CBCT - The Newfangled in Forensic Radiology

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Abstract

Forensic radiology has a lot of scope in human identification, it acts as vital evidence for antemortem and postmortem records and assists in identifying the person, age, gender, race, etc. This paper reviews the different radiological techniques using Cone beam computerized tomography (CBCT) and advances available for successful identification of the deceased.

Keywords: Forensic Odontology, Cone Beam CT, Age Estimation, Sex Determination, Pre and Post Mortem Data

Introduction

Forensic science deals with the identification of the dead which depend largely on the preservation of soft-tissue components of the body and cannot be used if the remains are burnt, decomposed, mutilated, and destroyed. In the human body, teeth and facial bones are resilient and withstand the decompositional/destructional forces well even under extreme forces and/or temperature variations.[1] Teeth are particularly useful in determining the gender where there is nothing to suggest the individual's identity.[2] As radiographs are able to capture characteristic anatomical features, they can be auxiliary tool in identification of the dead and in solving medico-legal cases. Radiographic identification technique is efficient, comparatively easy, records can be obtained in both living and dead, and they are economical than DNA technology. Radiographs of skull and teeth have been mostly used for forensic identification as these structures are the strongest and highly resistant to trauma and decomposition. With the advent of CBCT, which shows greater precision to diagnose trauma and pathologies of the cranium, the number of image requests by forensic professionals has increased, making possible the use of this technique to support human identification by comparing images of significant anatomical structures of the cranium. So, in the present review we have discussed various radiological techniques and new developments available for successful identification of the dead, cause of death, for medico legal purposes and also anthropological research.

Age estimation of living and deceased individuals is imperious in both forensic and clinical work. There is increase in skeletons and unidentified dead bodies globally due to instances such as fire, air crash, natural calamities, building collapse, railway accidents or manmade incidences like murder, bomb blasts or mass firing etc., hence it is essential to determine the identity of the dead person for legal, criminal and ethical perspectives.[3] In 1950, Gustafson was first to introduce a scientific method for age estimation using six age-related changes in tooth structure, such as secondary dentine formation, periodontal recession, attrition, apical translucency, cementum apposition and external root resorption[3,4]. Matsikidis et al. described that the characteristics of Gustafson method (except apical translucency) using dental radiographs. Subsequently, numerous studies [3,5, 6, 7] have been conducted with different dental radiographic techniques employing the characteristics studied by Gustafson to aid in age determination.

1. Age Estimation

In children, age can be estimated based on the tooth eruption sequences and the developmental stages of teeth, and henceforth it is a relatively simple; however, estimation of age in adults after maturation of third molars is a matter of controversy. To date several techniques have been explained to determine age in adult populations based on morphologic and structural changes in teeth.

1.1 Pulp Tooth Ratio

Secondary dentin deposition occurs throughout life on all the pulpal walls, resulting in a continuous decrease in the volume of the pulpal cavity of teeth. Therefore, age estimation in adults can be carried out by measuring the amount of decrease in the size of the pulpal cavity (fig: 1). In 2004, Cameriere *et al*,[8] for the first time conducted a preliminary study to evaluate the variations in pulp/tooth area ratio (AR) as an indicator of age estimation. Maxillary canines are usually chosen as they are the single-rooted teeth with the largest pulp area, normally the oldest teeth and undergo less wear as a result of diet than posterior teeth, and thus the easiest to analyze. The smaller size of the other single-rooted teeth leads to less clear measurement of the pulp/root ratio. In multi-rooted teeth, pulp changes are clear in the canal but less evident in the root. In addition, in adult subjects, molars and premolars are often missing or damaged as a result of wear. The CBCT imaging technique exhibits proper accuracy to determine the internal anatomy of teeth.[9] Therefore, this technique can estimate age by measuring the amount of decrease in the volume of the pulpal cavity of the teeth.

