Review Article

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Role of 3 D Cone Beam Computed Tomography Imaging in Forensic Dentistry: A Review of Literature

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Abstract

Cone beam computed tomography (CBCT) has gained its importance in the last few decades and has been widely employed in dento-maxillofacial imaging. The technique has a supplementary advantage of relatively lower radiation exposure over providing a high spatial resolution of osseous structures when compared with conventional or medical CT scans. Clinical dental setups necessitate a lesser space occupying imaging systems which are certainly offered by CBCT. The CBCT is employed for imaging in dental implantology, orthodontia, oral and maxillofacial surgery and has extended the boundaries into the field of forensics in dentistry. The CBCT archives serve as a reliable source of evidence for antemortem and postmortem records by assisting in age estimation, gender, and personal identification. The current review is an overview of various applications of using Cone beam computed tomography in the field of forensic radiology.

Keywords: Forensic Science; Forensic Radiology; Cone Beam Computed Tomography; Age Estimation; Sex Determination; Personal Identification; Human Identification; Pre & Post-Mortem Records.

Introduction

"The dead cannot cry out for justice, it is the duty of the living to do so for them." - Lois Me Master Bujold. An individual's identity is defined by a certain set of features including physical, functional or psychic, normal or pathological characteristics. Identification of unknown individuals was age-old practice and has proven to be a basis of civilization. The science of forensics employs the recognition of the unidentified and, deceased and this relies upon the conservation of the body's components and hence, are not a valuable source for identification when the remains are destroyed in the catastrophes and mishaps. Teeth and, the facial bones of the human body are considered to endure the destruction or decomposition even under temperature variations [1]. Teeth, in particular, are helpful in the age and gender determination in a plight where an individuals identity remains dubious [2]. Anatomy can be better demonstrated using radiographs and hence, these serve as a valuable adjuvant in resolving medico-legal cases by aiding in the identification of the unidentified corpses. Identification using radiography has a proficiency and advantages of the ease of technique, the retrograde records obtainment of both the living and the dead, and the cost-effectiveness compared to the DNA technology.

Cone-beam computed tomography is a relatively new, advanced imaging modality, had driven the interest in its applications in the field of dentistry. Unlike the CT where fan-shaped X-ray beam is employed, CBCT uses a cone-shaped X-ray beam with an additional advantage of lower radiation exposure and cost when compared to that of CT. CBCT uses a single, flat-panel detector or image intensifier radiation detector and the procedure involves a platform that rotates to which, the X-ray source and detector are fixed. Multiple multiplanar images are produced in a sequential manner as the X-ray source and detector rotate around the object, which are then mathematically reconstructed into a volumetric dataset. A single rotational sequence would capture enough data for volumetric image construction and probably offers a low radiation exposure because the target region is scanned in a single rotation [3]. CBCT may be useful in some forensic proceedings, which would offer advantages for pre-mortem and post-mortem forensic imaging such as good resolution for skeletal imaging, relatively low cost, portability, and simplicity [4]. It provides a noninvasive alternative for age estimation which is an important aspect of forensic dentistry [5].

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Radiology in forensic identification has employed the radiographs of cranium, face, long bones and teeth, of which face radiographs are better considered because of the presence of diverse geometrical contours which allow a precise superimposition into an identity. The advent of cone beam computed tomography showed a higher precision in the diagnosis of traumas 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 [6]. In this digital era, Dentofacial Radiography has become one of the routine procedures in dental and medical hospitals as a part of primary investigations, thereby maintenance of the antemortem records helps to identify the individual's age gender [7]. This article explores and highlights the versatile nature of the CBCT imaging modality by reviewing its application in the field of forensic dentistry. Forensic pre and postmortem records are used to evaluate the age, gender and personal identification of an unknown individual.

Age Estimation

Age estimation for the identification of an individual is important yet remains a difficult task in various anthropological studies and in the field of forensic sciences. Several methods based on the analysis of teeth have been reported in the literature to estimate the unknown age of individuals [8]. In 1950, Gustafson [9] 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. In children, age can be estimated based on the tooth eruption sequences and the developmental stages of teeth, henceforth it is relatively simple; however, estimation of age in adults after maturation of third molars is a matter of controversy [10]. Till date, several methods have explained to determine age in adults based on morphological changes in teeth.

