[5] or examination of skeletal remains such as the pelvis,[6] craniofacial bones,[7] and mandible,[8] their applicability is restricted due to a variety of factors, including the need for expensive equipment and time-consuming procedures or suboptimal condition of the bones, especially those severely mutilated.[9] In such situations, teeth are considered a practical adjacent in sex determination because of their structural durability to pre- and post-mortem insults [10, 11] and their ability to predict sex with an accuracy of 51.13% to 100%.[12-15] Moreover, since the complete development of dentition precedes skeletal maturation, teeth play an essential role in sex determination for younger individuals.[1]

The application of dentition in sex determination is primarily based on the distinctions between the dimensions or morphology of the teeth in males and females.[3, 16, 17] Among different types of teeth, the canine tooth has been consistently used for forensic purposes and is regarded as a "key tooth" in sex determination[1, 18] primarily because they show the most significant sex dimorphism in their dimensions. Moreover, they are the least frequently extracted teeth,[3] highly resistant to dental/periodontal diseases, and are more likely to survive post-mortem trauma.

Many studies on the effectiveness of canine teeth in sex determination used the canine index, which considers the mesiodistal width of the canine teeth and inter-canine arch width.[1-3, 15] However, some studies showed that the canine index has poor sex dimorphism ability, and its application in forensic works should be confined, and absolute measurements of the canine tooth are better sex indicators.[1, 3, 18] Another limitation of such studies is that they have not considered root measurements. This factor may impair the accuracy of sex determination since it has been demonstrated that the Y chromosome has a more decisive influence over root length growth than the X chromosome.[12]

Radiographic examinations are a non-destructive and ethical approach for evaluating the whole tooth if radiographs are taken due to clinical indications. Capitaneanu et al.[19] used panoramic radiographs to compare the length and width variables and ratios to determine the applicability of various maxillary and mandibular teeth in sexual determination. They showed that the tooth length of the mandibular canine was the most sexually dimorphic measurement. However, panoramic radiographs have disadvantages, such as unequal magnification and unpredictable distortion due to the patient positioning and location within the focal trough.[20] These factors preclude accurate measurements, and the results cannot accurately reproduce or represent direct measurements. In recent years, computed tomography (CT) or cone-beam CT (CBCT) has been increasingly used in forensic investigations, particularly for sex and age determination.[21] CT and CBCT provide images with a sub-millimeter resolution free from distortion, magnification, and superimposition of the adjacent structures,[22] which are not available in projection imaging and panoramic radiography and can positively affect the findings of the studies.[21] The portability, lower cost, ease of image acquisition, and user-friendliness of CBCT over CT make it more practical for forensic applications, particularly in skeletal imaging and odontology.[20]

Therefore, the present study aimed to assess the accuracy of sex determination in adult individuals using CBCT images based on the different length, width, and ratio measurements of the crown and root of canine teeth in mesiodistal and buccolingual dimensions in both jaws. Additionally, it attempted to present a specific formula for sex determination based on the canine teeth using the discriminant function analysis. The present study is the first to be conducted among the Iranian population. It is one of the few studies evaluating the accuracy of canine sex dimorphism considering the tooth root length and crown measurements.

MATERIALS AND METHODS

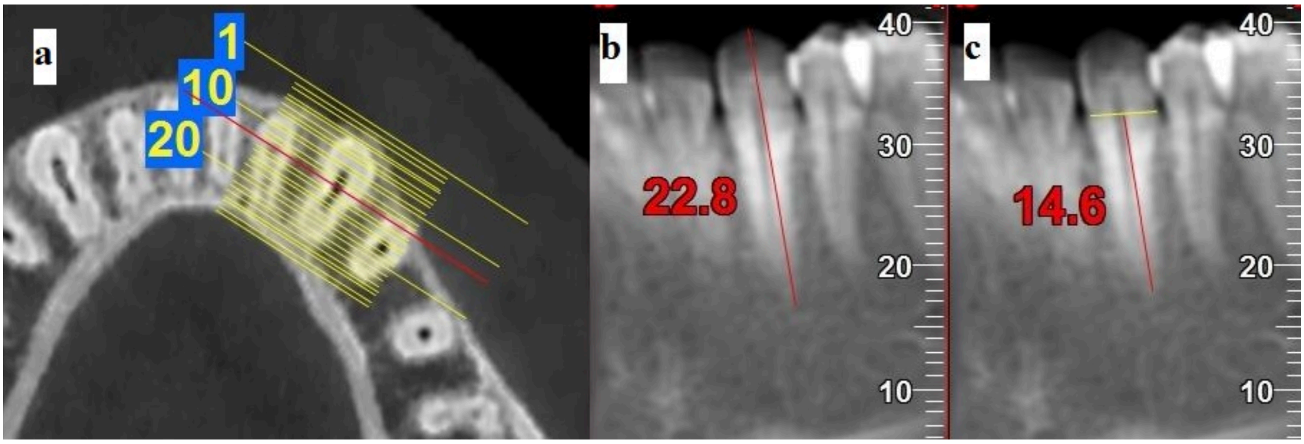
In this cross-sectional study, the CBCT scans of 196 individuals (96 men and 100 females) referred to the Dental School of Shiraz University of Medical Sciences (Shiraz, Iran) for purposes other than the present study were evaluated. The study complied with all relevant principles of the Declaration of Helsinki at the time of imaging. All subjects signed a written informed consent form authorizing the use of their anonymous radiographic data in research and publications. The Ethics Committee of Shiraz University of Medical Sciences, Shiraz, Iran, approved the study (IR.Sums.Dental.REC. 1399.206). The study sample age ranged from 20 to 80 years and was divided into five age groups: 20-29, 30-39, 40-49, 50-59, and 60+ years old. Except for the final group, which comprised 16 males due to a lack of individuals matching the inclusion criteria, all groups included 40 CBCT scans distributed evenly between the two sexes. The CBCT images were digitally captured using a New Tom VGi Evo CBCT unit (QR SRL Company, Verona, Italy) with 3 mA, 110 kVp, and 0.3 mm voxel size, in accordance with the manufacturer's instructions for positioning and exposure.

The inclusion criteria of the study were CBCT scans with good image quality, the presence of fully developed and erupted maxillary and mandibular permanent canine teeth, the absence of restorations, significant occlusal wear on the crown of the canine teeth, root resorption, dilacerations, significant buccolingual inclination in the canines, any pathology or skeletal disorders, and history of trauma or orthodontic treatment.

For each scan, the measurements were taken on the canine teeth of both jaws, i.e., maxilla and mandible. Since previous studies showed no significant difference in canine measurements between the left and right sides of the jaw,[3, 23, 24] all the measurements were made on the left canine teeth. Yet, if the left canine tooth did not meet the inclusion criteria, the procedure was made on its right counterpart. Each canine tooth underwent the following measurements:

- *The length measurements:* The maximum tooth length (TL) (defined as the distance between the most incisal tooth point and the root apex) and the maximum root length (RL) (defined as the distance between the cemento-enamel junction (CEJ) and root apex) (Figure 1).
- *The width measurements:* The maximum buccolingual width of the crown (BL), the buccolingual width of the tooth at the CEJ level (CEJBL), the maximum mesiodistal width of the crown (MD), the mesiodistal width of the tooth at the CEJ level (CEJMD) (Figure 2).
- *The ratio and proportions:* TL/RL, TL/MD, TL/BL, TL/ CEJMD, TL/ CEJBL, RL/MD, RL/BL, RL/ CEJMD, RL/ CEJBL, MD/ CEJMD, BL/ CEJBL, CEJBL/ CEJMD, BL/MD

Figure 1. Shows the tooth and root length measurements (TL & RL, respectively) used in the study: **Axial images** used for reconstruction of mesiodistal cross-section; **b** the maximum tooth length; **c** the maximum root length



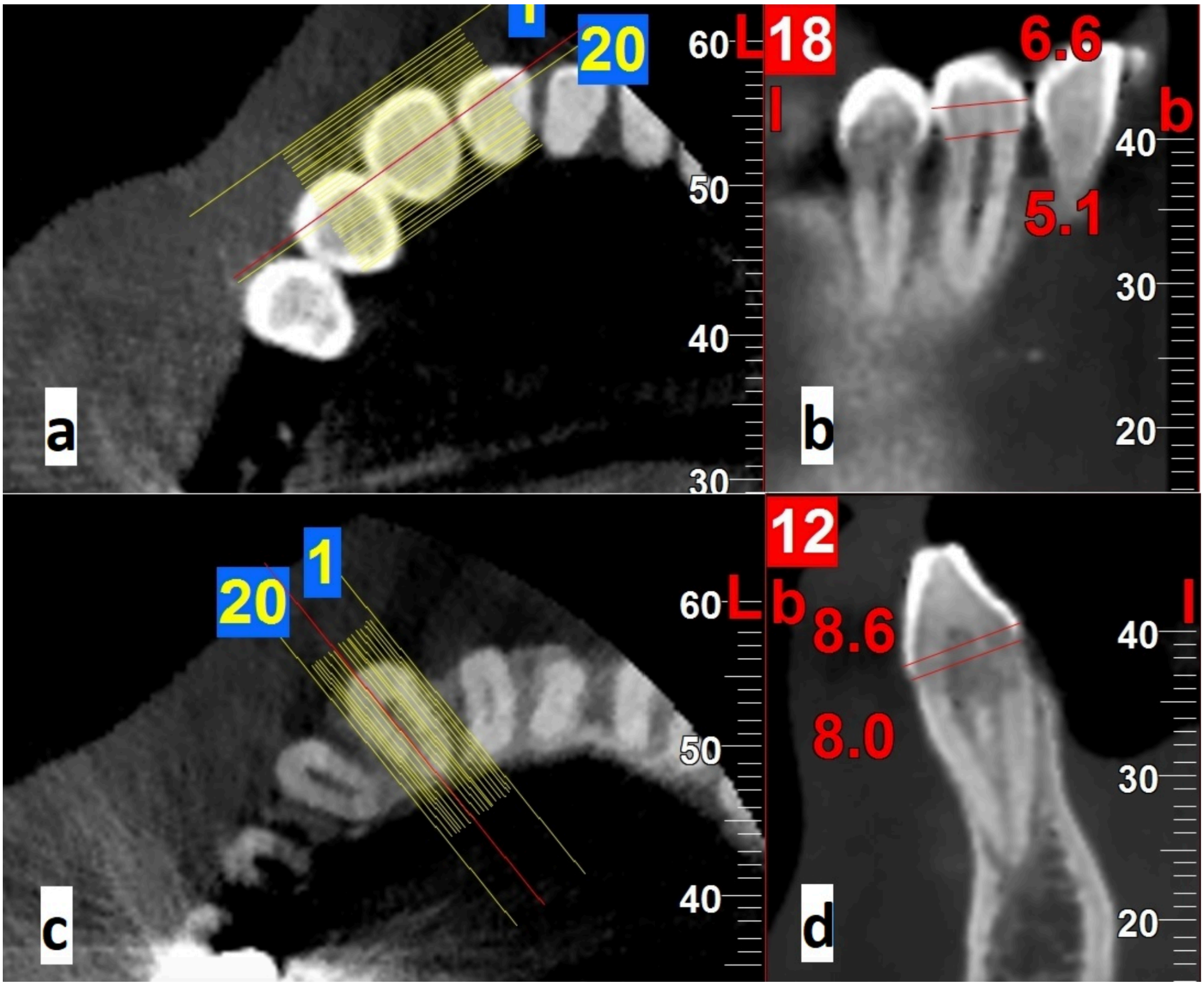
Based on the axial section at the mid-root level, cross-sections perpendicular to the canine tooth were prepared for the measurements. The length measurements (TL and RL) were done on the mesiodistal cross-sections. The thickness of these cross-sections was considered around 7 mm to account for the buccolingual inclination of the canine tooth and to include both the incisal edge and the apex of the tooth in one section. MD and CEJMD measurements were done on 1 mm thick mesiodistal cross-sections representing the maximum crown width. Buccolingual cross-sections with 1 mm thickness were prepared to measure BL and CEJBL variables. For each subject, additional information such as the subjects' birth dates, date of acquisition of the CBCT scans, and sex were also recorded.

Two examiners, an experienced oral and maxillofacial radiologist and a well-trained post-graduate oral and maxillofacial radiology student, recorded all the measurements separately using NNT Viewer software (NNT V2.21, Image works, Verona, Italy). The examiners were blinded to the subject's age and sex. To assess the intra- and inter-observer reliability, the examiners randomly selected one-third of the images and re-evaluated them after a two-week interval.

Statistical analysis

Data were analyzed using SPSS software, version 22.0 (IBM Corp., Armonk, N.Y., USA). For each variable, the two sexes were compared using an independent t-test. P values less than 0.05 were considered statistically significant. To find the best variables for sex determination, the discriminant analysis and stepwise selection method were used. The accuracy of inter- and the intera-examiner agreement was determined by Intra-class correlation coefficient test (ICC).

Figure 2. Shows the width measurements used in the study: an Axial image used for reconstructing mesiodistal cross-sections; b The maximum mesiodistal width of the crown (MD) and the mesiodistal width at the CEJ level (CEJMD); c Axial image used for reconstructing buccolingual cross-sections; d The maximum buccolingual width of the crown (BL) and the buccolingual width of the tooth at the CEJ level (CEJBL)



RESULTS

Based on the ICC values, there was a high inter and intra-observer agreement for all odontometric measurements (r>0.90 and >0.95, respectively). For analyzing the data, an average for each value was used.

According to the independent t-test results, all the maxillary and mandibular canine teeth length and width measurements significantly differed between the sexes (all P values <0.05). There were also significant differences between males and females in eight ratios of the upper jaw and two of the lower jaw (Table 1).

The results of the stepwise discriminant analysis are shown in Table 2. When all measurements from both jaws were considered, the most pronounced variables in sex group differentiation were the TL and RL of maxillary canines. Other variables based on the magnitude of Standardized Discriminant Function Coefficients (SDFC) scores were CEJMD of maxillary canine, RL, MD, and CEJMD of mandibular canines, respectively.

The discriminant function for all maxillary and mandibular measurements was formulated using the Canonical Discriminant Function Coefficient (CDFC) as follows:

Formula 1 (for both jaws): D = [-20.254+ 0.571 (MD of mandibular canine) + 0.463 (TL of maxillary canine) - 0.270 (RL of maxillary canine) + 0.168 (RL of mandibular canine) + 0.976 (CEJMD of maxillary canine) + 0.434 (CEJMD of mandibular canine)].

Based on this formula, the discriminant D-score was 0.023 (values greater than 0.023 indicate males, while lower values indicate females).

Based on the corresponding CDFCs, the following formulae were presented for obtaining the discriminant function separately for each jaw measurements:

Formula 2 (for the maxilla): D = -18.568+ 0.502 (TL) - 0.247 (RL) + 1.286 (CEJMD) + 0.529 (CEJBL)

The discriminant D-score was 0.022 (values greater than 0.022 indicate males, while lower values indicate females).

Formula 3 (for the mandible): D = -18.829+ 0.962 (MD) + 0.261 (RL) + 0.952 (CEJMD) + 0.542 (CEJBL)

The discriminant D-score was 0.019 (values greater than 0.019 indicate males, while lower values indicate females).

Based on the stepwise analysis, the best differentiating variables for each jaw were TL for the maxilla and CEJMD for the mandible.

As presented in Table 2, the maxillary canine had an accuracy rate of 87.3% (87.5% for males and 87.0% for females), and the mandibular canine had an accuracy rate of 80.6% (79.2% for males and 82.0% for females). When both jaws were considered, the accuracy rate was 85.7% (86.0% for males and 85.4% for females).