In a preliminary study with the use of CBCT imaging technique, the pulp-to-tooth volume ratios were calculated in single-rooted teeth with the use of primitive custom-made software program and a formula was designed to estimate age. It was reported that it is possible to calculate pulp-to-tooth volume ratios in living individuals by three-dimensional evaluation of CBCT images. There was an inverse and significant correlation between age and the pulp-to-tooth volume ratios in males and females, with a stronger correlation in males than females indicating that gender affects the formula used to estimate age, consistent with the results reported by Tardivo *et al* [9,10]. It was reported that simultaneous use of two maxillary canines are better and stronger in estimating age compared to the use of four human canine teeth, indicating the higher capacity of maxillary canines, compared to mandibular canines.[9]

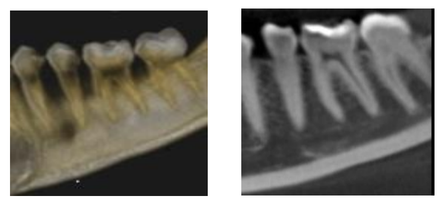


Fig. 1 Pulp tooth

1.2 Spheno-Occipital Synchondrosis

Analysis of ossification points plays a considerable role in forensic age estimation. Spheno-occipital synchondrosis, an important growth point on cranial base, provides significant information about age estimation through its late stage ossification nature. Spheno-occipital synchondrosis is a cartilaginous union between the body of the sphenoid and the basilar part of the occipital bone. This closure usually occurs about 2 years earlier in girls than in boys; this may be attributable to the early growth process or maturity of girls [11,12] . Shirley and Jantz[13], observed the fusion of synchondrosis in females occurs 4 years before males, whereas Bassed et al.[13](fig:2) in a recent study, found no significant differences in progress of fusion between males and females after the age of 16 years. Based on the direct inspection of the ectocranial site of the synchondrosis the fusion of basilar synchondrosis reflect sexual dimorphism and that complete fusion at the spheno-occipital synchondrosis occurs well before 25 years of age corresponding closely with the onset of puberty [11].Cranial base synchondroses essentially contribute to the craniofacial development and more so to dento-alveolar development and is of significance in orthodontic practices. Growth at the spheno-occipital synchondrosis carries the maxilla upward and forward relative to the mandible resulting in an increased facial height and depth. Rapid maxillary expansion is recognized to cause a minor widening of spheno-occipital synchondrosis in young persons.[14]

Sinanoglu et al [15] in their CBCT study on Spheno-occipital synchondrosis among 7 to 25 year old individuals found the mean ages for complete fusion (Stage 4) were 18 and 20 for females and males, respectively. Results showed that CBCT can be a method of choice for age estimation for above mentioned age group and can also add the value for determining age of 18 years, which affects the legal decision in most of the counties. In a retrospective CT study on spheno-occipital synchondrosis fusion[16] among the Turkish population of 10 to 25 years, it was found to be totally open at the mean (SD) age of 11.5 (1.5) years in males and 10.7 (0.8) years in females and it increased with age. Fusion starts approximately 2 years earlier in women than in men, and the process of fusion completes at the age of 17 years in both sexes. Consequently, analysis of spheno-occipital synchondrosis fusion degree in use with 1-mm computed tomography images will be helpful for age estimation between 11 and 17 years 5. Suture closure may possibly be affected by nutritional and health status of the deceased, exercise and physical activity of an individual, allometric growth, general growth and development of the bones, and to some extent by race. Because of the wide variability in the age of closure as presented in various previous studies it just provides a general pattern at various age levels. Thus, it acts as a guide rather than a determining feature in age estimation in the presence of other, more determinate and accurate, clues[16].

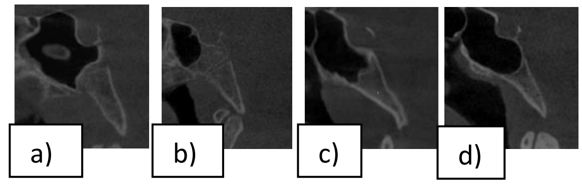


Fig. 2 Mid-sagittal CBCT images representing the spheno-occipital synchondrosis fusion stages. (a) Stage 0, unfused. (b) Stage 1, fusing endocranially. (c) Stage 2, fusing ectocranially. (d) Stage 3, complete fusion