A. Coronal Tooth- Pulp Ratio

The Decrease in the volume of the pulp in teeth is attributed to the continuous deposition of the secondary dentin on all the pulpal walls during the course of life. This decrease can be used for the calculation of the size of the pulp to estimate the age in adults. In 2004, Cameriere et al. conducted a preliminary study to evaluate the variations in pulp to tooth area ratio as an indicator of age estimation using Maxillary canines for, they are the single-rooted teeth with the largest pulp area normally and wear off is lesser than posterior teeth. The smaller size of the other single-rooted teeth results in the less clear measuring of the pulp/root magnitude relation. 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 off. Various ways are developed to check the dimensions of the pulp chamber, including tooth cross-sections and radiographs. Both panoramic and periapical radiographs have been used to assess the pulp/tooth area ratio of maxillary canines. The primary disadvantage of radiographs is that they are two-dimensional projections that are subject to sizable magnification and distortion errors. Therefore, a simultaneous assessment of the mesiodistal and buccolingual dimensions of teeth has been recommended. The CBCT imaging technique exhibits proper accuracy in order to determine the internal anatomy of teeth. Therefore, this technique can estimate age by measuring the amount of reduction 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 [11]. It was according to that it's potential to calculate pulp-to-tooth volume ratios in living people by three-dimensional analysis of CBCT pictures. 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. [12] It was reported that simultaneous use of two maxillary canines are better and stronger in estimating age compared to the use of four canine teeth, indicating the higher capacity of maxillary canines, compared to mandibular canines. A study conducted by N. Jagannathan et al. in 2011 [13] assessed the suitability of pulp/tooth volume ratio of mandibular canines for age prediction in an Indian population using CBCT. Volumetric reconstruction of scanned images of mandibular canines from 140 individuals (aged 10-70 years), using CBCT was used to measure pulp and tooth volumes.

B. Spheno-Occipital Synchondrosis

Assessment of Ossification centers in the body serves as a great tool in forensic age estimation. Spheno-occipital synchondrosis, an important growth center on cranial base, provides significant information about age 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. The complete fusion at the spheno-occipital synchondrosis occurs well before 25 years of age corresponding with the onset of puberty. 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. Shirley and Jantz [14], Cranial base synchondroses essentially contribute to the craniofacial development and more so to dentoalveolar 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. 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 the age of 18 years, which affects the legal decision in most of the countries. 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 provides a general pattern at various age levels.

Gender Determination

Sexual dimorphism serves as a unique feature and has always been an inherent part in cadaver identification of an unknown individual thereby the possibilities towards the right identification are narrowed down. 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 an easily achievable task. It has been reported that the accuracy 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 therefore the long bones, 90–95% from each of the skull bones and therefore the long bones and 80–90% from the long bones only [16]. Skull being largely composed of hard tissues is an easily detectable part of the human skeleton only next to pelvis henceforth the craniofacial structures are indestructible and denser bones like the mandible, mastoid process, foramen magnum, maxillary sinus etc., that are often recovered intact can be applied for sex determination. Anthropometric measurements of these structures on CBCT images can be used for gender determination.

A. Mandibular Measurements

Mandible plays a vital role in sex determination as it is one of the most dimorphic, largest, and strongest bones of the skull. It is very resilient due to the 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 the mandible is reflected in its shape and size in which the male bones are generally bigger and tougher as compared to female bones [17]. 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]. In CBCT, For the purpose of sex determination, six measurements are commonly used which include ramus length and breath, gonion-gnathion length, gonial angle, bigonial breadth, and bicondylar breadth. Saraswathi Gopal et al., 2016 [19], Gamba et al 2014 [20] have determined the sexual dimorphism using these landmarks in the ramus of the mandible and have reported significant values (Figure 1). Usually, the size and bone thickness of the male skeleton is bigger than that of the female; that is attributed to sex, nutrition and physical activity. Normally males have bigger masticatory force than females that influences the bone size. As regards to gonial angle, it had been found that females had a downward and backward rotation in lower jawbone whereas males had a forward rotation in the lower jawbone, with the gonial angle values in females higher than in males.