Based on the magnitude of SDFC scores, the best ratio variables for sex discrimination were MD/CEJMD and TL/MD of the maxillary canine. Based on the corresponding CDFCs, the discriminant function for ratio variables was formulated as follows:

Formula 4: D = -6.330 − 1.171(TL/MD of maxillary canine) + 7.995(MD/ CEJMD of maxillary canine)

With the discriminant D-score of 0.017 (values greater than 0.017 indicate males, while lower values indicate females). The overall accuracy of these ratio variables was 68.9%, which was the lowest among all the reported accuracies in the present study (Table3).

Table 1. Comparisons of all the variables of the permanent canine teeth between the two sexes)

		Variables	**Mean±SD**		**P value**
			Male	**Female**	
Width and length measurements	**Maxilla**	MD	7.12±0.47	6.63±0.51	<0.001*
		BL	8.27±0.56	7.57±0.56	<0.001*
		TL	26.30±1.82	23.43±1.86	<0.001*
		RL	19.16±1.84	17.01±1.67	<0.001*
		CEJMD	5.58±0.49	4.89±0.44	<0.001*
		CEJBL	7.53±0.51	6.90±0.52	<0.001*
	Mandible	MD	6.38±0.43	5.83±0.44	<0.001*
		BL	7.75±0.51	7.14±0.54	<0.001*
		TL	24.70±1.81	22.47±1.79	<0.001*
		RL	17.43±1.75	15.85±1.67	<0.001*
		CEJMD	5.47±0.53	4.84±0.56	<0.001*
		CEJBL	7.10±0.51	6.52±0.54	<0.001*

Ratios and proportions	**Maxilla**	TL/RL	1.37±0.07	1.38±0.06	0.601
		BL/MD	1.16±0.08	1.14±0.08	0.150
		RL/BL	2.32±0.23	2.26±0.24	0.038*
		RL/MD	2.70±0.28	2.58±0.28	0.002*
		TL/BL	3.19±0.25	3.10±0.28	0.026*
		TL/MD	3.70±0.31	3.55±0.35	0.001*
		TL/CEJBL	3.50±0.28	3.41±0.30	0.026*
		BL/CEJBL	1.09±0.03	1.09±0.03	0.349
		RL/CEJBL	2.56±0.26	2.48±0.27	0.040*
		MD/CEJMD	1.28±0.09	1.36±0.12	<0.001*
		CEJBL/ CEJMD	1.36±1.35	1.42±0.15	0.003*
		TL/CEJMD	4.74±0.47	4.82±0.53	0.0727
		RL/CEJMD	3.45±0.38	3.49±0.41	0.0572
	Mandible	TL/RL	1.42±0.10	1.42±0.10	0.940
		BL/MD	1.21±0.09	1.22±0.98	0.384
		RL/BL	2.25±0.26	2.22±0.27	0.440
		RL/MD	2.74±0.34	2.73±0.33	0.788
		TL/BL	3.19±0.26	3.15±0.29	0.331
		TL/MD	3.70±0.31	3.54±0.34	0.839
		TL/CEJBL	3.50±0.28	3.40±0.30	0.577
		BL/CEJBL	1.09±0.03	1.09.0.04	0.903
		RL/CEJBL	2.46±0.29	2.44±0.30	0.042
		MD/CEJMD	1.18±0.12	1.21±0.13	0.041*
		CEJBL/ CEJMD	1.30±0.14	1.36±0.15	0.024*
		TL/CEJMD	4.54±0.49	4.67±0.55	0.0751
		RL/CEJMD	3.21±0.41	3.29±0.46	0.0660

The results of the independent T-test are shown in the table
* P value less than 0.05 was considered statistically significant
MD: the maximum mesiodistal width of the crown; *BL:* the maximum buccolingual width of the crown; *TL:* the maximum tooth length; *RL:* the maximum root length; *CEJMD:* the mesiodistal width of the tooth at the CEJ level; *CEJBL:* the buccolingual width of the tooth at the CEJ level

Table 2. The length and width measurements of canine teeth with significant differentiating function based on discriminant analysis

Jaw	Variable	C.D.F.C *	S.D.F.C**	Overall Accuracy (%)
Both Jaws	TL2	0.463	0.857	85.7
	RL2	-0.270	-0.475	
	CEJMD2	0.976	0.458	
	RL1	0.168	0.288	
	MD1	0.571	0.253	
	CEJMD1	0.434	0.217	
Maxillary canine	TL	0.502	0.928	87.3
	CEJMD	1.286	0.603	
	RL	-0.247	-0.435	
	CEJBL	0.529	0.277	
Mandibular canine	CEJMD	0.952	0.477	80.6
	MD	0.962	0.428	
	RL	0.261	0.448	
	CEJBL	0.542	0.286	

* Canonical Discriminant Function Coefficient
** Standardized Discriminant Function Coefficient
TL: the maximum tooth length; ***RL***: the maximum root length; ***CEJBL***: the buccolingual width of the tooth at the CEJ level; ***MD***: the maximum mesiodistal width of the crown; ***CEJMD***: the mesiodistal width of the tooth at the CEJ level
1 and 2 indicate mandibular and maxillary measurements, respectively.

Table 3. The ratio variables of canine teeth with significant differentiating function based on discriminant analysis

Jaw	Variables	C.D.F.C *	S.D.F.C**	Overall accuracy (%)
Maxillary canine	MD/CEJMD	7.995	0.841	68.9
	TL/MD	-1.171	-0.386	

* Canonical Discriminant Function Coefficient
** Standardized Discriminant Function Coefficient
TL: the maximum tooth length; ***MD***: the maximum mesiodistal width of the crown; ***CEJMD***: the mesiodistal width of the tooth at the CEJ level

DISCUSSION

Exact sex estimation is the foremost step in the identification process. Teeth and skeleton-based methods have a prominent application in sex determination as they are usually the best-preserved remains.[9] Among different types of teeth, the canine tooth has consistently been considered the most sexually dimorphic and critical tooth across various populations.[12, 18, 25, 26] Most studies on the applicability and accuracy of the canine teeth in sex dimorphism are based on the crown measurements and canine index, and root measures have rarely been utilized for sex dimorphism analysis. This is mainly due to the inaccessibility of the tooth root.[27] The root, preserved in the bony socket, is considered a more resilient structure than the tooth crown and, unlike the crown, is not affected by wear.[28] According to Lähdesmäki and Alvesalo,[29] the Y chromosome may play a more significant role in root length development than the X chromosome, which may be responsible for the sexual dimorphic characteristics of the root. Zorba et al.[28] showed that root length measurements of single-rooted teeth were a reliable indicator of sex dimorphism. Moreover, other studies reported that the root length of permanent teeth had a higher degree of sexual dimorphism than the crown measurements.[9, 30] According to Garn et al.,[9] root length alone shows comparable or greater sexual dimorphism as the crown measurements. They also showed that combining root and crown measurements enhances the sexual discriminant power of each set of measurements on its own. However, few studies[9, 13, 19, 28, 31] considered canine tooth root measurements for sex determination.

Moreover, since different populations exhibited distinct patterns of sexual dimorphism, the findings of such studies were considered population-specific[13, 32] and should not be generalized. Only one study has examined tooth root dimensions for sex determination in the archaeological Iranian population.[13] This study was a CT volumetric examination of 52 archaeological skeletal remains dating from around 1400 to 800 BCE, which may not reliably represent the present population.

CBCT has been widely used for forensic purposes in recent years.[21, 33] Besides sub-millimeter resolution, CBCT offers other advantages over conventional two-dimensional radiographs, including distortion-free images, magnification, superimposition of the adjacent structures, and the capacity to adjust the structure orientation.[21] These features enhance the ability to locate the anatomic structures better, which leads to more accurate results. Sherrard et al.[34] investigated the reliability of the tooth measurements on CBCT scans. They found that the total tooth and root length measurements were not significantly different from the direct measurements on the extracted teeth. Similarly, Stratemann et al.[35] reported that the difference between CBCT-based measurements using NewTom scanning and direct measurements by caliper was just 0.07 ± 0.41mm. In addition, Kim et al.[36] found no statistically significant differences in the crown and root length in CBCT scans and direct measurements of the premolar teeth using a digital caliper. However, CBCT-based measurements demonstrated that the total tooth length of the premolars was 0.18 ± 0.44 mm shorter than the direct measurements. This study also found a weak positive correlation between the crown and root length in the canine and premolar teeth, indicating that the crown length cannot accurately estimate root length in most tooth types.

To lessen the impact of dental wear, the studies using tooth crown measurements for sex estimation[12, 19, 37, 38] had to restrict the age range of their study samples to young adults. According to Lambrechts et al.,[39] the annual enamel vertical loss *in vivo* ranged between 20 and 38 micrometers. Consequently, the teeth with significant attrition were excluded from the present investigation. On the other hand, since the present study included tooth root measurements, which were not affected by wear, the age range of the study sample was set at 20-80 years old. This age range was comparable to studies by Zorba et al.[28] and Kazzazi and Kranioti,[13] which similarly used root length and root volume measurements for sex determination.

The current study's findings indicated that all the length and width measurements of the maxillary and mandibular canine teeth were significantly higher in men than in women. However, only 8 ratio variables of the maxillary canines and 2 ratio variables of the mandibular canines demonstrated a significant difference between the sexes. Similarly, Capitaneanu et al.[19] assessed all the maxillary and mandibular teeth in the panoramic image and reported that males had higher mean tooth length and mean width measures. Other studies[1, 12, 24, 37] that evaluated the crown or cervical tooth measurements also found that men had higher values than women.

It is estimated that for the dental measurements to be used as the sole sex predictor, the accuracy should be at least 80%.[19] In the current study, discriminant analysis results indicated that maxillary canines had a higher sexual dimorphic ability with an accuracy of 87.3%, whereas mandibular canines had an accuracy of 80.6%.

When the measurements of both jaws were considered, the discriminant ability was found to be 85.7%. Dumančić et al.,[40] who explored sex dimorphism in canine teeth, reported an accuracy of 73.5% for mandibular canine crown dimension and morphology. Zorba et al.[28] evaluated the root length of single-rooted teeth and discovered that the maxillary lateral incisors and canine were the most dimorphic teeth. Similar to the present study, they reported that maxillary canine had higher sexual discriminant accuracy than mandibular canine. They reported 80% and 76.9% discriminant accuracy for right and left maxillary canine and 74.4% and 77.6% for right and left mandibular canine, which was lower than the present study. While Zorba et al.[28] only measured the root length, the current study considered the length measurements of the tooth and root and the mesio-distal and buccolingual width measurements of the canine tooth crown.

In the present study, the tooth length and root length of maxillary canines showed the most prominent sex dimorphism among all the variables. This finding indicated that root dimension and tooth length measurements are more sex dimorphic than crown measurement and should be considered in forensic investigations. These findings were in agreement with the findings of Capitaneanu et al.,[19] who reported that the length measurements of mandibular and maxillary canines had a higher discriminant ability than the width measures. They also reported that mandibular canine tooth length was the most discriminative variable among all teeth. According to the present study's findings, when the ratio variables were considered, the accuracy for sex dimorphism decreased to 68.9%. Similarly, Capitaneanu et al.[19] showed that combining tooth variables using ratios did not increase the discriminant ability. They introduced ratio variables to reduce the undesirable effect of unequal magnification of panoramic radiography. However, employing ratio variables, which likewise have less accuracy in sex dimorphism, seems unnecessary for this purpose, as using CBCT makes it possible to have real-sized images.

CONCLUSION

Based on the discriminant analysis results, the maxillary canine tooth was more sexually dimorphic than the mandibular canine tooth (87.3% vs. 80.6%). However, based on the accuracy, both had reliable sex dimorphism abilities. The use of ratio variables reduced the accuracy of sex dimorphism to 68.9%. The TL and RL of maxillary canine were the most discriminant variables of canine teeth. Root and total tooth measurements were more reliable sex indicators than crown measurements. Thus, it is recommended that root and total tooth measurements be considered in forensic investigations for sex determination.

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Machine learning assisted 5-part tooth segmentation method for CBCT-based dental age estimation in adults

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ABSTRACT

Background: The utilization of segmentation method using volumetric data in adults dental age estimation (DAE) from cone-beam computed tomography (CBCT) was further expanded by using current 5-Part Tooth Segmentation (SG_t^5) method. Additionally, supervised machine learning modelling —namely support vector regression (SVR) with linear and polynomial kernel, and regression tree — was tested and compared with the multiple linear regression model.
Material and Methods: CBCT scans from 99 patients aged between 20 to 59.99 was collected. Eighty eligible teeth including maxillary canine, lateral incisor, and central incisor were used in this study. Enamel to dentine volume ratio, pulp to dentine volume ratio, lower tooth volume ratio, and sex was utilized as independent variable to predict chronological age.
Results: No multicollinearity was detected in the models. The best performing model comes from maxillary lateral incisor using SVR with polynomial kernel (R_{adj}^2 = 0.73). The lowest error rate achieved by the model was given also by maxillary lateral incisor, with 4.86 years of mean average error and 6.05 years of root means squared error. However, SG_t^5 demands a complex approach to segment the enamel volume in the crown section and a lengthier labour time of 45 minutes per tooth.

INTRODUCTION

The emergence of cone beam computed tomography (CBCT) systems in dentistry has opened new possibilities in diagnostics and image analysis. Utilizing CBCT for patient diagnosis provides dentists with a clear and detailed visualization of the dentomaxillofacial feature.[1] The improved anatomical visualization provided by CBCT leads to more predictable post-operative outcomes and safer clinical practices.[2] On the image analysis front, researchers have used volumetric information to deeply analyze anatomical structures,[3] human growth,[4] and other changes that happens in the craniofacial region.[5] This volumetric information has also proven to be highly valuable in various dental analyses, including dental age estimation performed by forensic odontologists.[6]
The importance of volumetric information provided by the CBCT allows forensic odontologists to conduct a thorough investigation of regressive changes in teeth, which is essential in dental age estimation of adults when dental growth has ceased.[7] Recent research has expanded the capabilities of volumetric measurement for dental age estimation by

segmenting it into various anatomical regions to enhance the reliability of predictive models, namely: Lower Tooth Volume Ratio (LTVR), derived from the lower root chamber volume (LRCV) and lower hard tissue volume (LHTV);[8] Pulp to Dentine Volume Ratio (PDVR), derived from the pulp chamber volume (PCV) of the crown and dentine volume (DV); and Enamel to Dentine Volume Ratio (EDVR), derived from enamel volume (EV) and DV.[9] All these ratios can be included in a single predictive model. However, the introduction of more independent variables into a predictive linear model carries the risk of multicollinearity,[10] lower model reliability,[11] and inflated R^2.[12]

These problems were argued that it can be solved by calculating the variance inflation factor (VIF) and adjusted R^2 (R^2_{adj}) of the model. Modern solutions — such as Supervised Machine Learning (SML) — have also been reported to reduce the multicollinearity problem [13] while minimizing the error-rate of a dental age estimation model when compared to the traditional multiple linear regression model.[14]

Considering these aspects, the aim of this research is twofold: (1) to examine the predictive performance of the 5-Part Tooth Segmentation (SG_t^5) method by combining the variables introduced by Merdietio Boedi et al. [8-9] and (2) assessing the effectiveness of SML — namely, support vector regression (SVR) and regression tree (RT) — to improve the reliability of the variables in predicting chronological age (CA).