2. Sex Determination

Sexual dimorphism is one of the integral aspects in personal identification of an unknown cadaver thus narrowing down the identification heading towards the correct possibility. Bones that are conventionally used for sex determination e.g. pelvis, skull & long bones etc., are often recovered either in a fragmented, incomplete or commingled state especially in catastrophes like explosions, warfare, natural calamities, and other mass disasters like aircraft crashes, making identification and sex determination not a easily achievable task. It has been reported that the accuracy rate of sex determination is 100% from a skeleton, 98% from both the pelvis and the skull, 95% from the pelvis only or the pelvis and the long bones, 90–95% from both the skull and the long bones and 80–90% from the long bones only.

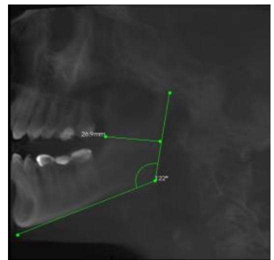
Subsequent to the pelvis, skull is the most easily sexed portion of the skeleton, the craniofacial structures being composed largely of hard tissues, which is relatively indestructible and denser bones like e.g. the maxillary sinus, mandible etc., that are often recovered intact can be applied for sex determination.

Anthropometric measurements of these structures on CBCT images can be used for assessing the sexual dimorphism.[17]

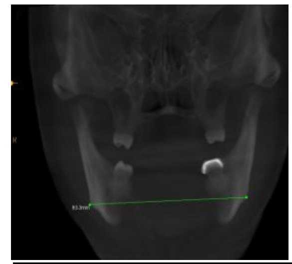
2.1. Mandibular Measurements

Mandible plays a vital role in sex determination as it is one of the most dimorphic, largest, and strongest bone of skull. It very resilient due to presence of a dense layer of compact bone and hence remains well preserved than many other bones. In this respect, the availability of plentiful antemortem orthopantomograms may be of great value in studying and developing population specific standards for accurate sex and age estimation. Dimorphism in mandible is reflected in its shape and size meanwhile male bones are generally bigger and tougher in as compared to female bones. The relative development (e.g.: size, strength, and angulation) of the muscles of mastication is known to influence the expression of mandibular dimorphism since there is a difference in the masticatory forces exerted for males and females.[18]

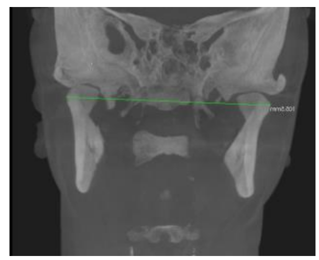
A study by Magdy et al[17] on Egyptian population using spiral CT, six mandibular measurements showed the overall predictive accuracy as good in both males and females. Mandibular measurements like ramus length, gonion-gnathion length, minimum ramus breadth, gonial angle, bicondylar breadth, and bigonial breadth (fig:3)can be used in sexual dimorphism and have very good sensitivity which was substantiated by the study done by Oliveira et al., [19] The success of estimating the sex was 92.96% for females and 85.45% for males. Taleb et al.[20] in their study revealed that males had statistically significant higher mean values regarding all the mandibular ramus linear measurements than females which is in agreement with Saini et al[21] who found significant sexual dimorphism with an overall accuracy of 81%. Usually, the overall size and bone thickness of the male skeleton is greater than that of the female; which is related to sex, nutrition and physical activity .Normally males have greater masticatory force than females that influences the bone size. As regards to gonial angle, it was found that females had a downward and backward rotation in mandible while males had a forward rotation in mandible ,with the gonial angle values in females higher than in males. Taleb et al.[20]



Gonial Angle and Minimum ramus breadth



Inter-Gonial distance



Inter-Condylar Distance

Fig. 3 Mandibular Measurements

2.2 Foramen Magnum (FM)

Cranial base is relatively thick/compact and protected due to its anatomical position, thus this area of the skull tends to withstand both physical insults and inhumation relatively than many other areas of the cranium, thus preserving this area for forensic examination. Various studies have found statistically significant differences between males and females for foramen length, breadth, and area [22, 23, 24]. Raghavendra Babu et al [23]in their study found that predictability of FM in the determination of sex as 65.4% , whereas Uthman[25] found an overall accuracy of 67% respectively. Higher mean values of length, breadth, circumference (fig. 4) and area of FM was found in males than in females and the most reliable indicator to predict the gender was FMA (Foramen Magnum Area). Considering the high sex predictability of FM dimensions, the foramen measurements can be used to supplement other sexing evidence available, so as to precisely ascertain the sex of the skeleton.

