Advanced International Journal for Research (AIJFR)
E-ISSN: 3048-7641 ● Website: www.aijfr.com ● Email: editor@aijfr.com

Forensic Prospect in Maxillofacial Radiology: A Condensed Review

Yugashri M. Kalambe[1], Chetan J. Bhadage[2], Ajay R. Bhoosreddy[3], Vishakha V. Virkar[4], Rutuja S. Santan[5], Madhura S. Shahakar[6]

[1,4,5,6]Post Graduate, Department of Oral Medicine and Radiology, MGVs KBH Dental college, Nashik, Maharashtra, India
[2]MDS, Professor and Head of the Department, Department of Oral Medicine and Radiology, MGVs KBH Dental college, Nashik, Maharashtra, India
[3]MDS, Professor, Department of Oral Medicine and Radiology, MGVs KBH Dental college, Nashik, Maharashtra, India

1. Introduction

Professionals in the legal industry are becoming increasingly interested and knowledgeable in the field of forensic science. Forensic science, which has emerged as a noteworthy and fascinating specialty, it is a notable branch of forensic medicine, forensic odontology deals with the appropriate assessment, management, and presentation of dental evidence in court. It is synonymous with the pursuit of justice.[1] It is essential for identifying the remains of victims—not just those who have been burned, disfigured, or decomposed, but also those who have been affected by bioterrorism or large-scale tragedies. A significant amount of information is provided by maxillofacial radiology for the identification of remains and evidence in judicial cases.[2] Radiographs have a strong diagnostic and analytical utility in forensic dentistry. They provide confidence and weight to identification decisions. When there are few restorations, radiographs can also be helpful in identifying other anatomical aspects, such as the trabecular bone pattern, root morphology, canal, and sinus radiographic outlines.[3] The conduct, interpretation, and reporting of radiographic tests and processes related to the legal system are all included in forensic maxillofacial radiology.[4]

In the interest of justice, forensic odontology handles the administration, review, assessment, and presenting of dental evidence in criminal or civil procedures.[5] The conduct, interpretation, and reporting of radiographic tests and processes related to the legal system are all included in forensic maxillofacial radiology.[6]

There are three main applications for forensic odontology as follows:

(1) Examination and assessment of injuries to the jaws, teeth, and soft tissues of the mouth for diagnostic and therapeutic purposes.

(2) The identification of persons, particularly those killed in large-scale accidents or criminal investigations.

(3) Bite marks that are frequently found in cases of child abuse, sexual assault, and self-defense should be recognized, examined, and evaluated.[7]

"Forensic Maxillofacial Radiology" has grown to be a valuable resource in the field of forensic odontology and has frequently assisted odontologists in their investigative work. Maxillofacial Radiology's contribution to the advancement of the discipline of Forensic Maxillofacial Imaging is now considered a "absolute witness.".[1] Within the field of forensic odontology, maxillofacial radiography is essential. In the current situation, dental and medical facilities and clinics perform it as standard procedure. It serves the purpose of comparative recognition, which compares the radiography record of the deceased person in an effort to provide a definitive identity.

The development of maxillofacial imaging is one factor contributing to its elevation to specialization. It has been discovered that maxillofacial radiography techniques have a significant role in human identity. When forensic consultations and medicolegal investigations are conducted, the maxillofacial radiologist's input yields crucial information.[6] A radiograph clarified a lot of things, both in terms of assessing the current state of affairs and drawing parallels with historical data. In attempts to evoke a person's lost identity by facial reconstruction procedures, such as reconstructive identification or dental profiling, it is also helpful. A methodical comparison of obtained postmortem (PM) data with antemortem (AM) data of the missing or deceased person is used in the forensic identification process.[2] It also helps with the examination of anatomical features for personal identity, biologic age estimation, evaluation of abuse or assault, and identification of the weapon of assault.[2]. Anatomical features and restorative shapes that are not visible during a clinical examination are depicted on radiographs. When comparing aggregated ante-mortem and postmortem data, radiographs are crucial. [3]

It is necessary for forensic pathologists, medical examiners, and anthropologists to evaluate imaging study results in order to advance medico-legal investigations. The radiologist is frequently called upon by the forensic investigator, and their knowledge may be quite helpful in forensic consultations.[7]

2. A Brief History of Forensic Radiology

This field of study applies dental sciences to the identification of deceased people through the comparison of antemortem and postmortem records. The distinctiveness of human teeth has facilitated the identification of persons throughout history.[8] The modern-day criminal investigation typically involves many different disciplines to solve a crime.[9] Among the first applications of forensic radiology, in 1896, a unique use of radiology is reported for the evaluation of an Egyptian mummy at the Natural History Museum in Vienna.[10] Realization of the full scope of forensic radiology is depend on the imagination and industry of modern scientists, and the indulgence or approval of the courts.[11] Forensic radiology must integrate the expertise of forensic pathologists and radiologists. With recorded beginnings dating back at least 5000 years, forensic medicine has a rich and lengthy past. Over the course of the Babylonian, Indian, Arabic, Greek, Roman, Byzantine, Chinese, and European civilizations, legal or forensic medicine evolved. [12]

The Agrippina and Lollia Paulina cases, which occurred in 49 AD, marked the beginning of ancient dental identification. It was discovered that Lollia had certain distinguishing characteristics in her teeth that were utilized to identify her after she passed away. Luntz made a case for Warren Evere based on the ivory

denture work he had completed for the man. This was the dentist's first identification case. In the case of the Charity Bazaar fire in Paris, antemortem (AM) and postmortem (PM) dental data were compared in order to identify the deceased, marking the first instance of dental identification following a mass disaster.[10.] Since 66 AD, identifying someone based only on their teeth has made a significant contribution to the identification of deceased people.