MATERIAL AND METHODS

Data acquisition

This observational cross-sectional study received ethical approval from the Research Ethics Committee of Universitas Padjajaran (Approval No. 899/UN6.KEP/EC/2021). The sample used in this study was acquired from Merdietio Boedi et al.'s (2023) and was adapted and reanalyzed for the current study.[9] The sample consisted of 45 males and 54 females of Bandung, Indonesian origin, aged between 20 and 59.99 years (Mean CA 40.69 ± 11.23). CBCT scans were acquired at Universitas Padjajaran Dental Hospital using the Instrumentarium Dental OP300 (Instrumentarium Dental, Tuusula, Finland) with patient-specific exposure settings, including 85 kV, tube current ranging from 3 to 8 mA, and an exposure time between 1.7 to 8.7 seconds. The voxel size used in this study were 0.125mm^3 (n = 14), 0.2mm^3 (n = 36), 0.3mm^3 (n = 43), and 0.4 mm^3 (n =6). In relation to the respective fields of view, the smaller voxel size was taken for the small field of view (250 x 250 x 250), whilst the 0.3 and 0.4 mm^3 size was used for the 400 x 400 x 400 scans. Importantly, no patient was subjected to radiation specifically for the study, as the sample collection was retrospective and taken from an existing image database of CBCT scans acquired for clinical purposes.

The inclusion sample for the current study consists of maxillary teeth with fully erupted, closed apex, and a visible cemento-enamel junction (CEJ). Teeth with restorations, caries, impaction, resorption, associated tumors, cysts, pulp calcification, visible accessory root canals, or any interventions that may affect tooth formation or structure were excluded. The total sample size for this study includes 240 teeth (Table 1) consisting of maxillary canines (C, n = 80), lateral incisors (Li, n = 80), and central incisors (Ci, n = 80).

Table 1. Total sample size of each examined tooth for each sex and age range.

Age (Years)	M			F		
	C	C	Li	Ci	Li	Ci
20-24.99	5	5	5	5	5	5
25-24.99	5	5	5	5	5	5
30-34.99	5	5	5	5	5	5
35-35.99	5	5	5	5	5	5
40-44.99	5	5	5	5	5	5
45-49.99	5	5	5	5	5	5
50-54.99	5	5	5	5	5	5
55-59.99	5	5	5	5	5	5

M = Male, F = Female, C = Maxillary Canine, Li = Maxillary Lateral Incisor, Ci = Maxillary Central Incisor

Sample processing

The volumetric information of each tooth was segmented into 5 distinct components: PCV, DV, EV, LRCV, and LHTV (Fig. 1). These measurements were carried out using ITK-SNAP ver. 3.8 (ITK-SNAP, UPenn & UNC, USA).[15] The primary settings in ITK-SNAP were consistently configured as follows throughout the measurement process: 3D brush settings ON, all label opacities were set to 35, "initialize with current segmentation" option ON, and "thresholding" option was chosen in the segmentation mode. All volumetric measurements are conducted through the built-in region of interest (ROI) function within ITK-SNAP.

The SG_t^5 method starts with the volume calculation for the crown region (i.e., PCV, DV, and EV) followed the protocol described by Merdietio Boedi et al. in their 2023 work,[9] while for the root region (i.e., LRCV and LHTV), the procedure follows to their 2022 work.[8] The volumetric measurement started with the calculation of PCV, followed by the entire crown volume, demarcated by the highest or most apical CEJ in the sagittal view of the CBCT. Subsequently, the volumetric information was partitioned into DV and EV. Lastly, the calculation extended to LRCV and LHTV (Fig. 2). In the separation of the crown and root regions, the regions of interest (ROI) were ensured to overlap, ensuring the continuity of segmentation. All the calculated volume will then be converted to 3 volumetric ratios:

EDVR ($\frac{EV}{DV}$), PDVR ($\frac{PCV}{DV}$), and LTVR ($\frac{LRCV}{LHTV}$).

The superscripted letter notation corresponds to the specific tooth's volumetric ratio calculation (i.e., $EDVR^{Li}$ represents the EDVR calculation for tooth Li). Generally, the meantime taken for the SG_t^5 method was 45 minutes for each tooth.

Figure 1. Illustration of the 5-Part Tooth Segmentation method. The demarcation between the crown area and root area is defined using the highest or most apical point of the cemento-enamel junction in the sagittal section of the CBCT.

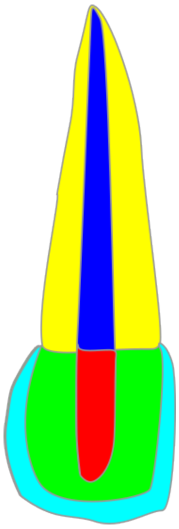
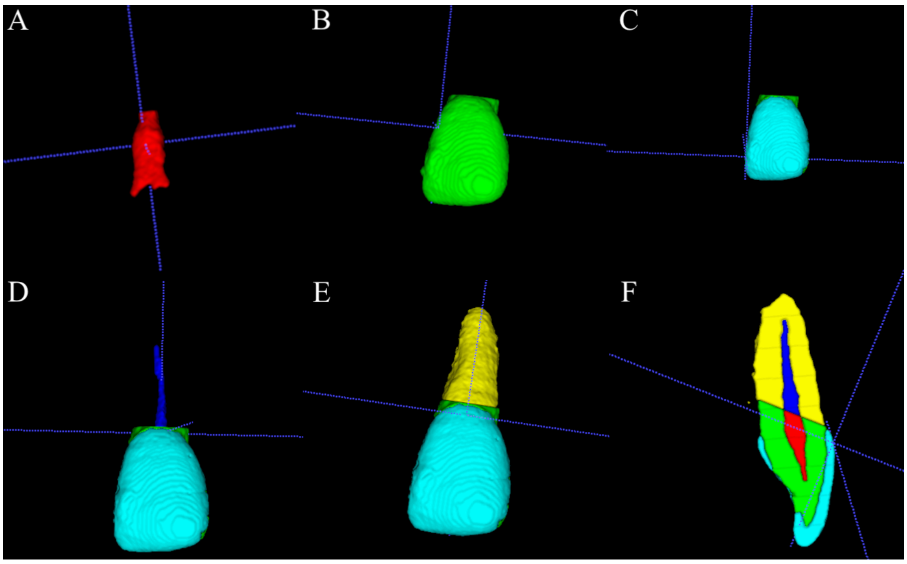


Figure 2. 5-Part Tooth Segmentation sequence in ITK-SNAP three-dimensional rendering. A: Pulp Chamber Volume (red), B: Whole Crown Volume (green), C: Separation between Dentine (green) and Enamel (light blue) Volume, D: Lower root chamber volume (blue), E: Lower hard tissue volume (yellow), F: Visualization of the cross-sectioned volumetric data depicting the separation between 5 volumetric information.



Data analysis

Inter- and intra-observer variabilities were calculated using the Intraclass Correlation Coefficient (ICC). Inter-observer agreement was determined by the first author— a forensic odontologist with 7 years of experience, with calculations repeated after a two-week interval between observations. Furthermore, the inter-observer analysis was accomplished by comparing the observations of the first author with a second observer — an oral and maxillofacial radiologist with 3 years of experience — recruited for the study. These analyses were based on a randomly selected set of 20 CBCT scans from unpublished data.

Initial analysis was performed by calculating Pearson's correlation coefficient (*r*) cross-tabulation for each variable. Then, three predictive models, namely MLR, SVR, and RT, were developed using CA as the dependent variable, volumetric ratios as independent variables, and sex as a covariate. All data analysis was conducted using R (version 3.4.1, R Foundation for Statistical Computing, Vienna, Austria) with the caret extension. Model training parameters in caret were set using the "repeated cross-validation" training method with 5-fold cross-validation and 2 repetitions. The hyperparameters for both SVR and RT were set to center and scale for the preProcess function, and the tuneLength parameter was set to 5. Two SVR kernel will be tested: linear (SVR-L) and polynomial (SVR-Poly) kernels.

Model reliability was assessed using R^2_{adj}, root mean squared error (RMSE), and mean absolute error (MAE). Additionally, performance evaluation included the use of the variance inflation factor (VIF) to detect multicollinearity, with VIF > 5 indicating multicollinearity among independent variables. To ensure reproducibility in the randomization, the pseudo-random number generator in R was controlled using set.seed = 30.

RESULTS

Volumetric measurements demonstrated good consistency, with intra- and inter-observer agreement reported in Table 2.

All *r*-values in the cross-tabulation (Table 3) were statistically significant. Negative correlations were observed between CA and independent variables, indicating that as CA increases, the ratio measurements reflecting regressive changes in the observed tooth decrease. The highest negative correlation between CA and an independent variable was observed in $PDVR^C$ (r = -0.68). Positive *r*-values between independent variables indicate that both variables change in the same direction; in this case, all independent variables decrease over time. The highest and lowest positive correlations between independent variables were observed for $PDVR^C$ to $EDVR^C$ (r = 0.57), and $PDVR^{Li}$ to $LTVR^{Li}$ (r = 0.38), respectively.

Table 2. Intra and Inter-Class Correlation Coefficient between and within observers.

Variables	ICC	
	Intra	Inter
PCV	0.78	0.78
DV	0.82	0.81
EV	0.7	0.76
LRCV	0.92	0.92
LHTV	0.9	0.73

Table 3. Pearson's correlation coefficient values for each variable.

Tooth		EDVR	PDVR	LTVR	CA
C	EDVR	-	0.57	0.51	-0.67
	PDVR	0.57	-	0.44	-0.68
	LTVR	0.51	0.44	-	-0.66
	CA	-0.67	-0.68	-0.66	-
Li	EDVR	-	0.47	0.60	-0.61
	PDVR	0.47	-	0.38	-0.65
	LTVR	0.60	0.38	-	-0.73
	CA	-0.61	-0.65	-0.73	-
Ci	EDVR	-	0.55	0.47	-0.60
	PDVR	0.55	-	0.51	-0.65
	LTVR	0.47	0.51	-	-0.61
	CA	-0.60	-0.65	-0.61	-

C = Maxillary Canine, = Li = Maxillary Lateral Incisor, Ci = Maxillary Central Incisor, EDVR = Enamel to Dentine Volume Ratio, PDVR = Pulp to Dentine Volume Ratio, LTVR = Lower Tooth Volume Ratio

MLR models were calculated as follows:

$$y = 69.83 - 17.69EDVR^C - 168.59PDVR^C - 132.77LTVR^C$$

$$y = 62 - 164.06PDVR^{Li} - 196LTVR^{Li}$$

$$y = 70.83 - 20.57EDVR^{Ci} - 164.47PDVR^{Ci} - 132.28LTVR^{Ci}$$

where y is the estimated dental age. The sex covariate did not exhibit a significant contribution to the MLR models, and similarly, $PDVR^{Li}$ did not show significance in predicting CA. All VIF values

were below 5, indicating no multicollinearity among the independent variables.
A comparison of the models revealed that SVR-Poly consistently achieved superior performance in predicting CA compared to the other modelling approaches, as evidenced in Table 4. Notably, the highest R^2_{adj} values also translated to a lower MAE and RMSE metrics. The third-degree SVR-Poly model in C utilizing all independent variables and sex as predictor yielded the lowest MAE (4.97 years) and RMSE (6.37 years), with R^2_{adj} value of 0.71. Conversely, the Ci SVR-L model employing all independent variables produced the highest MAE (6.6 years) and RMSE (7.97 years), with the lowest R^2_{adj} value of 0.55.

Table 4. Model performance comparison for each tooth. All error values were reported from the cross-validated data using 5-fold cross-validation with 2 repetitions.

Tooth	Metrics	Models			
		MLR	**SVR-L**	**SVR-Poly**	**RT**
C	R^2_{adj}	0.66	0.65	0.71	0.62
	MAE	5.42	5.23	4.97	5.77
	RMSE	6.86	6.8	6.37	7.18
Li	R^2_{adj}	0.69	0.7	0.73	0.69
	MAE	5.14	5.15	4.86	5.28
	RMSE	6.46	6.42	6.05	6.67
Ci	R^2_{adj}	0.56	0.55	0.68	0.56
	MAE	6.4	6.6	5.27	6.26
	RMSE	7.7	7.97	6.67	7.7

C = Maxillary Canine, = Li = Maxillary Lateral Incisor, Ci = Maxillary Central Incisor,
R^2_{adj}= Adjusted R^2, MAE = Mean Average Error, RMSE = Root Mean Squared Error, MLR = Multiple Linear Regression, SVR-L = Support Vector Regression with Linear Kernel, SVR-Poly = Support Vector Regression with Polynomial Kernel, RT = Regression Tree

DISCUSSION

Although studies on dental age estimation might use different approaches, several key objectives need to be addressed by researchers to establish a robust methodology.[16] Firstly, an adequate sample size is essential, not only in the quantity of analyzed data but also the distribution across age group and sex.[17] This key objective ensures that the results evade the age mimicry phenomenon, where the final error rate may be skewed toward a certain age group or population reference.[18]
Secondly, the proposed methodology must incorporate inter- and intra-observer error, certainly with a proper quantification analysis to ensure methodological reproducibility. For instance, when dealing with ordinal data (e.g., staging, atlases), Cohen's Kappa should be employed for analysis, while continuous data (e.g., measurements) necessitate the use of ICC.[19]
Thirdly, the reliability of the model is signified by the error-rate that should be shown along with the conversion of the age-related dental data, and this can be achieved through scoring systems, diagrams, or models. Importantly, the error-rate should be calculated from a different dataset than the one used for model creation to prevent overfitting — a scenario that occurs when a model is too closely tailored to the training data and may not perform well on new, unseen data. The most straightforward approach to prevent overfitting is to separate the dataset into training and testing subsets. For instance, considering a dataset denoted as x, the training data could use the $x - i$ portion of the data, while the model derived from the training dataset is evaluated against the i data. Another method — as employed in this research — involves k-fold cross-validation. This technique divides the data into k parts or folds, utilizing $k - 1$ segments for training the dataset and reserving the untrained fold for testing. This process is repeated k times, with each fold serving as the test data exactly once.
CBCT can be used for dental staging,[20] alveolar bone loss measurement,[21] metric assessment,[22] and specifically for volumetric measurement application. Volumetric data has shown the highest reliability within the adult population.[6] This is primarily attributed to the absence of dental maturation process, a method commonly employed for children and adolescents. Regressive dental changes are subtle when compared to dental maturation, necessitating data granularity to ensure even the smallest shifts in adult tooth structure are captured accurately. Unlike conventional radiographs — which provide only two-dimensional measurements, volumetric data captures these details through CBCT voxels to approximate radiographic structure volume, acquired from the height, width, and depth of the images.[24] Therefore, the

accuracy of the volumetric method has much to recommend it for the assessment of the dental age of adults.

This study utilizes volumetric approximations of a tooth obtained through CBCT scans employing various voxel sizes. As noted in previous studies, inconsistencies in measuring or observing age-related variables can introduce errors in the final estimated age.[25] Lee et al. recommend a 0.2mm^3 voxel for optimal dental structure evaluation.[27] Even so, Adisen et al. concluded that different voxel sizes have not significantly improved overall result.[26] While smaller voxel sizes offer increased clarity, methods utilizing CBCT volumetric information can still function appropriately with larger voxel sizes with good quality scans. Whenever feasible, uniform sampling if images based on the same voxel size should be preferred to standardize the methodological settings.