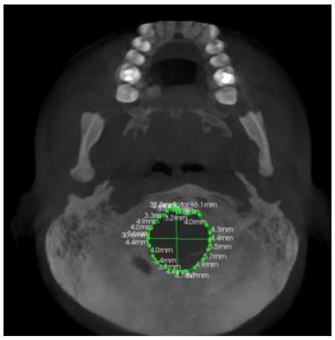


Fig. 4 Foramen Magnum Measurement: length, breath and circumference

2.3 Frontal Sinus (FS)

Frontal sinus is one of the para nasal sinuses of the skull which is a primary tool for personal identification, but the significant dimorphic characteristics in its measurements can also be used for sex determination as well. The frontal sinuses can provide significant evidence for forensic identification. The irregular forms of the frontal sinuses, initially observed in anterior-posterior radiographs have been extensively studied since the first assumption that these are found to show an individual pattern like fingerprints. It has been proven that there are not two people with the same frontal sinuses, even being monozygotic twins.[6] The frontal sinus index (FSI) (height/width ratio) as a maturity indicator or tool for sex determination [26]. The points analyzed on lateral cephalometric radiographs are the Nasion - Sella (NS) line horizontally. The studies done by Patil A and Ravinkar A V[26] using 2 dimensional Cephalometric radiographs.

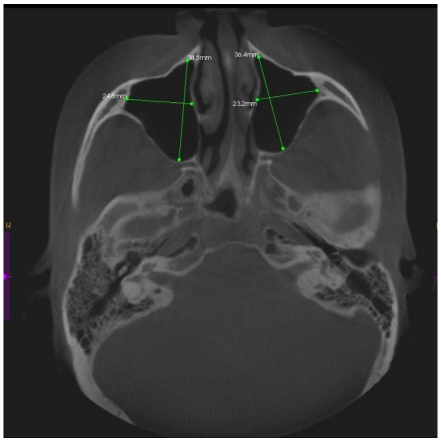
Benghiac A.G. et al [27] in CBCT study concluded that the FSI can be used as a reliable tool for sex determination. Motawei et al.[28] in their study on frontal sinus as a system for personal identification using cone beam computerized tomography and concluded that frontal sinus can be accurate tool for gender determination. Significant differences were observed in the frontal sinus measurements between males and females supporting the dimorphic features of frontal sinus in humans with 67.59% accuracy rate. Sai Kiran et al.[29] Therefore frontal sinus index can be used as a reliable tool in sex determination.

2.4 Maxillary Sinus (MS)

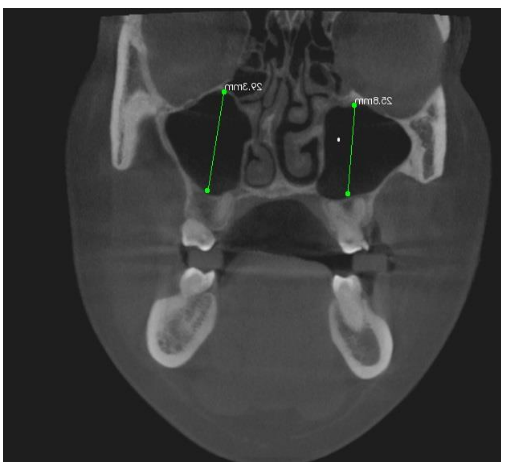
Maxillary sinuses are air spaces, located in the maxillary bone and can be in various sizes and shapes. They appear at the end of the second embryonic month and reach their mature sizes at the age of about 20 years, when the permanent teeth fully develop and tend to stabilize after the second decade of life. MS remains intact even when the skull and other bones may be badly disfigured, and hence it can be used in forensic identification. The radiographic images of maxillary sinuses provide adequate measurements for use in morphometric forensic analysis that cannot be approached by other means.