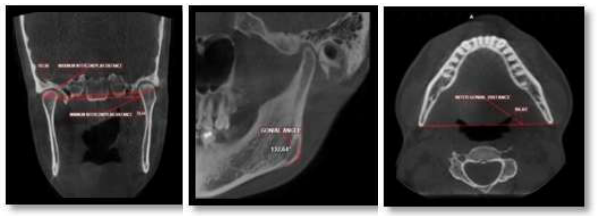

Fig. 1: Mandibular measurements in coronal, sagittal and axial 3 D CBCT images taken in planmeca

B. Foramen Magnum (FM)

The FM may be a three-dimensional aperture inside the basal central region of the membrane bone and is also a transition zone between the spine and bone. Its position between the brain associated funiculus plays a very important role as an anatomic landmark. Cranial base is comparatively thick/ compact and guarded because of its anatomical position, thus this area of the skull tends to withstand physical insults relatively than many other areas of the cranium, thus preserving this area for forensic examination. Therefore, the FM may be a notably fascinating structure for anatomy, forensic medicine, and anthropology. Firstly, Teixeria in 1982 reported that the measurements concerning the FM may be useful in the estimation of sex and since then numerous studies were published regarding the analysis of FM dimensions for sex estimation in several populations. Afterward, it has been concluded that the measurements of its size and intracranial volume are reliable for determination of sexual dimorphism [21,22,23]. Various studies have found statistically significant differences between males and females for foramen length, breadth, and area. Raghavendra Babu [22] et al. in their study found that predictability of Foramen magnum 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, 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 certainty of FM dimensions, the opening measurements may supplement an alternative proof out there, thus exactly ascertain the sex of the skeleton.

A Study by Saraswathi Gopal et al. to evaluate foramen magnum as an indicator in gender determination proved that circumference and area of the foramen magnum facilitates the gender determination with an accuracy of 67% and 69.3% respectively [25].

C. Frontal Sinus

Frontal sinus is one of the paranasal 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 [26]. The frontal sinus index (FSI) (height/width ratio) as a maturity indicator or tool for sex determination. The points analyzed on lateral cephalometric radiographs are the Nasion - Sella line horizontally. Benghiac A.G. et al. [27] in CBCT study concluded that the FSI can be used as a reliable tool for sex determination. Saraswathi Gopal et al. in CBCT study (Figure 2) on Frontal sinus width, Frontal sinus height, Anteroposterior diameter, Total sinus width, Intersinus width, Distance between highest points between two frontal sinuses, Distance between highest point of left sinus and maximum lateral limit measurements had highest accuracy of 89% accuracy in measuring with CBCT. 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 an accurate tool for gender determination. Significant differences were observed in the frontal sinus measurements between males and females supporting the dimorphic features of the frontal sinus in humans with 67.59% accuracy rate.

Fig. 2: Frontal sinus width, Frontal sinus height, Anteroposterior diameter, Total sinus width, Intersinus width, Distance between highest points between two frontal sinuses, Distance between the highest point of left sinus and maximum lateral limit measurements in coronal CBCT images

D. Orbit

Orbit is an important anatomical landmark and morphological variations of the orbital aperture measurements can act as a parameter for sexual and ethnic determination. The orbital aperture morphometry can be considered a valuable tool in gender determination since orbit possesses resistance to damage and disintegration processes. CBCT study conducted by Saraswathi Gopal et al.

2017 (Figure 3) in assessing the orbital measurements in determining gender signifies that orbital width, orbital height, Bi orbital breadth, inter-orbital distance, and orbital index can be measured and orbital index is more in female compared to male and the orbital height, width and breadth is more in male compared to female with accuracy of 85%.

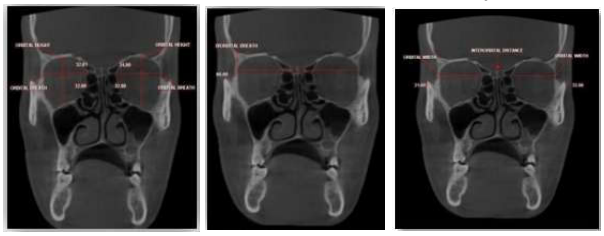

Fig. 3: Orbital height, width and breadth measurements using CBCT

E. Maxillary Sinus

Maxillary sinuses are the air areas, set within the jaw bone and may be in varied sizes and shapes. They appear at the end of the second month of embryonic development and reach their maximum sizes at the age of about 20 years when the permanent teeth fully develop and tend to stabilize after the second decade of life. Maxillary sinus remains intact even when the skull and other bones are disfigured and hence it can be used in forensic identification [29,30]. 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 jaw sinuses area unit is considerably larger in males than in females. The computed tomography measurements of maxillary sinuses may be useful to support sex determination in forensic medicine. In a CBCT study, a 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. 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. [31]) 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 an overall accuracy of 76% and the CBCT study conducted by Saraswathi Gopal et al. in 2017 [32] also showed measurements in Mediolateral, Anteroposterior, Superoinferior, Intermaxillary distance were larger in males compared to females.