The potential variability in CBCT-based measurements was seen by Yang et al. whom conducted a comparison of pulp size obtained from an Archimedes' principle experiment to CBCT-derived volumes, yielding an acceptable error rate of ±7.6%.[28] Further work by Star et al. revealed a more substantial discrepancy between software measurements and the gold standard, with differences of up to 21% and 16% for pulp and tooth volume, respectively.[29] Adding to this complexity, previous research has identified a significant correlation between individual stature and tooth volume.[30] This implies that larger individuals may tend to have larger teeth, potentially introducing bias into the volumetric measurements. This study used a ratio as its independent variable, mitigating the influence of both intrinsic variability in CBCT measurements and the correlation between stature and tooth size.

This study employed a segmentation method to achieve higher model performance by discerning multiple volumetric regressive changes in anterior teeth using CBCT images. Previous studies have primarily utilized tooth volumetric data, conducting this approach across various populations,[7] each with their own modifications aimed at either improving model performance or adopting a more user-friendly approach. For instance, (1) Zhang et al. utilized only the enamel and pulp chamber of an impacted third molar to eliminate the influence of external factors affecting the rate of enamel attrition,[31] and (2) Pinchi et al. simplified volumetric measurements by using geometric approximations of upper central incisors to reduce operating time.[32] A direct comparison of R^2 values with the current methodology reveals a higher R2 value of 0.71 for the Li SVR-Poly model when compared to Zhang et al. ($R^2 = 0.42$), Pinchi et al. ($R^2 = 0.58$), or similar population study conducted by Anjani et al. ($R^2 = 0.58$). However, it is important to note that the SG_t^5 approach involves a more complex segmentation process, and hence a greater time commitment, for each part of the tooth to achieve enhanced model performance.

The error rate in adult dental age estimation was found to be higher and possible causes include external factors, regressive dental changes, and population-specific influences.[33] For instance, individuals with bruxism may experience a higher rate of attrition, resulting in reduced enamel volume. Additionally, error rates may vary significantly depending on the specific population, as seen in the Indonesian populations. Marroquin et al. (2018) conducted pulp/tooth volume calculations on two distinct samples —Colombian and Malaysian— concluding the necessity of population-specific methods for age estimation due to discriminatory results.[34] Du et al. (2021) observed significant differences in error rates when a model derived from Chinese samples was applied to Black Americans, because the original MAE of 7.9 years Increased to 14.04 years for the later population.[35] Hence, the model performance reported in this study may be population-specific, underscoring the importance of methodological validation when a model is applied to a new or different populations.

The limitations of this study are two-fold and linked primarily to sample size and methodological constraints. First, the sample size was 80 per tooth position, above the required minimum sample size of 67 from G*Power analysis for a-priori sample size determination with effect size of 0.3, Power 0.95, and 4 estimated predictors. However, a bigger sample size to achieve a lower effect size may result in better age estimation performance that more accurately representing dental regressive changes in adults.[36] Moreover, a non-uniform distribution of voxel sizes was obtained during sampling process — a situation justified by the institutional protocol that require patient-specific modeling of energy parameters for image acquisition. Second, the inclusion of EV calculation affected the operating time of the segmentation, approximately 45 minutes, and with a steeper learning curve. In contrast, similar segmentation study that divided the tooth volumetric information into four segments without EV calculation took only 10 minutes.[8] This drawback certainly comes with a better overall performance. As reported in the previous study, the current SG_t^5 approach shows an increase of R^2 between 0.1 to 0.23. Hence, the current SG_t^5 is better suited for evaluating individual dental identification cases, where time constraints are presumably more lenient compared to mass disaster cases.

CONCLUSION

The SG_t^5 approach combined with SVR-Poly model gives an overall better performance when compared to other modelling approaches, with the maxillary canine affording the best overall performance in comparison to other anterior maxillary teeth examined. Nonetheless, this improvement in model performance comes with greater labor time costs and a steep learning curve for methodology application. Future research might consider the application of this segmentation methodology to additional teeth, particularly molars, given their relatively greater protection within the oral cavity, thus potentially enhancing their usefulness in disaster scenarios.

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Artificial intelligence in age and sex determination using maxillofacial radiographs: A systematic review

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KEYWORDS

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Convolutional Neural Networks,
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Mandible,
Forensic Odontology,
OPG,
Lateral Cephalogram

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ABSTRACT

In the past few years, there has been an enormous increase in the application of artificial intelligence and its adoption in multiple fields, including healthcare. Forensic medicine and forensic odontology have tremendous scope for development using AI. In cases of severe burns, complete loss of tissue, complete or partial loss of bony structure, decayed bodies, mass disaster victim identification, etc., there is a need for prompt identification of the bony remains. The mandible, is the strongest bone of the facial region, is highly resistant to undue mechanical, chemical or physical impacts and has been widely used in many studies to determine age and sexual dimorphism. Radiographic estimation of the jaw bone for age and sex is more workable since it is simple and can be applied equally to both dead and living cases to aid in the identification process. Hence, this systematic review is focused on various AI tools for age and sex determination in maxillofacial radiographs. The data was obtained through searching for the articles across various search engines, published from January 2013 to March 2023. QUADAS 2 was used for qualitative synthesis, followed by a Cochrane diagnostic test accuracy review for the risk of bias analysis of the included studies. The results of the studies are highly optimistic. The accuracy and precision obtained are comparable to those of a human examiner. These models, when designed with the right kind of data, can be of tremendous use in medico legal scenarios and disaster victim identification.

INTRODUCTION

Forensic odontology deals with the proper administration and evaluation of dental evidence in criminal or civil legal proceedings in the interest of justice.[1] It involves identification by assessing and analysing the unique structures in the oral cavity.[2] Identification is the most important aspect of forensic and the application of forensic odontology involves teeth and jaw bones to aid in the process of identification. Identification through age and sex of bony remains is viable due to its ability to last longer under physical, mechanical stress.[3] Identification is attained with 100% accuracy if a complete skeleton is available, although this is rarely the case. In cases of mass disasters, with complete or partial loss of human structure or burns, it is impossible to find an intact human skeleton.[4] For age and sex determination after pelvis, skull is the most dimorphic structure. The Mandible being the strongest bone of the skull, is the bone of choice for age and sex determination.[5,6] Radiographs are simple, accessible, and cost effective and demonstrate high accuracy for age and sex determination. They can be easily advised in both living and dead.[7]

Artificial intelligence (AI) can be described as an intelligent computer system with the unique ability to mimic human potential in decision making, problem solving, understanding language and learning. AI models developed using machine learning, can predict events with given sets of observations in the form of images or data. AI not only overcomes the subjectivity of any diagnosis or individual examination but also reduces the overall cost.[8] Deep learning is another type of neural networks where the model on its own learns about the data and how to process the given data. Deep learning neural network have neurons in hidden layers in thousands and millions.[9,10] AI and its advent in the field of medical science have made the possibility of sound diagnosis and prompt prediction with decision making achievable.[11] The major feature of decision making with already known observation is the main feature of AI which will be of great significance in the field of forensic odontology. Studies have shown that AI has the accuracy and precision equivalent to trained examiner in age and sex determination of the individuals.[12,13] Hence this systematic review is aimed at reporting on Artificial intelligence in age and sex determination in forensic odontology.

MATERIALS AND METHODS

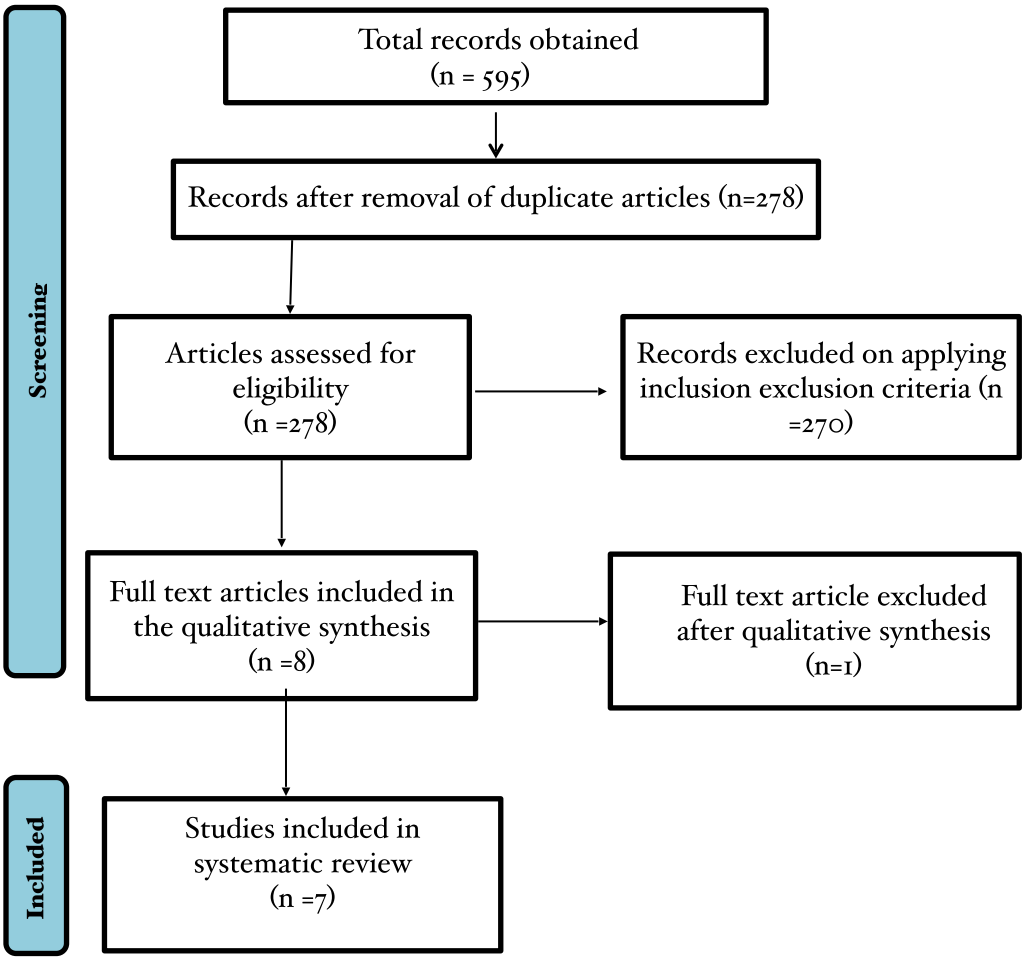
Search strategy and Review framework

To conduct this systematic review, articles that were based on the application of artificial intelligence in the mandible for age and sex determination were selected. Preferred reporting items for systematic reviews and meta-analyses PRISMA guideline for diagnostic test accuracy were used Fig.1.[14] The data search was conducted through various search engines, namely Pubmed, Cochrane, Google Scholar, and Scopus. The search duration spans 10 years, from January 2013 to March 2023. The following key words were used in various combinations to improve the search strategy like Artificial Intelligence (AI) Convolutional Neural Networks (CNN), Artificial Neural Networks (ANN), Mandible, Forensic Odontology, OPG, and Lateral Cephalogram. The PICO guideline was used for searching for the right kind of study to be included in the systematic review (Table 1).

Table 1. Table showing PICO (P = Population, I = Intervention, C = Comparison, O = Outcome) and Research Question.

RESEARCH QUESTION **How will Artificial intelligence tool be used in mandibular age and sex determination in forensic cases?**	
Population	Patients maxillofacial radiographs (Orthopantomogram, lateral Cephalogram, CBCT images)
Intervention	AI algorithms for age estimation and sex determination
Comparison	Comparison across different AI models, reference standards, expert opinions
Outcome	Measurable or predictive outcomes such as accuracy, Correlation Coefficient, sensitivity, specificity, ROC = receiver operating characteristic curve, AUC = Area Under the Curve.

Figure 1. PRISMA Flow chart showing the selection of articles for the systematic review.



Methodology
For the preliminary search, 585 articles were identified using database searches, and through other sources, an additional 11 articles were identified. The net article available after the first stage was 595. The retrieved articles were full texts and abstracts. In the first stage articles were chosen, based on their titles and the abstracts that addressed our research question. In the second stage, 278 articles were eligible for review after the removal of 278 articles because of duplication. The following inclusion and exclusion criteria were considered for the eligibility of the studies:

Inclusion criteria
The article must be about the application of AI to the mandibular bone. There should be specific mention of the AI based model used in the study. There should be a specified data set for each model to be applied for age or sex determination. There should be a measurable outcome to assess the role of AI in the study.

Exclusion criteria
Articles on tools apart from AI technology.
Articles with only abstracts and not full text.
Articles in languages other than English.

Data management
Post application of the above eligibility criteria, only 8 articles were obtained. Qualitative assessment was done for each article based on QUADAS 2 (Quality Assessment and Diagnostic Accuracy Tool) by the author.[15] One article was found to be a misfit amongst the 8 articles (Fig 1). 7 articles were available for final analysis, and these were read in full length so that AI application in the mandibular age and sex determination could be analysed. Each article was discussed among 4 domain namely patient selection, index test, reference standard, and flow

and timing. For each domain risk of bias was assessed in terms of high risk, unclear risk and low risk. Patient selection, index test, reference standard also assessed the applicability.

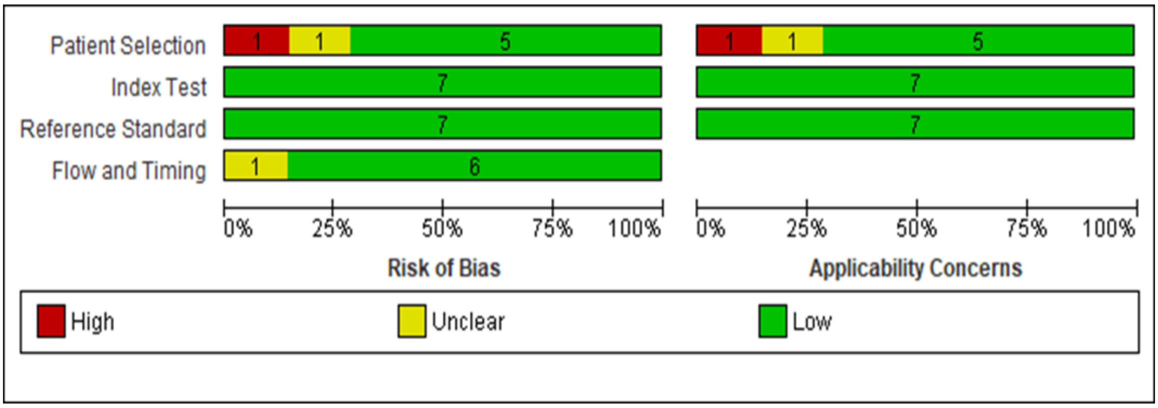
RESULTS

While conducting the systematic review, 7 articles were analysed for quantitative data. All studies that were finally analysed were conducted in the past five years, although inclusion criteria stated a duration of 10 years. All the studies were based on the AI tool and its application in mandibular age and sex determination. The models used in the study were ANN[16], ML[17], KCNN-KNN[18], BCNN[19], and CNN.[20-22] These neural network models were used to evaluate panoramic radiographs[16-20,22] and lateral cephalograms.[21]

Risk of bias

Risk of bias assessment was conducted under 4 domains, in patient selection, one study showed high risk[17] and one showed unclear risk.[20] Overall, 72% of studies showed low risk in patient selection. All studies focused on age and sex determination through the AI models therefore, there was an overall low risk for reference standards and index test. For the flow and timing of the study, one study showed unclear risk[17]. This risk of bias in assessment and applicability concern is shown in Fig. 2. The applicability showed similar results.

Figure 2. Figure showing the number of studies and their proportion under high risk, unclear and low risk categories for both Risk of Bias and Applicability Concerns.