1849 - The first person recognized as an expert in forensic odontology is Dr. Paul Revere. With the use of ivory and silver bridges, he identified the body of Dr. Joseph Warren. Six The first instance that the law accepted was in 1849.[2, 6]

1895 - The first documented occurrence employing conventional radiography occurred in North America on Christmas Eve, 1895, when a surgeon requested a radiograph of an injured limb. The radiograph that was taken after a 45-minute exposure revealed that the bullet had flattened between the tibia and fibula, allowing the surgeon to remove it.[9]

1896 - In 1896, a malpractice suit for a missed fracture and subsequent complications and disability due to the misdiagnosis of Adolf Hitler was filed in the United States. This was the first civil case to accept radiographic evidence in court. The case involved radiographic imaging of Adolf Hitler's teeth in 1944, which confirmed Hitler's identity after his suicide.[13]

Forensic radiography was initially employed by Prof. Arthur Schuster in 1896 to show that a victim had lead bullets in their skull. Dr. Oscar Amoedo's first dissertation on forensic odontology was published in 1898 under the title L'Art Dentaire en Medicine Legale.

1921 - Schuller recommended radiography used in 1921 as a means of identification. Pneumatic sinus cells were used by Culbert and Law in 1927 to give the whole radiological identification of the skull.

Forensic maxillofacial radiology also helps the police assess the age of living children whose identities are unknown and who are suspected of crimes or violent acts under exacerbating conditions. The increasing role of DNA sampling of the saliva on and around the tooth marks on skin or other objects has perhaps led some to rely on this as too much of a gold standard to the detriment of more established and well-tried methods of odontological forensic detection.[14] Identification of the deceased by a variety of methods is the focus of forensic science.

1990 - When comparing antemortem and postmortem radiographs of the frontal sinuses, Kultman claimed 100% success in 1990. [15]

3D imaging is required for forensic identification in order to get over the drawbacks of 2D radiography, such as dimensional fluctuations in images and differences in vertical and horizontal angulation.[15] In order to improve forensic odontology even further, Welty and Glasgow introduced computers in 1946. They built a computer system that could store 500 people's dental records in less than a minute.[7,8] Combining radiology and forensic pathology, postmortem imaging is a relatively new specialty in radiology. Considered the 'Gold Standard' for comparing antemortem and postmortem radiographs, computed tomography (CT) was introduced by Sir Godfrey Hounsfeld in 1967, and magnetic resonance imaging (MRI) by Paul Lauterbur in 1973 for identification in forensics. [16].

1977 - In 1977, a head injury from a bullet occurred in the first case of forensic CT that was documented. Still, there aren't many papers discussing whether postmortem CT imaging is feasible.[12] The data found in AM CT scans can be used to create postmortem facsimile imaging. Since their initial development by Robles RA in 1982 for angiography, cone-beam CT (CBCT) scanners have grown in importance as a 3D imaging modality, particularly in dentistry. Kieser-Nielsen used mathematics to evaluate each tooth's uniqueness. Thus, gannaes et al. (1982) used a computer program to compare the bitemarks of twins and discovered that each bitemark was distinct and varied.[6]

1991 - On May 21, 1991, there was a comparison made between the assassinations of US President John F. Kennedy and Rajiv Gandhi. Of the eighteen bodies found throughout the investigation, seventeen—including Rajiv Gandhi's body—were recognized.[10]

2000 - The Virtopsy Project was started in 2000 at the University of Berne's Institute of Legal Medicine in Switzerland. In 2004, forensic odontology was able to identify victims of the Tsunami in southeast Asia.[12] There is ample historical evidence demonstrating the significant influence that forensic odontology has had as an identification technique for [10].

2011 - The International Society of Forensic Radiology and Imaging (ISFRI) was established on November 27, 2011. The ISFRI organized a two-day international forensic radiology research summit, wherein it discussed the state of forensic radiological research today and developed a research agenda for the upcoming years in collaboration with the International Association of Forensic Radiographers (IAFR), the National Institute of Justice (NIJ, Washington, D.C., United States of America), and the Netherlands Forensic Institute (NFI, the Hague, the Netherlands). The four categories of identified research subjects were as follows: multimodal imaging, identification and biological profiling, big data and statistics, and visualization and presentation. [15.]

3. PURPOSE AND SCOPE

The human species is still having issues in the twenty-first century, despite tremendous advances in science and technology. These include natural calamities (tsunamis, earthquakes), medical advancements, crime, and violence that claim many lives. In such cases, the importance of a deceased person's personal identification has grown significantly for social, legal, and personal reasons. Analyzing the amount of teeth that have erupted in youngsters can help determine their age at death and aid in the identification process for skeletons that are unknown. [16]

In contrast to conventional autopsy findings, which are inherently unique and cannot be fully repeated, forensic radiological findings are easily disclosed and shared over time while maintaining the same diagnostic accuracy.[12] Furthermore, forensic radiology offers fresh perspectives on harmful incidents by providing an overview of the body without endangering its integrity. This final point is put into practice when radiology is needed to identify the cause of death. Because of this, forensic radiology is frequently mentioned in both forensic clinical practice and scientific publications.