It has been reported in previous studies that the maxillary sinuses are significantly larger in males than in females. The computerized tomography measurements of maxillary sinuses may be useful to support sex determination in forensic medicine[30,31]. In a CBCT study, comparison between male and female groups showed that the female group had statistically significant lower values for both the right and left maxillary sinuses as regards the width, length and height dimensions (fig.5).

It was also found that the maxillary sinus height is the most reliable discriminant parameter that could be used for the purpose of sex discrimination. S.S. Tambawala et al.[32] This findings are in consensus with the results of the CBCT study by Paknahad et al. who found the accuracy rate of sex determination at 78% in females and 74% in males with overall accuracy of 76%.



a) Measurement of width (the greatest distance from the most medial point of the sinus to the most lateral point of sinus) and length (the largest distance from the most anterior point to the most posterior point of sinus) of left and right maxillary sinuses in



b) Measurement of the maximum distance from the lowest point of the maxillary sinus floor to the upper most point of the roof defined as the height of left and right maxillary sinuses in coronal view of CBCT image

Fig. 5(a,b) Gender Determination: Maxillary sinus Measurements

2.5 Mastoid Process

In the skull, the mastoid bone is tough and strong, hence resistant to physical damage. The mastoid region is favorable for sex determination for two reasons, the compact structure of the petrous portion and its protected position at the base of the skull. So it is commonly found remained intact in skeletons of very old age. Even though skull is fragmented, the mastoid stays intact. From the size of mastoid sex can be presumed i.e. a larger mastoid suggests male sex and a smaller mastoid suggests female sex.[33] Study done on human skull by Swati Shah and Pratik Patel [33] showed that mastoid process had significant craniometric difference between male and female mastoid triangles.

Females have smaller mastoids than males, greater mean mastoid size values was found among males (114.5 mm^3) than females (89 mm^3). This finding could be attributed to the fact that female skulls preserve a juvenile type of small size mastoid process, whereas, the larger size mastoid of males could be ascribed to the attachment of more vigorous musculature, such as the sternocleidomastoid muscle. This is confirmed by the relatively rougher and more irregular surface of the mastoid process observed in males than in females. Moreover, in male subjects, the stronger muscles attached to their mastoids had affected this boney process to maintain an upright position, i.e., a relatively more vertical and less medially inclined in direction which is more significantly manifested in males than in females as indicated by the greater intermastoidale distance (IMD) and greater distance between the lateral surfaces of the left and right mastoids (IMLSD) in males than in females; and greater mastoid flare (MF) and greater mastoid medial convergence angle (MMCA) in females than in males. Amin et al [34] Mastoid pnuematization of temporal structures of the temporomandibular joint (TMJ) and their relationships with age and sex using CBCT had the contradictory result's, in study done by Demirel O et al .[35]

3. Individual Identification

3.1 Facial Reconstruction

Forensic cranio-facial reconstruction is a combination of scientific standards and artistic skill to rebuild a face onto a skull to reconstruct the antemortem appearance of the deceased individual so as to identify and distinguish the decedent. It is also known as ''forensic facial approximation'' (FFR). [6 36] When other forensic approaches are not conceivable, FFR might be very useful investigations.[37 38]Three dimensional computerized programmes can be effective and have demonstrated good levels of accuracy for facial reconstruction Lee et al [39].

Conclusion

CBCT is useful in forensic contexts, offering several advantages for post-mortem forensic imaging including good resolution for skeletal imaging, relatively low cost, portability, and simplicity. 3D reconstruction, bite-mark analysis, age estimation, person identification and anthropological assessment using CBCT have shown promising results. CBCT imaging can provide the much-needed 3D perspective in certain cases that require more information that is beyond the scope of the traditional methods. There is a need for forensic odontologists to understand the role and scope of this imaging modality in the forensic practice. In future, CBCT will be a great tool and asset to the practice of forensic odontology.

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