DISCUSSION

Age and sex determination play a crucial role in the process of identification and in establishing an anthropological profile.[23] The resilience of jaw bones provides immense information for establishing the identity of any unknown body. Identification through bony and dental remains is critical in cases of chemical burns, burns, and complete or partial tissue loss.[24] The traditional morphometric measurement used for age and sex determination in radiographs fails to provide the proper identification. The ability of artificial intelligence to minimise error and precision in feature assessment, followed by prompt prediction, makes it a tool of choice.[15]

In the present systematic review, an effort has been made to analyse various AI tools for prompt identification involving age and sex in maxillofacial radiographs (Table 2).

Table 2. Details of studies in the systematic review involving AI based models in age and sex determination using maxillofacial radiographs.

Sl. No.	1.	2.	3.	4.	5.	6.	7.
Authors	Banjsak et al [22]	Baydogan et al [20]	Patil et al [16]	Khazaei et al [21]	Lee et al [17]	Back et al [19]	Sharifonnasabl et al [18]
Year of Publication	2020	2022	2020	2022	2022	2020	2022
Algorithm	CNN	CNN	ANN	CNN	ML	BCNN	HCNN-KNN
Objective	Convolutional neural network to estimate age of archaeological skull remains	Age detection for Deep learning from Dental panaromic radiographs	Artificial neural network for gender determination using mandibular parameters	CNN model for sex determination using lateral cephalogram	Machine learning algorithm for age group prediction using panaromic metric parameters	Age estimation using Bayesian convolutional neural network	Hybrid HCNN-KNN Model for Age estimation accuracy in orthopantomogr aphy
Training data set	3228	627	509	1180	471	2400	1537
Validation data set	403	Not clear	63	296	Not clear	Not clear	384
Testing data set	89	Not clear	63	296	Not clear	Not clear	none
Comparison	3 models	none	3 models	3 models	none	none	none
Study factor	Mandibular architecture and teeth	Mandible and teeth	Mandibular parameters	Mandible	Mandible and dental metric parameters	Upper and lower jaws	Upper and lower jaws
Modality	Orthopantomo grams	Orthopantomo grams	Orthopantomo grams	Lateral cephalogram	Orthopantomo grams	Orthopantomo grams	orthopantomo grams
Result	Model1:53% Model2:42% Model3:73%	84%	Discriminant analysis:69.1% Logistic regression:69.9% ANN:75%	DenseNet 121:90% ResNet:62% VGG 75%	87%	Concordance correlation coefficient ccc=0.91	99.80%
Effective(+) Non-effective(-) Neutral(-)	Effective(+)	Effective(+)	Effective(+)	Effective(+)	Effective(+)	Effective(+)	Effective(+)
Outcome	The study demonstrated noteworthy accuracy in placing images in correct age group	The study depicted high accuracy of dental age estimation	Outcome of the study depicts higher accuracy for gender prediction using ANN model	CNN based DenseNet121 has high predictive accuracy in sex determination using lateral cephalometric images	In machine learning models age group prediction accuracy was more than acceptable	Bayesian CNN quantifies the predictive uncertainty which is important in legal context	The model correctly classified age with 99.8% accuracy. Evaluating the proposed model on a new dataset with different races also proved the superior performance of the model
Recommend ation	Further development of neural net and training would offer better results	In future studies, different feature extraction and increasing number of data to be included for state- of- the art classifier	The results also needs to be extrapolated using larger population considering other confounding factors like origin, race,age, masticatory muscles	Further studies with larger sample size are desirable to more accurately determine sex correctly on larger scale	Additional classification with larger sample size is needed to determine whether the prediction performance will increase	Results are encouraging although the accuracy is not yet at the level that warrants routine application	none

In a study conducted by Back et al[16] for age estimation(15-25 years age), Bayesian Convolutional neural network was used to attain the concordance correlation coefficient ccc=0.910. Age estimation in orthopantomograms was formulated using a regression task and CNN was designed in which Inception V3 architecture was used. There was a considerable agreement between true age and predicted age; however, the mean absolute error was almost 2 years, which is highly unacceptable for legal purposes. The results were encouraging for the application of AI in the form of BCNN, but not to the level that confirms routine application.

Banjsak et al[22] used CNN for archaeological age estimation (19 to 85 years of age) through transfer learning. A VGG architecture pre trained on the ImageNet feature extractor was used. Three models were used for age prediction by just changing the hyperparameters. Model 1 showed 53% accuracy, Model 2 showed 42% accuracy, and Model 3 showed 73% accuracy. This study demonstrated a noteworthy accuracy that should be considered for further analysis using an orthopantomogram.

In another study conducted by Baydogan et al[20] for age determination (2 to 13 and 13 to 31 years) using orthopantomograms, CNN was used with the Alexnet architecture for feature extraction, followed by four classification algorithms. The K nearest neighbour algorithm showed the highest accuracy (84% accuracy). This study depicts high accuracy with the intervention of AI in age determination.

In a study conducted by Patil et al[16] for sex determination using ANN, orthopantomogram was used. Logistic regression and discriminant analysis were used for sex determination, along with an artificial neural network. ANN had an accuracy of 75%, much higher than the other two models. This study stated that ANN could be a promising prediction tool for sex determination in forensics.

Sharifonnasabi et al[18] conducted a study on orthopantomograms for age determination (15 to 23 years) using the HCNN-KNN model. This model had a very high accuracy of 99.8% for age determination. The precision was as high as +_ 6 months. Principal component analysis was used to compensate for overfitting. This study proves that a substantial model design could facilitate prompt age classification.

Khazaei et al[21] conducted a study on sex determination from lateral cephalometric radiographs using CNN. The three models, DenseNet, ResNet, and VGG, were evaluated for their ability to correctly determine the sex of the lateral cephalogram. DenseNet 121 architecture depicted the highest accuracy of 90%. The study also showed the importance of transfer learning to attain high accuracy in sex determination. The study gives desirable results and can be implemented with a larger sample size.

In a study conducted by Lee et al[17] for age determination (11 to 69 years), machine learning was used. Five machine learning models were formulated. Each model demonstrated high accuracy for age group prediction. Overall accuracy of 87% was achieved, although a larger sample size is needed to determine the true prediction accuracy.

The above mentioned studies have used various models in order to provide age or sex determination with accuracy higher than the already existing methodology. All these studies have certainly high accuracy, but translating the results into routine applications will require a deeper and more detailed study. Although the present study is based on AI application on mandibular bone, expanding the application to dental age and sex determination can be of great help if interpreted together. Teeth based age and sex determination using a hybrid transformer model can add significant value to overall results.[26] The ability of AI to provide objective and accurate decision making can be used explicitly in other domains like bitemark, facial identification, and dental comparison.[27] AI is a game changer when the correct data is available. Data in the form of maxillofacial radiographs is a prerequisite for such studies. In several studies deep convolutional network have proven to be of high accuracy and practical significance with accuracy as high as 94.7%.[28] The advent of AI in the field of forensic medicine and odontology will certainly aid in quality decision making. This overarching domain requires skilled manpower and high quality data to provide highly objective and accurate results. Artificial intelligence provides an opportunity to revolutionise the disciple, but comes with certain challenges. The issue of data privacy being one of the major hindrances, followed by the availability of a huge amount of good quality data is a challenge. This in turn could perpetuate bias and amplify incorrect discrimination ability.[29] In order to mitigate the possible disadvantages offered by AI, extensive research, an expanding knowledge base, and exploring the true potential of deep learning and machine learning algorithms are to be done. Good quality data is the cornerstone of all AI applications. This data can be helpful for obtaining prompt results in age and sex determination in real-life scenarios, and could be of great help in cases of mass victim identification, decomposed bodies, and criminal cases where it is important to establish age and sex along with other parameters.

CONCLUSION

We are at the doorstep of another technological advancement, which will be directed by artificial intelligence. AI and its ability to mimic human capabilities and decision-making are already taking over various sectors. Forensic medicine, forensic odontology, and anthropology are no exceptions. The advent of AI, with the help of good-quality data and vast information, can be an excellent tool. For age and sex determination, quality and quantity of data are imperative to facilitate the development of proper models or tools that the authorities can rely upon. The development of such a model can be utilised by medical, legal, police, and forensic authorities. Therefore, future studies are recommended by utilising the application of AI in age and sex determination in a wider maxillofacial radiographic data set.

Statements and Declarations:
No competing interest have appeared to affect the work.

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Are computed tomography images of the mandible useful in age and sex determination? A forensic science meta-analysis

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KEYWORDS

Mandible,
Jaw,
Computed tomography,
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Human Identification

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ABSTRACT

Objectives. This meta-analysis addresses the use of mandibular computed tomography (CT) scans for age and/or sex determination in forensic science.
Methods. Six databases were searched until June 2023, using the keyword "mandible" combined with keywords related to "multislice computed tomography" (MCT) or "cone-beam computed tomography" (CBCT) and keywords related to "skeletal age determination" or "sex determination analysis."
Main Results. Among the 23 studies included, 11 used MCT and 12 used CBCT to perform forensic assessments. Age determination was the aim of a single study, sex and age determinations were the objective of five studies, and the other studies investigated the determination of sex only. Meta-analysis could be performed only for sex determination.
Conclusions. Mandible measurements are useful in sex determination, as the bicondylar and bigonial breadth are larger in males than in females. For the mandible angle, the meta-analysis results confirm sex dimorphism in CBCT scans but not in MCT scans. For age estimation, further studies are needed to prove that the mandible hole is a reliable parameter for age estimation. PROSPERO registration number: CRD42021260967.

INTRODUCTION

In forensic science, sex and age determination are fundamental aspects of personal identification. As the mandible is the largest and longest-lasting facial bone, it has a critical role in human identification, particularly in the absence of a complete skull or pelvis.[1] Determining individual features using the mandible comprises the use of measurements and macroscopic morphological form assessments.[1]

The integration of forensic science and medical imaging technology has contributed to considerable advances in forensic science; it is now possible to evaluate body structures in highly decomposed or contaminated bodies or in cultures with low autopsy acceptance.[2] Although plain radiographs have their value in forensic practice, technologies with 3D outputs, such as computed tomography (CT),[2] that provide accurate and reliable imaging of maxillofacial structures have been largely studied and applied in forensic science.

Multislice computed tomography (MCT) and cone-beam computed tomography (CBCT) are CT imaging techniques that use the same imaging reconstruction principle, although they differ in radiation dose and in spatial, contrast, and temporal resolution.[3] CBCT is typically applied in cases of dental and jaw disorders; however, it is not applied in cases of neoplastic lesions where the administration of contrast agents and evaluation of soft tissues is required.[3]

For postmortem human identification, several combinations of distinct mandible landmarks and linear or angular measurements have been proposed and extensively studied. However, this process is complicated by the fact that it is difficult to access and assess complex anatomical structures or sites in mandibles covered by soft tissue. Thus, MCT and CBCT have been utilized as imaging tools in forensic investigations. Frequently, the objective of such investigations was to verify the correlation between the linear or angular measurements of mandibular anatomical sites and age or sexual dimorphism in different populations. Some of the studies also investigated the influence of age and sex on mandible shape. However, comparisons that include distinct populations have not yet been performed.

Hence, the objectives of the present systematic review were to determine 1) the mandible sites that have been studied for skeletal age and sex determination, 2) the main results and conclusions of the reviewed studies, and 3) whether mandible images are useful in the determination of age and sex for human identification. It should be noted that only studies that used MCT or CBCT for mandible-based assessment of age and/or sex were included in the review.

MATERIALS AND METHODS

Protocol and registration

This systematic review and metanalysis is registered at the National Institute for Health Research, International Prospective Register of Systematic Reviews (PROSPERO). The registration number is CRD42021260967. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist was followed.[4]

Data selection

The selection of studies potentially eligible for inclusion in this was performed using the following databases: PubMed Central® (United States National Institutes of Health's National Library of Medicine), Embase® (Excerpta Medica Database), Scopus® (Elsevier), Cochrane Central Register of Controlled Trials, Web of Science® (Institute of Scientific Information – Clariative Analytics), and Google Scholar® (Google). The aforementioned databases were searched without language and time restrictions (until June, 2023). The Boolean operators "AND" or "OR" were used to combine and optimize the searches.

Itemized search strategies were established for each database based on keywords determined by "Medical subjects headings" (MESH): "Mandible" combined with keywords defining MCT as: "Multislice Computed Tomography OR Multidetector Computed Tomography OR Multidetector-Row Computed Tomography OR Multisection Computed Tomography" or keywords defining CBCT as: " Cone-Beam Computed Tomography OR CT Scan, Cone-Beam OR Cone-Beam CT OR Cone-Beam Computer-Assisted Tomography OR Cone-Beam Computerized Tomography OR Volume CT OR Volume Computed Tomography OR Volumetric CT OR Volumetric Computed TomographyCT Scan, Cone-Beam OR Cone-Beam CT OR Cone-Beam Computer-Assisted Tomography OR Cone-Beam Computerized Tomography OR Volume CT OR Volume Computed Tomography OR Volumetric CT OR Volumetric Computed Tomography".

For searches regarding age determination, the following keywords were added to the aforementioned combination: "Age Determination by Skeleton OR Bone Age Measurement OR Skeletal Age Measurement OR Skeletal Maturation Index". For searches regarding sex determination, the following keywords were added: "Sex Determination Analysis OR Sex Determination Technics OR Sex Determination Techniques".

Manual searches were also performed.

Eligibility criteria: Types of studies and Participant groups

Published research articles or technical notes were considered for inclusion. Abstracts, oral presentations, case reports and literature reviews were excluded.

Investigations with mandible measurements or morphologic classifications for age and sex determinations in forensic science, using MCT or CBCT were considered for inclusion. Investigations about development of software or equations for age or sex determination without measurements or morphologic classifications were excluded.

The articles considering the following assessments were excluded: dental status, canal mandibular,

mandibular foramen, mental foramen, alveolar bone evaluations.
MCT or CBCT scans performed in human beings were included. Studies performed in dried mandibles or that did not used MCT or CBCT were excluded. Investigations that not included mandible bone in the assessment, were not considered for inclusion.

Data extraction
Data extraction was executed by two independent reviewers, who initially screened the titles and abstracts, and then evaluated the full text of each selected study. The screening and selection of potentially included studies will be performed using Rayyan QRI (https://www.rayyan.ai/).[5]
The search results were summarized in one flow chart, according to PRISMA statement[6] (Figure 1 – data selection) and tables (Tables 1 to Table 4).

Data analysis – risk of bias
The quality of each original research were be assessed using the Cochrane risk of bias tool for non-randomized studies, [7] and demonstrated in a figure (Figure 2) using Robvis tool[8] (https://mcguinlu.shinyapps.io/robvis/).