F. 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 the 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]. A Study done on the human skull by Swati Shah and Pratik Patel showed that mastoid process had a significant craniometric difference between male and female mastoid triangles [34]. Females have smaller mastoids than males, greater mean mastoid size values were found among males (114.5 mm3) than females (89 mm3). This finding might be attributed to the actual fact that feminine skulls preserve a juvenile form of little size mastoid bone, whereas, the larger size mastoid of males could be ascribed to the attachment of additional vigorous system, 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 insertion to their mastoids had affected this bone to keep up upright position, i.e., a comparatively vertical than medially inclined in direction which is more significantly manifested in males than in females as indicated by the greater inter mastoidale 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.) Amin W et al [34] conducted the osteometric analysis of mastoids on 192 JORDIAN adults and identification of sex was with an accuracy of 90.6%.

Personal Identification

A. Frontal Sinus and nasal septal patterns:

The frontal sinuses can serve as an efficient evidence in forensic identification. The sinus characteristics and its pertinence for criminal investigations are studied for several years, notably in toothless people. Its use in identifications has been widely accepted by anthropologists, radiologists, pathologists and

the court of justice as judicial evidence with scientific validity. 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 individuals with the same frontal sinuses including monozygotic twins [6]. CBCT when used as a substitute in assessment of frontal sinus images, the proposed anatomical references are to be adopted such as to do the axial slicing, which should have its plane being tangent to the upper limit of the orbital cavities, as well as the sagittal slicing, which should be done under the midline, so that all sinus boundaries would be determined whereas error margin in getting comparative images would be reduced. The identification results from the morphometric comparison of the frontal sinuses ante- and post-mortem, with regard to forms, size and contours in the images available. A retrospective study conducted by Saraswathi Gopal et al. in 2016 [35] (Figure 4) comprised of randomly selected 80 full skull projection on CBCT taken on Planmeca Proface taken for different diagnostic functions were evaluated for patterns of FS and NS.

Frontal sinus symmetry was determined in thirty-five (43.75%) individuals and asymmetry in 39 individuals (48.75%). Frontal sinuses were absent (bilateral aplasia) in four people (5%). Unilateral aplasia was seen in two individuals (2.5%). The Straight septum was seen in twenty-seven (33.75%), right deviation in 24 (30%), and left deviation in 18 (22.5%) individuals. Sigmoid was seen in four people (5%), reverse sigmoid in seven people (8.75%). Another study conducted in CBCT by Saraswathi et al. 2017 [32] in determining frontal sinus dimensions in 100 sample size to determine personal identification by evaluating frontal sinus patterns using cone beam computed tomography with an accuracy of 79.6% (Figure 4).

B. Implant Backtracking

Dental implantology has become one of the emerging sub-disciplines in the recent past owing to the minimal risks involved in the procedure and also a marked curtail in the costs. Forensic odontology extends its wings into the core divisions of dentistry and relies on dental evidence because of its low cost, availability of past dental records and its eccentricity in each individual. In the contemporary era of dental management using implants, these dental implants can also serve as a tool in forensic identification. Some implants have perforations, grooves, top chambers, and threads that square measure visible solely at rotation or angulations. These options are also distinctive and change the recognition of a specific product. A recent study conducted on implant backtracking by Dr. Saraswathi Gopal et al. [36], (Figure 5) showed accuracy in identifying persons based on implants design. This study enclosed forty implant images, correlative on basis of implant shapes, size and designs with the implant catalog/Library tool, and the implant brand will be recognized. Out of forty implant images assessed, a positive correlation was seen in 33 cases. The study found that dental implants may well be radiographically differentiated by company kind.