Forensic radiology is one of the most crucial areas of forensic science, which demands an integrated, interdisciplinary strategy for criminal identification.[13] Every year, radiologists play a more crucial role as essential members of the forensic science team. Assessment, modulation, and interpretation of radiological

tests, as well as related procedures, are all part of forensic radiology and are related to the legal system. A crime scene's identification and investigation depend heavily on radiographic analysis.[14] Additionally, the same person's antemortem and postmortem radiographs must always be obtained in order to compare them and improve the individual's identity. Forensic radiology is therefore essential to anthropology and odontology. Radiographic exams are crucial for determining both non-accidental injuries and any kind of medical negligence.[15] This is especially crucial for women and children, as these groups are more likely to experience maltreatment. Radiographic analysis can also be used to infer biological age. In the ideal scenario, the radiologist would receive training in the rapidly developing field of forensic imaging, which would include learning about typical post-mortem alterations, the meaning of the way of death, radiologic indicators that point to a particular cause of death, and the kinds of questions that law enforcement officers may pose. Thus, we might envision a future in which the two medical specializations are seen as indispensable to one another in evaluating necropsy cases as well as in certain medical-legal lawsuits, while yet retaining their fundamental particular qualities.[16]

These are the primary justifications for the collaboration between forensic specialists and clinical radiologists. They ought to be conscious of their separate obligations in a court of law. [17] In forensic radiography, radiograph storage and record organization are crucial, and as such, their roles have a lot of room to grow. The following categories apply to B.G. Brogdon's classification of forensic radiology's scope.

<table>
<tr><td rowspan="6">1.</td><td rowspan="6">Service</td><td colspan="2">i. Determination of identity</td></tr>
<tr><td rowspan="3">ii. Evaluation of injury and death</td><td>a. Accidental</td></tr>
<tr><td>b. Nonaccidental
• Osseous injury
•Missiles/foreign bodies
• Other trauma
• Other causes.</td></tr>
<tr><td rowspan="2">iii. Criminal litigation</td><td>a. Fatal</td></tr>
<tr><td>b. Nonfatal.</td></tr>
<tr><td colspan="2">iv. Civil litigation</td></tr>
<tr><td colspan="2">v. Administrative proceedings.</td></tr>
<tr><td>2.</td><td>Education</td><td colspan="2"></td></tr>
<tr><td>3.</td><td>Research</td><td colspan="2"></td></tr>
<tr><td>4.</td><td>Administration</td><td colspan="2"></td></tr>
</table>

In forensic dentistry, scanning methods that incorporate various digital radiograph and picture formats are approved. Accurate identification of human beings has been made easier by the diversity of dentition patterns among them. Dental radiographs, which are vital to the forensic sciences, have reportedly been identified as one of the most often used Ante mortem evidences for human identity.[18] The acquired evidence from dental remains must be processed, reviewed, and evaluated by forensic dentists in order to produce objective, scientific facts that may be presented to legal authorities. Over the past few decades,

forensic dentistry has evolved greatly from being sporadically utilized to becoming essential to identification processes.[19]

Mass disasters result in high death tolls, which means managing significant resources is necessary. Because these events are frequently surprisingly violent, there are often a considerable number of victims that need to be found as soon as possible using a cost-effective and dependable manner.[20] In many situations, such as airplane crashes and fire incidents that compromise the macrobiometric traits, such fingerprints or faces, conventional identification techniques are ineffective. In these situations, a more durable feature set should be used in the recognition process. The best approach now available for successfully identifying victims through meticulous methods and accurate data interpretation is forensic dentistry.[21]

When a body is irreparably disfigured beyond recognition by family members, as is frequently the case in drowning, burn, and car accident instances, it can also aid in the identification process.[22]. Certain dental components, such as pulp, enamel, and dentin, are retained in the tooth even after the body's tissues have broken down. In order to help with identification, teeth are thought to be a good source of genomic DNA, which can be extracted from these calcified structures and compared with pre-mortem or paternal DNA already in existence.[19] The identification of dental remains is crucial in cases where the body has been burned, mutilated, skeletonized, or degraded. The main benefit of dental evidence is that, similar to other hard tissues, it is frequently preserved until demise.[23] Even a person's dental health varies throughout the course of their life, and the proportion of teeth that are filled, missing, and decaying may be measured and compared at any one period. All regular radiographs exposed during the course of a dental practice must be properly repaired and cleaned in order for them to stay viewable years later. Original antemortem dental radiographs are extremely valuable for comparison.[24]

Techniques involving the observation of the morphologically diverse stages of mineralization are typified by the use of radiography. These decisions also take into account the stage of eruption, the degree of root and crown structure creation, and the degree to which primary and adult dentitions are mixed together.[25] Dental radiographs are a crucial forensic identifying clue that are readily accessible. Dental radiographs are used to determine the following parameters: dental caries, diastemas, endodontic treatment, intraradicular posts, intracoronal posts, teeth present, absent teeth, residual roots, and supernumerary teeth noncarious lesions like attrition, abrasion, fractures, bone resorption from periodontal disease, bone pathology, and dental caries. Using conventional radiography, one can observe features such as crestal bone, pulp architecture, coronal shape and size, etc. Every person has a unique frontal sinus configuration, which can be utilized as a criteria for unique identification. Variations in the frontal sinus's size, shape, symmetry, border contour, and quantity and existence of cells and septa are the factors used to compare images of the sinus.[26] Numerous software programs have been created to aid with picture rotation, translation, and scaling. These programs enable precise alignment of ante- and post-mortem radiographs, thereby obviating the need for additional exposures. Forensic odontology can thus utilize the hidden dental information obtained through the use of radiographic techniques. Even after millions of years, skulls can remain unchanged and serve as a unique form of identification.[27] The skull appearance plays a major role in identifying the person's sex. A laser video camera interfaced with a computer or with CT scanning is used in the computerized facial reconstruction procedure. After this, a completely shaded 3D surface is imaged using the skull data. Computer software (such as the volumetric visualization program Vitrea 2.3

version) can be used to draw the face. It has been discovered that 3D-CT imaging is more accurate than 2D-CT image reconstruction and imaging done directly on CT slices.[28]