Figure 1. PRISMA flow diagram illustrating the literature search

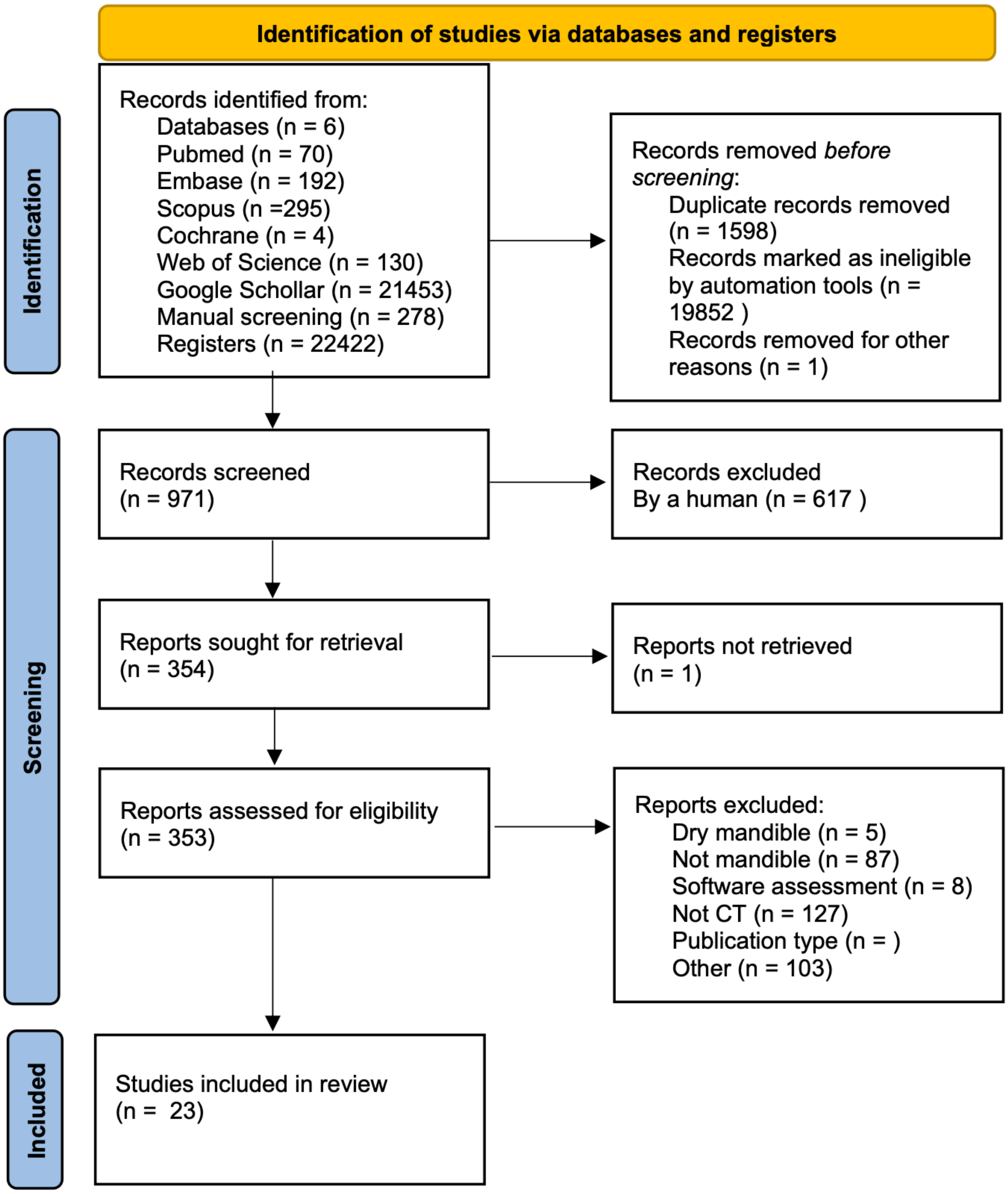


Table 1. Year of publication, main subject (skeletal age or sex determination), type of computed tomography used (Multislice computed tomography or cone beam computed tomography), sample features and ethnicity of the group studies

Author	Year	Country	Determination sex or age?	Bones included	Type of CT	Sample features	Origin of the population studied
Atef et al.[9]	2020	Libya and Egypt	Sex	Mandible	MCT	200 CT scans: minimum age 18 years; maximum age 60 years; 87 females, 113 males	Libyan Population in Tripoli
Imaizumi et al.[10]	2020	Japan	Sex	Mandible and Skull	MCT	100 CT scans: minimum age 23 years; maximum age 65 years; 114 females, 99 males	Japanese
Gillet et al.[11]	2020	France	Sex	Mandible and Skull	MCT	120 CT scans, minimum age 23; maximum age 84 years, 57 females and 63 males, divided in three groups: whole sample, over 40 years, under 40 years.	French
Motawei et al.12	2020	Egypt, Saudi Arabia, Taiwan	Age and Sex	Mandible	CBCT	213 CT scans: minimum age 7 years; maximum age 63 years; 114 females, 99 males	Egyptians
Okkesim and Erhamza[13]	2020	Turkey	Sex	Mandible	CBCT	70 CT scans: minimum age 18 years; maximum age 29 years; 35 females, 35 males	Central Anatolian Turkish
Fan et al.[14]	2019	Australia and Belgium	Sex	Mandible	CBCT	654 CT scans: minimum age 8.5 years; maximum age 19.5 years; 386 females, 268 males	Australian? (Email sent to the author)
Albalawi et al.[15]	2019	Saudi Arabia	Sex	Mandible	CBCT	200 CT scans: minimum age 18 years; maximum age 60 years; 104 females, 96 males.	Saudi Arabia
Bulut et al.[16]	2019	Germany and Turkey	Sex (according to age ranges)	Mandible	MCT	300 CT scans: minimum age 20 years; maximum age 80 years; 150 females, 150 males.	White (country of origin not specified)
Tassoker et al.[17]	2019	Turkey	Sex and age	Mandible	CBCT	121 CT scans: minimum age 10 years; maximum age 69 years; 71 females, 50 males	Turkish (from Middle Anatolia)
Alias et al.[18]	2018	Malaysia	Sex	Mandible	MCT	79 CT scans: minimum age 18 years; maximum age 74 years; 31 females, 48 males.	Malaysian
Barak et al.[19]	2018	Turkey	Age and Sex	Mandible	CBCT	433 CT scans: minimum age 8 years; maximum age 31 years; 260 females, 173 males.	Turkish
Barbieri et al.[20]	2018	Brazil	Age and Sex	Mandible	CBCT	60 CT scans: 30 females, 30 males. The scans were divided in groups according to age (5 examinations for each decade of life).	Brazilian
Zheng et al.[21]	2018	China	Sex (age as secondary objective)	Mandible and maxilla	CBCT	420 CT scans: minimum age 18 years; maximum age 70 years; 210 females, 210 males.	Han adults in Northeast China

Deng et al.[22]	2017	China	Sex	Mandible	CBCT	219 CT scans: minimum age 7 years; maximum age 20 years; 108 females, 111 males	Central Chinese
Tunis et al.[23]	2017	Israel	Sex	Mandible	MCT	438 CT scans: 214 females, 224 males; male mean age 53.3 ± 19.9; female mean age 56.2 ± 20.6 years.	Israeli
Inci et al.[24]	2016	Turkey	Sex	Mandible	MCT	415 CT scans: minimum age 18 years; maximum age 60 years; 214 females, 201 males.	Turkish
Gamba et al.[25]	2016	Brazil	Sex	Mandible	CBCT	160 CT scans: minimum age 18 years; maximum age 60 years; 86 females, 74 males.	Brazilian
Dong et al.[26]	2015	China	Sex	Mandible	CBCT	203 CT scans: minimum age 20 years; maximum age 65 years; 107 females, 96 males.	Chinese Han
Kano et al.[27]	2015	Japan	Sex	Mandible	MCT	232 CT scans from cadavers: minimum age 16 years; maximum age 100 years; 106 females, 116 males	Japanese
İlgüy et al.[28]	2014	Turkey	Sex	Mandible	CBCT	161 CT scans: minimum age 18 years; maximum age 85 years; 95 females, 66 males.	European descendants
Lin et al.[29]	2014	China and Republic of Korea	Sex	Mandible	MCT	240 CT scans: minimum age 21 years; maximum age 70 years; 120 females, 120 males.	Korean
Minier et al.[30]	2014	France	Age	Femur and mandible	MCT	167 CT scans of fetuses (74 females and 93 males), aged from 20 to 40 weeks. The mandible was missing in 16 fetuses	Not specified
Karoshah et al.[31]	2010	Egypt and Saudi Arabia	Sex	Mandible	MCT	500 CT scans: minimum age 6 years; maximum age 60 years; 250 females, 250 males.	Egyptian

Abbreviations: MCT: multislice computed tomography; CT: computed tomography; CBCT: cone beam computed tomography

Statistical Assessment

Variables were assessed only if data provided was available as "mean values" and "standard deviations" from 3 or more investigations using exactly the same measurement and the same type of CT. Data was not considered for the meta-analysis if incomplete or missing the population origin. The analysis was carried out using the standardized mean difference as the outcome measure. A random-effects model was fitted to the data. The amount of heterogeneity was estimated using the maximum-likelihood estimator. In addition to the estimate of tau^2, the I^2 statistic are reported.

Meta-analysis assessments were performed using Jamovi version 1.6 (The Jamovi Project).

Table 2. Summary of the methodology, results and conclusions of the studies included

Author	Methodology applied	Results	Conclusions
Atef et al.[9]	Quantitative assessment (measures in mandible)	There are differences between male and female in all mandibular parameters except minimal ramus breadth and gonial angle.	Mandible can be used to differentiate sex as evidenced by that female were higher than male except gonial angle.
Imaizumi et al.[10]	Morphologic studies and machine learning for shapes creation.	The validation results on actual casework skulls were less acceptable than expected; a larger sample is needed to achieve better results.	The sex estimation method developed enables to perform objective identification of skeletal remains.
Gillet et al.[11]	Metric and geometric morphometric methods to evaluate size and shape-related sexual dimorphism.	Cranium was the most dimorphic structure, regardless of which analysis method and individual's age. The assessment of mandible did not increase sex estimation accuracy for the whole skull.	Although the mandible does not appear to be the most dimorphic structure of the cephalic extremity sample, it remains a useful tool in the absence of an intact skull.
Motawei et al.[12]	The length of the ramus of the mandible was measured in lateral CT scans.	There are no sexual dimorphism of the mandible ramus length until the age of 17 years.	The mandibular ramus length is valuable in age estimation and less valuable in sex determination.
Okkesim and Erhamza[13]	Linear parameters were measured using the mouse-driven method.	It was found that all variable of mandibular ramus on CBCT models showed a statistically significant difference between males and females.	The development of standards to each population for accurate gender identification from skeletal remains is needed.
Fan et al.[14]	Growth trajectories of the mandible in males and females were modelled using a non-linear kernel regression framework.	Mandibular sexual dimorphism already exists at 9 years of age, but this is mostly in size, but not in shape. Significant dimorphism was evident by 11 years and increased through adolescence.	Growth direction in both males and females is similar but is faster, peaks later and occurs over a longer period in males than in females.
Albalawi et al.[15]	Mandibular angular measurements using 3D images.	Measurements presented differences between males and females.	The angle formed by the intersection of lines from the left and right gonion to mention helps in providing anthropological data.
Bulut et al.[16]	Measurements and comparisons of gonial angle, using 3D CT imaging. Sample divided according to sex and grouped according to age ranges.	The authors showed that the gonial angle is sexually dimorphic in senior adult ages (60 – 80 years). Females have larger gonial angles in all 3 age groups (no statistic test showed for the aforementioned information provided by authors).	The results revealed that the gonial angle is not a particularly good indicator to identify the sex from the cranium and should not be used as a sole criterion.
Tassoker et al.[17]	Authors compared panoramic radiographs with CBCT using linear and angular measurements.	According to CBCT examinations, right and left gonial angle are higher in females than males.	Panoramic radiography measurements showed significant differences from CBCT in the mandible.
Alias et al.[18]	Morphometric and morphological parameters analysis using 3D imaging	In this study, all parameters were found to be greater in male mandibles than in female. By stepwise discriminant function analysis, from the bigonial breath and condylar height were the best parameters selected in the analysis.	The mandible could be distinguished according to the sex in the Malaysian population.

Barak et al.[19]	Condyle cortication assessment using visual classification: type 1 (no cortication); type 2; type 3 (surface with similar or higher density than the surrounding cortical areas).	For Males: *Type I mean age observed: 14.14 years *Type II mean age observed: 16.11 years *Type III mean age observed: 19.39 years For Females: *Type I mean age observed: 13.01 years *Type II mean age observed: 15.52 years *Type III mean age observed: 17.95 years	Chronologic age increased as the stages of the cortication progress from Type I to Type III in male and female individuals, and all the stages of the cortication in the mandibular condyle of male occur compared to female.
Barbieri et al.[20]	3D models generated from 3D angular measuring tools.	No differences were found between mandibular incision measurements in both sexes, or age ranges groups.	The structure evaluated cannot contribute to forensic anthropology evaluations.
Zheng et al.[21]	The maxillofacial bones were measured in the median sagittal position.	Evaluation of variables using CBCT reconstruction technology provided a new theoretical basis and practical means for sex determination.	Sex determination of maxillofacial region using CBCT has a high accuracy rate and is also applicable to different countries.
Deng et al.[22]	Four linear variables were selected in the mandible 3D images.	It was demonstrated that the breadth size of the mandible is a useful in sex determination in the studied population.	Virtual measurements obtained from 3D images by CBCT may serve as a substitute for direct anatomic measurements.
Tunis et al.[23]	Linear measurements from 3D reconstructions of the mandible.	Except for mandibular angle, males have a greater mean value than females.	The method applied is not age dependent.
Inci et al.[24]	Linear distances and angle measurements.	There was no statistical difference in the mandibular flexure angle between males and females. Mandibular angle values were higher in females. Comparing the accuracy rates of sex determination, the upper ramus vertical height showed the highest dimorphism.	Morphometric measures of the upper part of the ramus, can provide valuable data to determine sex in a Turkish population.
Gamba et al.[25]	Measurements obtained from 3D sagittal views and axial views	Authors validated a formula that provided an imaging metric that can assist the dental examiner.	Bicondylar breadth, Ramus length, Bicondylar breadth, and Gonial angle showed better reliability for sex estimation.
Dong et al.[26]	Linear or angular measurements using 3D images from CBCT scans.	All of the measurements studied were sexually dimorphic, with the maximum mandibular length and bi-condylar breadth being the most dimorphic.	Mandible expresses sexual dimorphism in the contemporary adult Han Chinese population.
Kano et al.[27]	Quantitative measurements and correlation with body height as a secondary data.	Although these parameters weakly depended on the body height, the correlations were insufficient for stature estimation.	These findings suggest the efficacy of CT morphometry of the mandible for sex discrimination with quantitative assessment.
İlgüy et al.[28]	Measurements were performed using 3D imaging.	The mean values of mandibular measurements were greater for males than females except for gonial angle.	The sagittal diameter of foramen magnum seems to be useful according to the discriminant analysis test for sex determination.
Lin et al.[29]	Measurements using mandible 3D models.	Males are larger than females in all variables, except for mandibular flexure angle, mandibular flexure depth and mandibular flexure lower border and mandible angle.	The upper ramus above flexure has the larger potentials than the mandibular ramus flexure itself to discriminate sexes.