Advantages of CBCT [37]

1. CBCT serves as a relatively noninvasive modality in forensic dentistry.
2. Customization with respect to the field of interest (FOV) is inherently present in most of the CBCT machines thus enabling one to image a volume of only three teeth when localized information is required and also larger regions like maxilla and mandible or entire craniofacial complex..

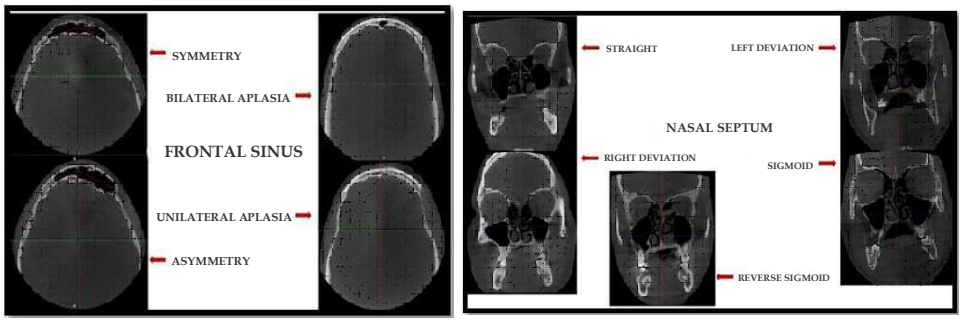

Fig. 4: Planmeca 3 D CBCT images of Frontal Sinus and Nasal Septum Patterns [27].

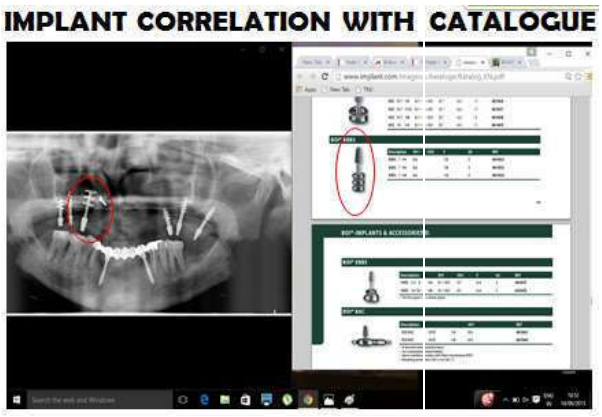

Fig. 5: Implant Correlation with Catalogue [36]

3. Practical advantages include relatively small size, portability, and low cost. Technical advantages include good spatial resolution and metal artifact reduction tool.
4. Time taken to complete the scan is as low as panoramic imaging in particular when the volume to be imaged is smaller.
5. Multiplanar correlation of the obtained images enables the operator to view the entire depth of the tissue added on to which is the availability of three-dimensional reconstruction.
6. Images are dimensionally accurate. With CBCT, the projection magnification is computationally corrected during primary reconstruction, creating an orthogonal image with 1:1 ratio.

Disadvantages of CBCT [37]

1. CBCT is cost ineffective when compared to the conventional radiographic techniques.
2. CBCT images depict increased noise due to scattered radiation which is relatively lower in the medical CT, which is due to superior collimation of the exit beam in CT machines but it results in greater patient exposure.
3. Streaking and beam hardening artifact have been noted when radiation passes through dense objects (amalgam restorations and implants) and does not reach the receptor.
4. Motion artifacts are inevitable during the scanning process which would affect the entire data set and the whole of the image and can be avoided by using head stabilizing devices.
5. Limited soft tissue contrast and measurement of bone density cannot be done using Hounsfield units.

Conclusion

Imaging techniques are a powerful tool in forensic odontology, radiographic examination plays a key role in a positive identification of unknown human remains. There are interesting imaging technologies on the horizon such as automated dental identification systems, however, ultimately it is the decision of the radiologist who decides whatever technique is to be used. CBCT, a variant of CT technology has emerged to outstand its pioneer; the 3D imaging modality has potential applications within the head and neck and dentomaxillofacial regions, imaging high-contrast structures with superiority in detecting osseous changes. Multiple researchers have supported with proof its ability to capture high-spatial resolution images with relatively low patient dose. There is a need for forensic odontologists to understand the role and scope of this imaging modality in the forensic practice. In future, CBCT becomes a regular imaging modality like OPG for maxillofacial imaging which aids in forensic identification.

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