It is the duty of every dental practitioner to comprehend the forensic aspects connected to their work. It is important to inform dental students and practicing dentists about the latest technological advancements and their applications in forensic dentistry. In order to use contemporary technology in the process of establishing a person's identity, it is necessary to support new research in the field of forensic dentistry.[21] Expert testimony on mental health may be supported by neuroimaging. A CT scan of John W. Hinckley's brain was utilized by a defense specialist to bolster the theory that he was suffering from schizophrenia at the time of his attempted assassination of former president Ronald Reagan. Positron emission tomography and other functional neuroimaging methods can show how variations in brain activity are correlated with variations in blood flow. Functional neuroimaging evidence is an addition to behavioral and clinical data and has been utilized in criminal cases to support insanity defenses, allegations that a defendant was incapable to stand trial, and pleas for leniency in sentencing. [29]

Forensic identification is witnessing a new revolution in the use of diagnostic imaging techniques such as dual X-ray absorptiometry (DEXA) to measure bone mineral content (BMC) and bone mineral density (BMD). Calculating the body mass index, bone length, composition, bone structure, and neutral density in different body areas are just a few of the many applications for measuring bone density. DEXA is a widely recognized tool in the field of diagnostic imaging for conditions such as osteoporosis, osteomalacia, and other disorders that include bone density measurement. To use this more recent modality in the field of forensic anthropology and for the identification of skeletal remains, numerous field investigations and studies are carried out. [30]

4. Radiographic Techniques Used in Forensic Identification

Radiographs are crucial to forensic dental examinations because they offer unbiased proof of the anatomical conditions and dental treatments received up to that point.[31] They are advantageous because they are rapid, easy, and non-destructive ways to gather information. Moreover, they are less expensive than DNA technology. Radiographs are very useful for analysis and diagnosis and provide decisions about identification credibility and certainty.[32] When there aren't many restorations, radiographs can also be helpful in identifying other anatomical elements such the root morphology, canal, trabecular bone pattern, and sinus radiographic outlines.[33] The doctor who is in charge of submitting the dental records may have overlooked the inaccuracy or forgotten about it when they are required to be filed as antemortem records, which might happen months or years after the last visit or treatment.[34] It is commonly acknowledged that imaging techniques are important in forensic medicine. To determine identity, odontologists and forensic anthropologists frequently compare radiographic plates taken before and after death. The majority of medicolegal processes require x-rays since they are essential for locating foreign bodies and gas emboli as well as for documenting fractures and other sorts of injuries.[35] Additionally, if undetected prior to the autopsy, exploding bullets that penetrated the body without detonating, undetonated explosive material, and retained sharp souvenirs (foreign bodies) can cause serious injuries to forensic investigators. That why radiographic studies of the body are essential for the early recognition of hazardous objects.[36] Both clinical radiological examination are important tools for diagnosing nonaccidental harm in individual. [37]

To make it easier to describe radiographic patterns, McDonald outlines two diagnostic radiography guidelines. There is the "5 S Rule," which examines the place under evaluation in terms of its Shade, Shape, Site, Size, and Surroundings. The "3 D Rule" includes displacement, density, and diameter as three of its evaluated factors (MacDonald, 2011).

Radiographic Techniques Used in Forensic Identification are

4.1. Intraoral radiographic technique
4.2. Extraoral radiographic technique
4.3. Computed tomography and Magnetic resonance imaging

4. 1. INTRAORAL RADIOGRAPHIC TECHNIQUE:

4.1.1. Periapical

It consists of a sequence of radiographs, showing the teeth and supporting structures. They are often produced with speed film in D or F. Film technology is frequently replaced with digital images created on a phosphor plate, a scintillation screen sensor, and a charge-coupled device or complementary metal oxide semiconductor.

4.1.2. Bitewing

the most typical dental radiograph taken intraorally. primarily used to monitor alveolar bone levels and interproximal deterioration in relation to the maxillary and mandibular posterior teeth.

4.1.3. Occlusal

often employed to delineate the axial plane shapes of the mandibular and maxillary dental arches. This view is also useful for evaluating the palate or floor of the mouth for substantial extradental radiological abnormalities. The 57 x 76 mm dimension of this film makes it suitable for use in the PM evaluation of resected jaws in the saggital plane from a forensic perspective.

4.2. EXTRAORAL RADIOGRAPHIC TECHNIQUE

4.2.1. OPG

The panoramic X-ray scanning of the upper and lower jaws that produces an extensive radiologic graph from the human dentition is known as orthopantomography, sometimes known as panoramic radiography. Dental panoramic radiography has become a widely used standard technique in dentistry as supplemental information and preliminary tests for oncological therapies due to the low radiation dose and quick imaging time. [38]

As a result, orthopantomography is now frequently utilized to identify victims of mass tragedies, including war fatalities. The corpse fixation technique makes it possible to obtain a trustworthy panoramic graph during the post-mortem data recording process, on which the most frequently observed dental pattern is displayed. [39] The only drawback to employing the panoramic technique is its susceptibility to body misalignments that could cause image distortion, despite the fact that OPGs are one of the standard techniques for human identification since they provide a wealth of useful information. [18]