Minier et al.[30]	Linear and angular measurements of the mandible and femur.	Femoral length and mandible measurements presented correlation with age; however femoral length correlation was stronger than mandible correlation.	Mandible is a reliable indicator for estimating fetal age at death.
Karoshah et al.[31]	Measurements in 3D models	Significant differences and included: bicondylar breadth, gonial angle and minimum ramus breadth.	The overall predictive accuracy of the prediction model constructed was 83.9%

Table 3. Measurements performed, and their main values, angles or morphometric parameters reported (values or classification, if applicable) and statistical analysis results from publications that used MCT in the assessments

Authors	**Measurements in mandible**	**Mean values provided (mm)**		**Angles measured in mandible or morphometric parameters**	**Values reported for the mandible angles measured or morphologic features**		**Statistical analysis results***
		Male	**Female**		**Male**	**Female**	
Atef et al.[9]	*Ramus length[a] *Minimal ramus breadth *Coronoid height *Gonion-gnathion length *Bicondylar breadth *Bigonial length	58.2 23.3 53.7 60.1 96.3 77.7	49.1 23.4 47.1 50.3 87.9 76.7	*Gonial angle	121.51	125.0	Except for minimal ramus breadth, variables showed statistically significant differences. Mandible angle was higher in females than males.
Imaizumi et al.[10]				*Mental eminence *Gonion *Chin	Projected Everted Squared	Little/no projection Little/no eversion Oval	Virtual shapes created showed clear sexual dimorphism.
Gillet et al.[11]	*Mandibular symphyses height *Ramus height[a] *Bigonial breadth *Bicondylar breadth	Male 32.25 58.96 94.94 104.16	Female 29.43 54.34 87.52 96.77	*Gonial angle	Not reported		Male presented higher mean values than females, except for gonial angle.
Bulut et al.[16]				*Gonial angle (20 – 39 years) (40 – 59 years) (60 – 80 years)	123.73 123.38 122.99	124.03 124.16 124.69	No statistically difference was observed among the age groups in both sexes; except for the age range 60 – 80 years, with higher values for the gonial angle for females than males (p = 0.04).

Alias et al.[18]	*Maximum breadth of ramus *Minimum breath of ramus *Condylar height *Maximum height of ramus *Coronoid height *Mandibular Body Height *Symphyseal height *Bicondylar Breadth *Bigonial Breadth	Mean values not provided		*Shapes chin: Squared Pointed *Gonial flare Everted Inverted *Muscle markings More prominent Less prominent	92% 85% 90%	84% 80% 90%	The independent t-test showed significant difference between males and females.
Tunis et al.[23]	*Ramus length[b] *Ramus width *Body length *Mandibular angle Width *Coronoid width *Coronoid height *Condyle width *Chin width *Bicondylar Breadth *Bigonial breadth *Chin height[a] *Chin thickness *Chin area *Symphysis area *Symphysis Thickness *Symphysis height	66.9 31.8 79.9 34.5 23.7 19.4 20.3 28.3 122.4 94.0 21.6 4.0 52.9 322.9 15.5 33.1	58.9 30.2 75.0 31.5 22.4 17.5 18.4 23.2 115.7 87.1 21.0 3.9 50.3 283.5 14.4 30.1	*Mandibular Angle	123.5	125.6	Significant differences between males and females were found for all mandibular external measurements and for most of the internal measurements. Except for mandibular angle, males have a greater mean value than females.
Inci et al.[24]	*Minimum ramus breadth *Maximum ramus breadth *Mandibular flexure upper border Distance *Mandibular flexure lower border Distance *Mandibular flexure depth vertical distance *Mandibular ramus flexure vertical height *Maximum ramus vertical height *Upper ramus vertical height	Mean values not provided		*Mandibular angle *Upper mandibular flexure angle (Mandibular flexure upper border - posterior plane of mandibular ramus) * Mandibular flexure angle (Mandibular flexure upper border - Mandibular flexure lower border)	Mean values not provided		Mandibular flexure angle presented no statistical difference between males and females. Mandibular angle values were higher in females (P<0.001); all other values were higher in males (P<0.001).

Kano et al.[27]	*Bicondylar breadth *Bigonial width *Gnathion - Condylus	128.4 102.9 125.2	121.7 95.8 117.4	*Angle formed by bilateral gnathion and condyles *Mandibular Angle	61.5 126.0	63.3 129.8	Sex difference in virtual measurements were observed in the angle formed by bilateral gnathion and condyles. No mention about mandibular angle results.
Lin et al.[29]	*Minimum Ramus Breadth *Maximum Ramus Breadth *Mandibular Flexure Upper Border *Mandibular Flexure Lower Border *Mandibular Flexure Depth *Mandibular Ramus Flexure *Maximum Ramus Vertical Height *Upper Ramus Vertical Height	36.46 46.71 26.01 17.08 2.22 26.71 57.62 30.92	34.24 44.08 22.92 18.01 2.24 24.96 51.52 26.56	*Mandibular Angle *Upper Mandibular Flexure Angle *Mandibular Flexure Angle	122.53 52.52 165.31	124.30 50.01 164.62	Mean measurement values between male and female showed statistically significant differences, with the exception of mandibular flexure angle, mandibular flexure depth and mandibular flexure lower border. Males are larger than the females except for mandible angle ($p<0.05$).
Minier et al.[30]	*Coronoid process-Condylar process *Condylar process-Mandibular angle *Mandibular angle-Mental tubercle *Condylar process-Mental tubercle *Coronoid process-Mandibular angle *Coronoid process-Mental tubercle	Mean values not provided		*Mental Tubercule-Coronoid process-condylar process *Coronoid process-condylar process-mandibular angle *Condilar process-mandibular angle-Mental tubercule *Mandibular Angle-Mental Tubercule-Coronoid Process	Mean values not provided		Distances Coronoid process to Condylar process and Coronoid process to Mandibular angle (R2=0.85);Condylar process to Mental tubercle (R2=0.72).
Karoshah et al.[31]	*Ramus length[b] *Minimum ramus breadth *Mandibular base length (gonion–gnathion length) *Bigonial breadth *Bicondylar breadth	Male 65.1 28.7 76.2 104.8 108.9	Female 64.7 27.96 83.1 100.8 99.6	*Gonial angle	Male 122.8	Female 121.1	Bicondylar breadth and minimum ramus breadth were significantly higher in males than in females. Gonial angle in males was significantly greater than that in females.

[a]Distance between gonion and condilyon
[b]Distance from the highest point on the condyle to the gonion
*Pertaining to data demonstrated in this table only

Table 4. Measurements performed, and their main values, angles or morphometric parameters reported (values or classification, if applicable) and statistical analysis results from publications that used CBCT in the assessments

Authors	Measurements in mandible	Mean values provided		Angles measured in mandible or morphometric parameters	Values reported for the mandible angles measured or morphologic features		Statistical analysis Results*
		Male	Female		Male	Female	
Motawei et al.[12]	*Mandible Ramus Length (07 – 17 years) (17 – 58 years)	4.79 6.04	4.66 5.42				No significant differences between sex in age range of 7 to 17 years; significant difference between males and females for the mean length of the mandible ramus in the age range of 17–58 years.
Okkesim and Erhamza[13]	*Coronoid height *Condilar height *Mandibular ramus height *Maximum ramus breadth *Minimum ramus breadth	63.54 66.65 53.91 38.41 31.68	57.57 59.98 48.00 35.16 28.97				All measurements in mandible ramus presented significant differences.
Fan et al.[14]				*Gonial angle *Chin Females = more obtuse gonial angle and a narrower chin compared with males. These two traits become more distinct during growth.		More obtuse narrower	Females presented a more obtuse gonial angle and a narrower chin compared with males. These two traits become more distinct during growth. Considering the total sample, mandible was larger in males than in females at all ages. The size difference became greater, as the size of the mandible increased more rapidly in males than in females. The growth rate is similar at 9–10 years for both
Albalawi et al.[15]	*Linear distance from the gonion right to menton *Linear distance from the gonion left to menton *Linear distance from the gonion right to gonion left	86.8 49.5 47.7	82.6 47.7 46.6	*Angle formed by gonion right to menton to gonion left.	129.9	126.7	Statistically significant values were found for differences for all variables studied (p = 0.000)

Tassoker et al.[17]	*Right Ramus length *Left Ramus length *Right maximum ramus breadth *Bigonial width	6.51 6.35 4.11 17.42	5.92 5.83 3.84 16.38	*Right gonial angle *Left gonial angle	117.13 118.02	120.03 119.41	Males have mostly higher mandibular measurements on panoramic radiographs and CBCT except the gonial angle. Maximum ramus breadth presented statistical significance differences when comparing distinct age ranges.
Barak et al.[19]		Qualitative assessment of mandibular condyle cortication		*Type I: (no cortication) Mean age: 14.14 *Type II: Lower density in superior surface Mean age: 16.11 *Type III: Similar or higher density in superior surface Mean age: 19.39			Males with Type I and II cortication were older than females. Females presented more Type III cortication than males.
Barbieri et al.[20]				*right mandibular notch angle *left mandibular notch angle	102.01 102.70	105.25 103.55	No statistically significant differences were found between mandibular incision measurements in both sexes, and in the different age groups studied.
Zheng et al.[21]	*Area of mandibular Foramen *Bigonial breadth *Direct distance between right and left coracoid *Height of symphysis * Min-height of mandibular notch *Min-breadth of mandibular ramus *Buccal side bone thickness of Mandibular foramen * Tongue side bone thickness of Mandibular foramen *Vertical diameter of Mandibular foramen *Horizontal diameter of Mandibular foramen *Vertical from prosthion to palatal breadth	7.18 103.39 102.01 32.52 52.33 34.61 1.03 5.91 2.23 3.84 38.70 41.60	5.95 95.83 97.11 29.64 47.82 32.00 0.93 5.76 2.23 3.50 37.17 40.37	*Mandibular angle (total sample) (18 – 24 years) (25- 30 years) (31- 40 years) (41-50 years) (51- 60 years) (61 – 70 years)	121.52 122.70 120.44 122.45 120.92 121.83 120.80	125.44 125.35 124.78 126.19 125.42 125.62 125.27	Significant differences were not observed in two variables: Tongue side bone thickness of mandibular foramen and vertical diameter of mandibular foramen. Female presented higher values of Mandibular angle. Considering age ranges, mandibular angle and the other variables did not present differences when genders were compared.

Deng et al.[22]	*Bicondylar breadth *Bigonial breadth *Biantegonial notch breadth *Bimental foramina breadth	129.70 100.19 89.81 49.45	121.80 93.55 85.72 47.32				All the breadth dimensions described were significantly larger in males than in females.
Gamba et al.[25]	*Ramus length *Gonion-gnathion length *Minimum ramus breadth *Bigonial breadth *Bicondylar breadth	54.36 70.37 28.70 118.48 94.96	49.41 67.14 28.91 110.03 87.47	*Gonial angle	121.28	119.83	All variables showed differences between sex except minimum ramus breadth. Gonial angle in male was larger than in female.
Dong et al.[26]	*Bicondylar breadth *Bigonial breadth *Bi-antegonial notch breadth *Bi-mental foramina breadth *Distance between mental foramen and mandibular inferior border *Maximum mandibular ramus breadth *Maximum mandibular length *Maximum mandibular ramus height *Maximum mandibular body length	130.00 100.281 90.072 49.734 15.297 45.413 126.198 65.962 86.458	121.44 93.594 85.674 47.228 14.006 41.996 117.398 58.243 81.462	*Mandibular angle *Mental angle	123.444 72.909	126.648 71.974	Mental Angle was the only measurement that did not presented statistical significance.
İlgüy et al.[28]	*Ramus length *Min ramus breadth *Gonion–gnathion length *Bigonial breadth *Bicondylar breadth	61.67 29.89 71.86 100.33 120.79	54.72 28.09 67.73 94.77 116.23	*Gonial angle	121.14	122.31	The mean values of mandibular measurements were greater for males than females except for gonial angle.

Figure 2. Risk of bias assessment according to Robvis

Study	D1	D2	D3	D4	D5	D6	D7	Overall
Atef et al.	+	+	+	+	+	+	+	+
Imaizumi et al	+	+	+	+	+	+	+	+
Gillet et al	+	+	+	+	+	+	+	+
Motawei et al.	+	+	+	+	+	+	+	+
Okkesim and Erhamza13	+	+	+	+	+	+	+	+
Fan et al.	+	+	+	+	+	+	+	+
Albalawi et al	+	+	+	+	+	+	+	+
Bulut et al	+	+	+	+	-	+	+	+
Tassoker et al	+	+	+	+	+	+	+	+
Alias et al	+	+	+	-	+	+	+	-
Barak et al	+	+	+	-	-	+	-	-
Barbieri et al	+	+	+	+	+	+	+	+
Zheng et al.	+	+	+	+	+	+	+	+
Deng et al	+	+	+	+	+	+	+	+
Tunis et al	+	+	+	+	+	+	+	+
Inci et al.	+	+	+	+	+	+	+	+
Gamba et al.	+	+	+	+	+	+	+	+
Dong et al.	+	+	+	+	+	+	+	+
Kano et al	+	+	+	+	+	+	+	+
İlgüy et al.	+	+	+	+	+	+	-	-
Lin et al.	+	+	+	+	+	+	+	+
Minier et al	+	+	+	+	+	+	+	+
Karoshah et al	+	+	+	+	+	+	+	+

Domains:
D1: Bias due to confounding.
D2: Bias due to selection of participants.
D3: Bias in classification of interventions.
D4: Bias due to deviations from intended interventions.
D5: Bias due to missing data.
D6: Bias in measurement of outcomes.
D7: Bias in selection of the reported result.

Judgement
- Moderate
+ Low

RESULTS

A total of 23 studies were included. 9-31 Eleven studies perform forensic assessments in MCT[9-11, 16, 18, 23, 24, 26, 28-30] and twelve studies in CBCT.[12-15, 17, 19-22, 25, 27, 31] Some author also evaluate other bones but mandible, such as the femur, [29] maxilla[21] and skul.l[9, 10] The number of CT scans evaluated ranged from 60[20] to 654[14] and the age of the patients that performed the CT scans ranged from 6[30] to 100[26] years old, except for a study that included fetuses.[29] The origin of the population included in the samples were highly heterogeneous and highly specific, as Libyan from Tripoli[11] or Turkish from Middle Anatolia.[17] Data about the year of publication, country of the assessments origin, bones included, type of CT and sample features are available on Table 1.

Age alone was the aim of a single study, which investigated mandibles of fetuses.[29] Sex and age determinations was the objective of five studies, [12, 16, 17, 19-21] although age determination was a secondary data in two of them. [16, 21] The other studies investigated the possibility to determine sex using mandible bone data with different methodologies.[9-11, 13-15, 17, 18, 20, 22-28, 30, 31]

In Table 2, the methodology applied in the studies, the results and the main conclusions are summarized. Most of the studies used quantitative analysis in their methodologies, with linear or angular measurements, [9, 11-18, 20-24, 26-31] although some of them used morphologic assessments[10, 14, 18, 19] or created nominal/qualitative classifications for determining age or/and sex, [14, 18, 19] or even for machine learning. [10]

The landmarks, measures and/or classifications applied by the authors that used MCT, as well as the statistical evaluations results of each investigation are available on Table 3. For CBCT is available in Table 4.

Meta-analysis assessments

The investigators used a highly heterogeneous landmarks and measures or qualitative classifications, which limited the articles included in meta-analysis. First, as it was necessary to include in each assessment the same type of CT as measurements varies between CT and CBCT.[32] Secondly, it is also needed to include measurements using the exactly the same landmarks or sites of mandible. Considering the aforementioned, it was included both for MCT and CBCT for sex comparisons: mandibular angle (gonial angle),[11, 17, 21, 23, 25, 27, 28, 30, 31] bicondylar breadth,[9, 11, 22, 23, 25, 27, 30, 31] and bigonial breadth.[9, 21-23, 25, 27, 30, 31] Thus, means comparisons were limited to some populations, as Brazilians,[25] Chinese (central or Han),[21, 22, 31] European descendants,[27] Turkish,[17] French,[9] Israeli,[23] Egyptian,[30] Lybian and[11] Korean.[28] Meta-analysis results are available on Figures 3 to 5.

Data provided by authors regarding to age was insufficient to perform statistical assessments.

a) Mandibular angle

For mandible statistical analysis, it was included in statistical model four studies[11, 23, 28, 30] which performed MCT and five that performed CBCT in separate. [17, 21, 25, 27, 31] Mandible angle presented significant differences between males and females in the CBCT model but not presented in MCT model. Figure 3A and 3B demonstrates the meta-analysis graphics.

For MCT, the observed standardized mean differences ranged from -1.70 to 3.49. The estimated average standardized mean difference based on the random-effects model was 1.40 (95% CI: -1.46 to 4.27). The average outcome did not differ significantly from zero ($z = 0.96$; $p = 0.34$). The presence of heterogeneity was observed. Results are available on Figure 3A.

For CBCT, the observed standardized mean differences ranged from -1.45 to 3.92. The estimated average standardized mean difference based on the random-effects model was 2.10 (95% CI: 0.32 to 3.87). The average outcome differed significantly from zero ($z = -2.31$, $p = 0.02$). The presence of heterogenicity was detected although studies have good scores on quality assessments. Results are available on Figure 3B.

b) Bicondylar breadth

For bicondylar statistics analysis, both MCT[9, 11, 23, 30] CBCT [22, 25, 27, 31] four studies were included and results confirmed significant differences between male and females. Graphics are available on Figure 4A and 4B.

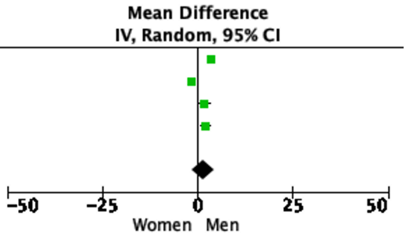
For MCT mean differences ranged from 6.70 to 9.84. The estimated average standardized mean difference based on the random-effects model was 7.97 (95% CI: 6.29 to 9.65). The average outcome differed significantly from zero ($z = 9.28$, $p < 0.0001$). Even though there may be some heterogeneity, the true outcomes of the studies are generally in the same direction as the estimated average outcome. (Figure 4A)

For CBCT, the observed standardized mean differences ranged from -8.56 to -4.91. The estimated average standardized mean difference based on the random-effects model was -7.34 (95% CI: -8.37 to -5.94). The average outcome differed significantly from zero (z = 10.32, p < 0.0001). Even though there may be some heterogeneity, the true outcomes of the studies are generally in the same direction as the estimated average outcome. (Figure 4B)

Figure 3. Mandible angle meta-analysis results for multislice computed tomography (MCT) and cone-beam computed tomography (CBCT)

	Women			Men				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Atef (Lybian)	125	2.31	106	121.51	2.9	113	25.6%	3.49 [2.80, 4.18]
Kharoshah (Egyptian)	121.1	3.9	250	122.8	4.3	250	25.6%	-1.70 [-2.42, -0.98]
Lin (korean)	124.3	6.09	120	122.53	6.64	120	24.0%	1.77 [0.16, 3.38]
Tunis (Israeli)	125.6	6.44	250	123.5	7.62	224	24.7%	2.10 [0.82, 3.38]
Total (95% CI)			726			707	100.0%	1.40 [-1.46, 4.27]

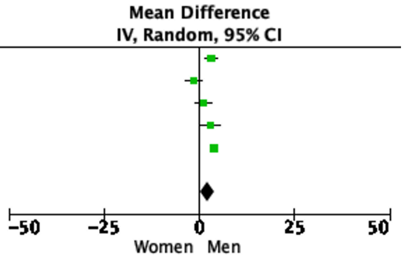
Heterogeneity: $Tau^2 = 8.19$; $Chi^2 = 106.80$, df = 3 ($P < 0.00001$); $I^2 = 97\%$
Test for overall effect: Z = 0.96 (P = 0.34)



A

	Women			Men				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Dong (Chinese Han)	126.64	5.63	107	123.44	5.95	96	21.5%	3.20 [1.60, 4.80]
Gamba (Brazilian)	119.83	6.68	86	121.28	8.21	74	18.0%	-1.45 [-3.79, 0.89]
Ilguy (European descendant)	122.31	6.79	95	121.14	6.56	66	19.2%	1.17 [-0.92, 3.26]
Tassoker (Turkish)	120.03	6.06	71	117.13	7.38	50	17.3%	2.90 [0.42, 5.38]
Zheng (Chinese Han)	125.44	5.13	210	121.52	5.5	210	24.0%	3.92 [2.90, 4.94]
Total (95% CI)			569			496	100.0%	2.10 [0.32, 3.87]

Heterogeneity: $Tau^2 = 3.15$; $Chi^2 = 19.85$, df = 4 ($P = 0.0005$); $I^2 = 80\%$
Test for overall effect: Z = 2.31 (P = 0.02)

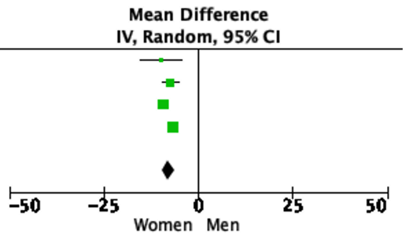


B

Figure 4. Bicondylar breadth meta-analysis results for multislice computed tomography (MCT) and cone-beam computed tomography (CBCT)

	Women			Men				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Atef (Lybian)	80.79	28.9	106	90.63	4.8	113	7.5%	-9.84 [-15.41, -4.27]
Gillet (French)	96.77	6.14	57	104.16	6.29	63	23.9%	-7.39 [-9.62, -5.16]
Kharoshah (Egyptian)	99.6	6.4	250	108.9	7.7	250	33.5%	-9.30 [-10.54, -8.06]
Tunis (Israeli)	115.7	5.64	214	122.4	5.77	224	35.2%	-6.70 [-7.77, -5.63]
Total (95% CI)			627			650	100.0%	-7.97 [-9.65, -6.29]

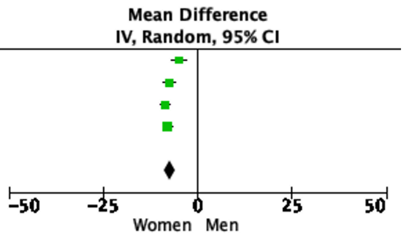
Heterogeneity: $Tau^2 = 1.80$; $Chi^2 = 10.33$, df = 3 ($P = 0.02$); $I^2 = 71\%$
Test for overall effect: Z = 9.28 (P < 0.00001)



A

	Women			Men				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Ilguy (European descendant)	116.23	5.5	95	121.14	6.56	66	21.6%	-4.91 [-6.84, -2.98]
Gamba (Brazilian)	87.47	5.36	86	94.96	6.08	74	23.0%	-7.49 [-9.28, -5.70]
Dong (Chinese Han)	121.44	4.75	107	130	5.31	96	27.0%	-8.56 [-9.95, -7.17]
Deng (Chinese central)	121.8	4.56	108	129.7	5.02	111	28.3%	-7.90 [-9.17, -6.63]
Total (95% CI)			396			347	100.0%	-7.34 [-8.73, -5.94]

Heterogeneity: $Tau^2 = 1.37$; $Chi^2 = 9.50$, df = 3 ($P = 0.02$); $I^2 = 68\%$
Test for overall effect: Z = 10.32 (P < 0.00001)



B

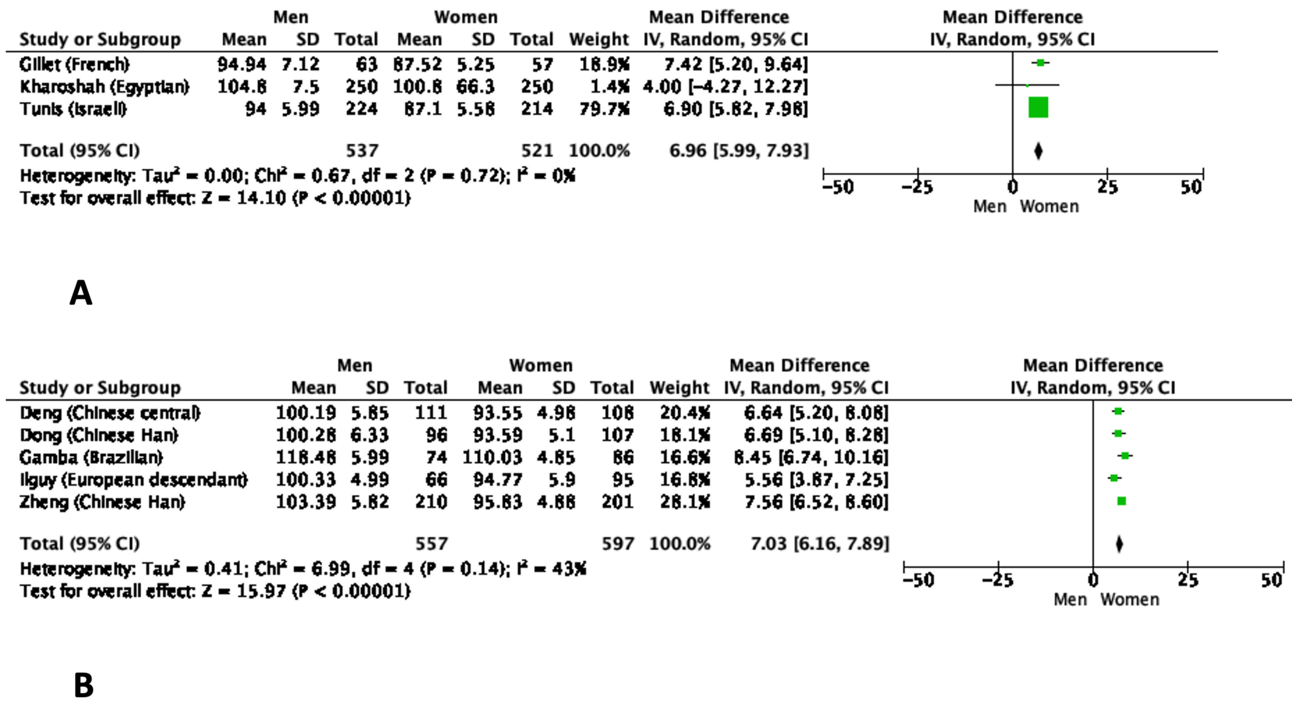
c) Bigonial breadth

For bigonial breadth analysis, three MCT[9, 23, 30] studies and five for CBCT. [21, 22, 25, 27, 31] Both assessments confirmed the statistical significant differences between male and females, as demonstrated on Figure 5A and 5B.

For MCT, the observed standardized mean differences ranged from 4.00 to 7.42. The estimated average standardized mean difference based on the random-effects model was 6.96 (95% CI: 5.99 to 7.93). The average outcome differed significantly from zero (z = 24.10, p = <0.00001). An examination of the studentized residuals revealed that one study (Kharoshah et al.[30]) may be a potential outlier in the context of this model. Results are available on Figure 5A.

Considering CBCT, the observed standardized mean differences ranged from 5.56 to 8.45. The estimated average standardized mean difference based on the random-effects model was 7.03 (95% CI: 6.16 to 7.89). The average outcome differed significantly from zero (z = 15.97, p < 0.00001). Results and metanalysis graph are available on Figure 5B.

Figure 5. Bigonial breadth meta-analysis results for multislice computed tomography (MCT) and cone-beam computed tomography (CBCT)



DISCUSSION

The process of identifying humans from physical features is not restricted to the identification of individuals who are declared dead. It is also used to identify asylum seekers (e.g., people without valid identification documents), unaccompanied minors,[33] and victims and perpetrators of crimes and war atrocities (e.g., in criminal prosecution).[34] Hence, because living individuals must sometimes be identified, the use of non-invasive methods, such as CT, is essential. The present review has shown that diverse methods based on MCT or CBCT have been used to determine age or sex for individual identification. Essentially, the studies selected in this review were highly heterogeneous in terms of the methodologies, measurements, evaluations, and populations included.

The minority of the studies aimed to associate a mandibular assessment of any nature with age.[12, 17, 19, 20, 29] Minier et al.[29] observed a significant correlation between age and mandible measurements in fetuses and that the coronoid process to condylar process and coronoid process to mandibular angle measurements had the highest correlations with age. Other studies estimated skeletal age based on the mandible dimorphism inherent to sex variation. On this point, all the collected information was complementary. Motawei et al.[12] reported that mandible ramus length correlates with age, particularly in the age range of 17–57 years old.

Also, Tassoker et al.[17] verified that the only mandibular bone measurement that correlated with age was the maximum ramus breadth, which has lower values in 10–19 year-olds compared to 60–69 year-olds.

When compared to the other facial bones, the mandible exhibits the greatest growth and morphological size and remodeling changes.[35] Considering that the mandible is isolated, others have concluded that the mandible ramus is the structure that best represents the remodeling changes that occur in certain age ranges and that changes in the mandible ramus strongly correlate with age.[35, 36] The findings of the included studies corroborate these conclusions.[12, 17]

Furthermore, the size and shape of the mandible are also used to predict an individual's sex.[35] Although sexual dimorphism is present at birth,[37] sex differences decrease rapidly during early life[12, 37] and only resume during the phase of puberty to adulthood[37] with the influence of sex hormones.[12] Thus, sex dimorphism is not only reflected in the size of the mandible, but also in its shape.[10, 14, 18] The mandible angle is one of the most-studied factors responsible for shape differences and more obtuse angles have been found in females.[14]

In MCT-based studies, the mandible angle was found to have higher mean values in females compared to males.[9, 11, 23, 24, 28] An exception was reported by Karoshah et al.,[30] who found that the angles were greater in males than in females in an Egyptian population. In CBCT-based studies, the results were similar,[17, 27, 31] except in Gamba et al.'s[25] study of a Brazilian population. In a study that included different age groups of males and females, Zheng et al.[21] also did not observe statistically significant differences in mandible angle between the sexes.

Hence, this meta-analysis of studies that focused on the mandible angle has shown that the results of MCT-based studies are dissimilar, with no significant differences found between males and females, and that CBCT-based studies have found significant differences between males and females. These findings raise the issue of whether this structure actually shows dimorphism or whether the imaging technique influences the final results. Considering the meta-analysis assessment method, more CBCT-based studies were included in the statistical analysis, and this may have influenced the statistical significance observed.

The bicondylar breadth was found to be greater in males than in females,[9, 11, 18, 22, 23, 25-27, 30, 31] as well as the bigonial breadth.[21-23, 25-27, 30, 31] Statistically significant differences were found in all populations studied.

In contrast to the findings of other studies included in the model, in a study with a Libyan population, Atef et al. [11] found that the bicondylar breadth had smaller mean values in females than males. The same observation was made by İlgüy et al.,[27] who studied a population of European descendants. These findings lead to the question: Do these Libyan and European-descendant populations differ from the other populations studied, or were the selected individuals not an appropriate representative sample of the populations?

In terms of sex differences, it was found that both bicondylar breadth and bigonial breadth could be used to determine sex. However, a study of an Egyptian population showed outlier results.[30] Hence, conducting larger studies that include distinct populations worldwide could answer the question of whether bicondylar breadth, bigonial breadth, and mandible angle measurements correlate with sex.

CONCLUSION

Considering the studies included in this review, we conclude that mandible measurements are useful for sex determination, as both the bicondylar and bigonial breadth have been found to have higher values in males than in females. Regarding the mandible angle, the meta-analysis results confirm that sex differences can be detected using CBCT scans but not MCT scans. In terms of age estimation, further studies are needed to prove that the hole of the mandible is a reliable parameter for age estimation.

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