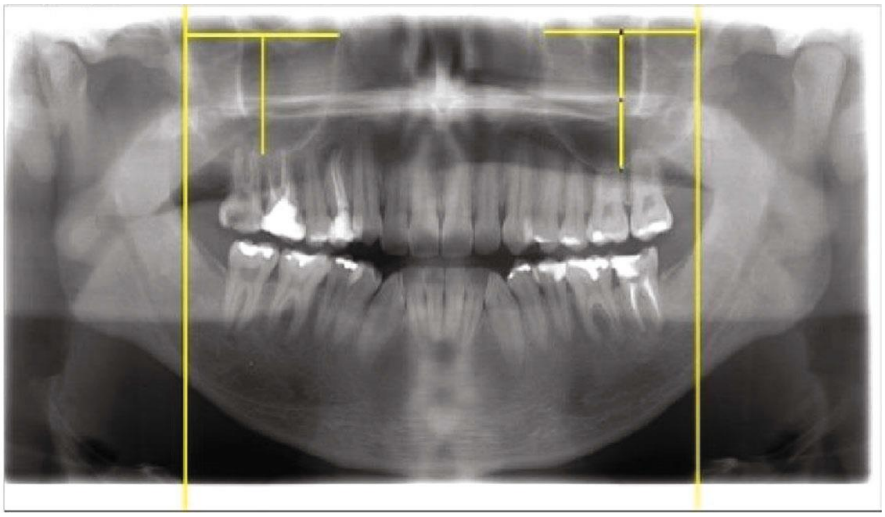


Fig. no. 1. a panoramic radiograph that shows the height and width of the maxillary sinuses. [18]

4.2.2. Cone-Beam Computed Tomography

All areas of dentistry, including orthodontics, endodontics, oral surgery/pathology, periodontics, and implant treatment planning, are making extensive use of the groundbreaking finding of CBCT. [40] It produces several multiplanar images sequentially using a single flat-panel detector or image intensifier radiation detector and a cone-shaped X-ray beam. These images are then mathematically rebuilt into a volumetric dataset, which is transformed into a readable image. The data acquired by CBCT can also be imported into third-party image enhancement software for 3D volumetric analysis; this software has been applied in a variety of forensic contexts. [41]

CBCT has two main areas of use in forensic dentistry—
(a)Diagnostic examination for missing/deceased persons
(b)the identification of individuals, in casualties, criminal investigations and mass disasters.

In the current day, CBCT is viewed as a promising method that offers an affordable way to obtain high-quality, undistorted 3D images with a low radiation exposure, all while guaranteeing precise localization and a thorough description of the osseous anatomy.[42] [43] Using complex yet user-friendly software, multiplanar correlation of the acquired pictures allows the operator to observe the whole depth of the tissue with the added benefit of 3D reconstruction.[43] Less severe metallic artifacts, faster image reconstruction times, more mobility, and a 96% lower radiation than standard CT are some of the benefits of CBCT. As a result, CBCT is now the preferred method for imaging the oral and maxillofacial region.[44]

Dental identification is accomplished by identifying the concordant spots for positive or potential identification by comparing the antemortem and postmortem radiographs of the dental and maxillofacial structures. Many dental findings are used to evaluate these data, including the number of teeth present or absent, extra teeth, the shape of a tooth's crown and roots, pulp architecture, rotten teeth, restored teeth,

endodontic treatment, and prosthetic treatment.[45] A positive identification is defined as the existence of sufficient distinguishing characteristics that allow for the explanation of variations between the antemortem and postmortem data while remaining identical. Both antemortem and postmortem radiographs can be correctly aligned with CBCT, eliminating the need for further exposures and enabling a precise evaluation of the spatial relationships of dental components such as teeth, roots, and supporting structures. It also helps reconstructive technologies by creating a biological profile of a deceased or missing person whose identity is unknown. [46]

Despite the fact that CBCT scans were once only used to image the cranio-maxillofacial complex, a wealth of research in this area has led to the expansion of the scans' use in a variety of head and neck applications, such as the visualization of sinus pathologies, tumors of the skull base, 3D analysis of the upper airway dimensions of patients with cleft lip and palate or obstructive sleep apnea, the visualization of cochlear implants, fracture detection, and intra-operative fixation plate placement.[47]. It is undoubtedly a great tool in forensic imaging because it is superior to CT in imaging injuries caused by high density bullets because it has fewer artifacts.[48] CBCT scans will become more widely available and, in due course, a necessary component of standard investigations in otolaryngology and maxillofacial surgery, as well as a potential source of forensic identification data.[49]

Age estimation, sex determination, bite mark analysis, facial reconstruction, implant retracking, and tissue damage analysis using various techniques detailed in the following sections are among the forensic identification domains where CBCT has made a significant contribution.

Using a variety of other anatomical landmarks, including orbital apertures, volumetric assessment of dental crowns, morphology of the articular eminence and the mandibular fossa, mandibular midline neurovascular canal structures, and shapes of cervical vertebrae, CBCT has proven to be a useful tool in determining gender and identifying an individual.[50] Bite marks in foodstuffs that could be discovered in a forensic case study were studied using CBCT, and it was discovered that bite marks in suitably dense meals may be subjected to metric analysis.[51] Dental implants are now extremely valuable unique identifiers as forensic proof for human identification in the modern era of dental management. Dental implants are a special kind of forensic identification tool because of their distinctive features, which include perforations, grooves, top chambers, and threads that are only visible at specific rotations or angulations.[52]

Gopal et al. (2017) found that a panoramic radiography study on implant backtracking had an accuracy of 82.5%, which opened the door for CBCT studies on the same for personal identification and it is suggested that further research on implant backtracking using CBCT is necessary in order to create a dataset suitable for use as an antemortem record.[53]

Von See et al. (2009) examined tissue damage and the positions of three distinct contemporary projectiles that were shot into the heads of cadavers using CBCT and CT. They came to the conclusion that because CBCT is less severely influenced by metallic artifacts, it is considerably superior to CT in detecting structural hard-tissue damage in the immediate area of high-density projectiles. [54]

A few drawbacks of CBCT include motion artifacts, inadequate soft-tissue contrast when compared to CT, and the inability to estimate bone density using Hounsfield units.44 Furthermore, CBCT has not yet been used to investigate dual-energy scanning, which improves tissue portrayal. Currently, CBCT only allows for cranial and extremities imaging because it is primarily utilized to examine craniofacial structures. As a result, whole-body imaging with CBCT is not feasible.[2] In order to offer reference material for various ethnic and racial groups, and to update the ones currently used as baseline reference material, differences among populations and ethnicity also call for further population-based research employing CBCT for age and gender determination. The importance of virtual autopsies is growing, thus it's important to look into how CBCT functions in these processes and create specialized software and tools to help with them. However, the area of forensic investigations has yet to completely explore the breadth and possibilities of this innovative technology. [55]

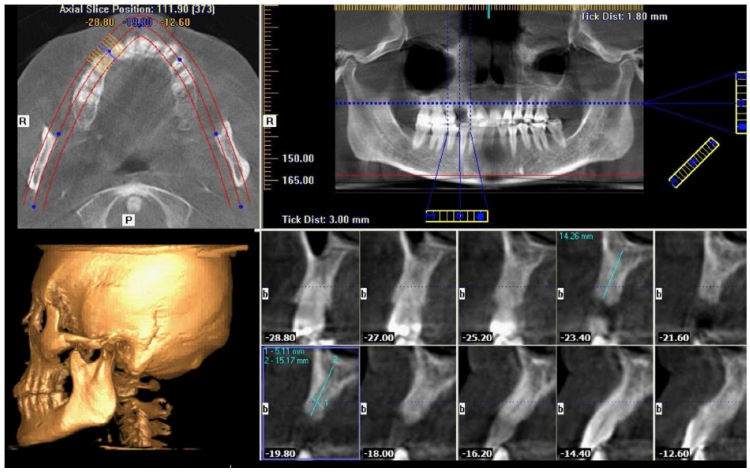


Fig 2. A typical CBCT screen about two minutes following the acquisition [40]

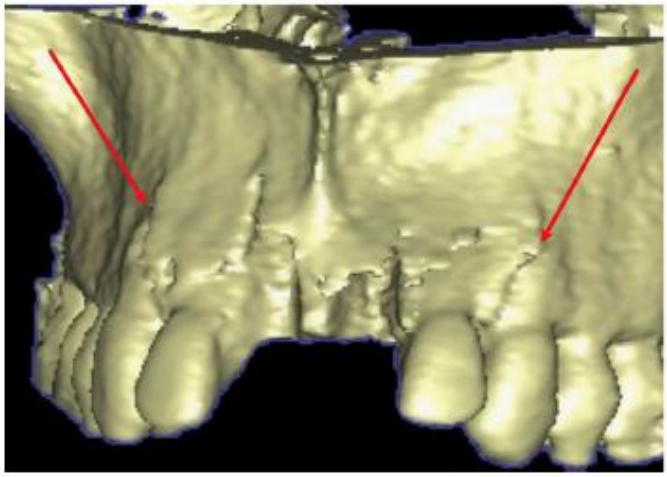


Fig 3. Following a car collision, a reconstruction of a CBCT clearly demonstrates bone fractures on an axial picture (right) and a 3D view (left, arrows).[40]

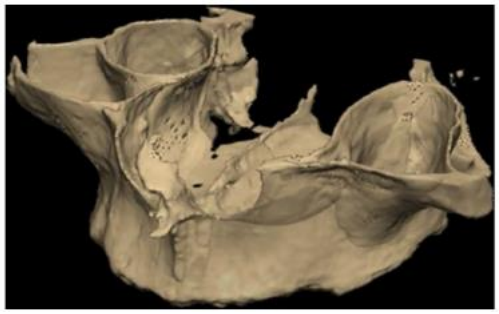


Fig 4. 3D reconstruction from CBCT displaying anatomical anomalies in the right maxillary sinus. [40]

4.3. COMPUTED TOMOGRAPHY and MAGNETIC RESONANCE IMAGING

4.3.1. COMPUTED TOMOGRAPHY

Computed tomography created in 1972 by Godfrey Hounsfield and Allan Cormack to create thin transverse sectional images through the body or anatomical area using radiography. The technology uses a circular array of photomultiplier tubes to detect a collimated X-ray beam that is sent through the body in place of a photographic plate.[41] Although more modern technologies use many tubes to shorten the scan duration, the X-ray tube may rotate around the body. The image's accuracy increases with decreasing scan sizes. On a scale where maximum absorption is represented as 100 HU (Hounsfield units) (such as bone) and minimum absorption is represented as –1000 HU (such as air), the scan data are examined for absorption patterns. The final image is constructed from a matrix of 2D picture image elements (pixels), which finally represents the three-dimensional (3D) volume elements of the tissue studied (voxels). The image is projected digitally onto a monitor, from which films may be produced.

When it comes to abuse victims and suspected air embolisms, the utilization of imaging methods like CT and MRI is highly recommended. One cannot overstate the significance of performing a thorough radiological assessment on both clinical cases of suspected abuse and postmortem cases.[56] Abused children 18 months of age and younger frequently have radiological signs of bone trauma; the location, type, and multifocal feature of these injuries are thought to be unique to nonaccidental injuries. Radiological imaging is essential for assessing craniospinal injuries, and it is recommended that CT and MRI be used in all suspected cases of non-accidental cranial injuries. [57]

The quick technological advancement of CT and MRI over the last few decades has made clinical radiology a crucial component of clinical practice. Postmortem imaging, which blends radiology with forensic pathology, is a relatively new specialty in radiology.[58] In 1977, a head injury from a bullet occurred in the first case of forensic CT that was documented. Still, there aren't many papers discussing whether postmortem CT imaging is feasible.[59] For thorough visualization of vascular tissue abnormalities,

parenchymal diseases, going beyond unenhanced postmortem CT.[61] With this information, the forensic pathologist can decide on an alternative autopsy technique or even point them toward the pathology, which is difficult to dissect.62 Furthermore, postmortem CT imaging makes it easier to see vascular pathologies in hard-to-reach places like the cranio-cervical junction, the spinal canal, and the small pelvis, as well as in areas that are typically not dissected like the face, upper thoracic aperture, and smaller intestinal vessels. This enhances and facilitates forensic autopsy procedures. [63] Both CT and MRI are equally effective in displaying epidural hematomata, while CT is recommended for fracture identification.

Without removing any tissue, postmortem imaging also provides the opportunity to estimate the deceased's height, age, and sex. When estimating age in clinical practice, conventional radiography of the left hand is typically used, and ossification is compared to reference image. Postmortem CT allows for image reconstruction that can be utilized in a various manner. [64]

Forensic science has designated Multi-Modal Imaging (MMI) as an important research priority. Historically, imaging techniques such as photography, radiography, and light microscopy have been used by forensic investigators to record tangible evidence.[65] An extensive range of new and more potent imaging techniques with potential use for forensic inquiry have been made possible by ongoing technological advancements as well as advancements in other disciplines, such as physics and clinical medicine..[66] Forensic cases involving the assessment of living patients or medicolegal death investigations, for instance, are increasingly utilizing CT and MRI, which are conventional techniques of clinical practice.[67] Additionally, there has been a significant advancement in image capture and processing techniques recently, which creates new opportunities for combining image data collected by one or more modalities across multiple length scales or points in time and visualizing the data in novel ways..[68]

Four research topics have been recognized as critical to enabling the forensic science community to leverage both current and future imaging technology. The first is the deployment of new imaging techniques or other analytical procedures for fundamental research that may enhance the forensic use of older techniques. The second is integrating cutting-edge analytical or imaging techniques which aren't often employed in forensic investigations. The creation of specialized tools or methods, such as portable imaging devices made especially for use at crime scenes, as well as the assessment of current imaging technologies in light of potential new forensic uses, are examples of research in this field.

Thirdly, employing microscopic or molecular approaches to obtain a more detailed image while utilizing macroscopic imaging methods to pinpoint regions-of-interest. Optical spectroscopies and spectrum imaging, mass spectroscopy, magnetic resonance spectroscopy (MRS) and magnetic resonance spectroscopic imaging (MRSI), optical microscopy (histology, immunofluorescence, etc.), and electron microscopy are additional methods that can yield more detail.[69] Fourth is creating new and more potent techniques to synthesize and present visual data from different modalities. [70, 71]

Similarly, no studies have been conducted to ascertain whether potential jurors find 2D and 3D reconstructions from a modality like CT to be more or less understandable and less unfairly biased than standard courtroom illustrations (e.g., photographs, diagrams, mannequins, etc.).[72] According to preliminary research, a group of lawyers questioned preferred color-coded CT images and 3D

reconstructions over written reports because they were easier to understand and more affordable. Research on how evidence is presented can evaluate the value of radiological pictures, three-dimensional models, and autopsy photos. It can also compare the use of different types of evidence.[15]

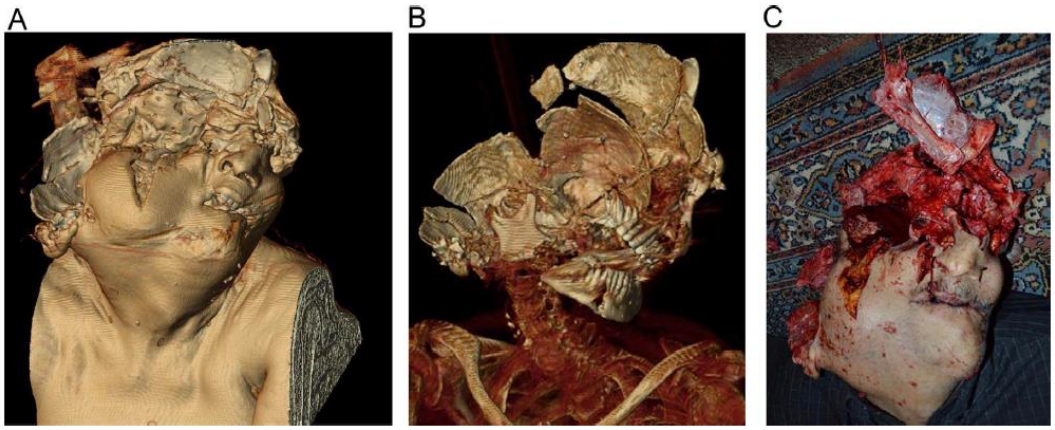


Fig 5. Using postmortem CT with skin reconstruction (A) and bone reconstruction (B) instead of a crime scene photo (c) allows for a less biased depiction of injuries.

When compared to traditional radiography projection, three-dimensional computed tomography (CT) offers numerous advantages and is a helpful imaging technology for human identification. Compared to other modalities, there is very little superimposition, elongation, or shortening of the pictures, and there is a feature that allows for the assessment of minute changes in density.[73]

CT offers a number of benefits, including the ability to segment pictures, which is useful information when evaluating interior spots. Easy picture processing, better imaging quality with outstanding color scale and transparency, and details on volume and area measurement as well as angular and linear measurements are additional benefits.[74] An further benefit of employing antemortem CT images is that they can be used to construct a postmortem image by precisely locating craniometric sites and performing measurements.[39]

The risk of radioactive exposure and the expense of regularly maintaining the equipment, in addition to the setup costs, are the drawbacks. Nevertheless, the presence of metal such as projectiles will frequently result in artifactual streaking or shadowing in digital images. This is because metal has a density that is significantly higher than that of bone. As a result, precise imaging might not always be achievable.[41] Nonetheless, it has been demonstrated that the process of performing CT scans has an impact on the quality of the 3D image reconstructions. [75]

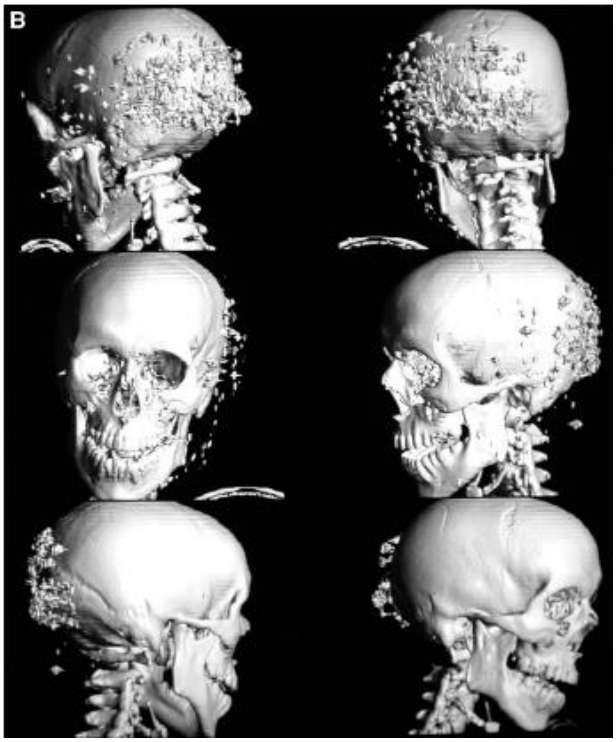


Fig 6. Digital three-dimensional reconstruction combined with postmortem computed CT imaging reveals that the shot was located completely extracranially, primarily in the left and posterior lateral regions of the head. It is possible to observe the cracks extending beyond the projectile bulk.[41]

Head and neck trauma-related deaths remain a significant component of accidental or homicide investigations. Congenital or acquired periosteal markings or disease, wormian bones, non-penetrating blunt trauma marks, and complex soft tissue and bony injuries to the skull and facial bones can all be identified and demonstrated in court using multislice CT with soft tissue and bony 3D reconstruction.

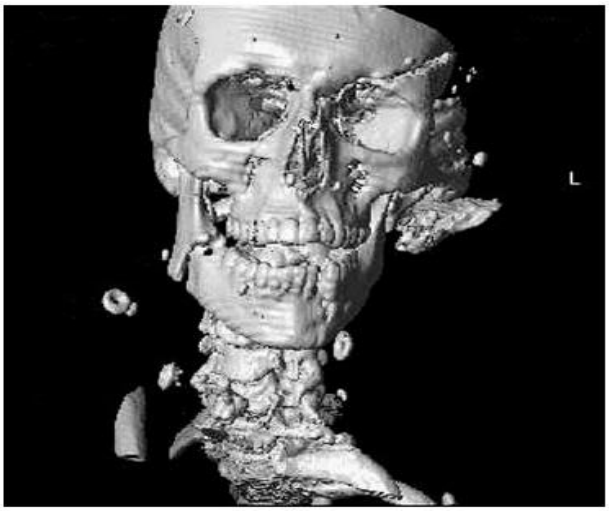


Fig 7. Digital 3D reconstruction from CT data allows the production of "sterile" images acceptable for use within courts. The precision of the images allows identification of fractures across the left supraorbital region, extending into the nasal complex, with a fracture of the right angle of the mandible in a case of death caused by multiple blunt trauma.[41]

4.3.2. MAGNETIC RESINANCE IMAGING

In the past ten years, forensic radiology has undergone tremendous change and cross-sectional imaging techniques like CT and MRI have been incorporated into the practice of forensic medicine. The primary benefits of CT and MRI over continuing autopsy procedures are the accurate and easy preservation of forensic results. In addition, these are non-intrusive methods. Advanced forensic imaging also has the benefit of providing more details on critical reactions.[39]

Paul Lauterbur and Peter Mansfield developed MRI in 1980, which makes use of the rotating motion that hydrogen ions (H+) naturally exhibit. The H+ is aligned with the externally applied field, either in parallel or antiparallel, by applying a strong external magnetic field. Most of the ions are oriented parallel to the total field vector. Applying an external second magnetic field at the same frequency and perpendicular to the first. This field is applied by a different coil, which causes the H+ to realign 90° to their prior net orientation while maintaining phase precession. T1 relaxation is the process by which the energy input from the RF pulse dissipates to the surrounding molecules when the pulse ends. As the protons dephase, T2 relaxation is brought on by the loss of transient precessational synchronization. The RF receiver coils pick up on these phases, generating the magnetic resonance signal that serves as the image's foundation. Therefore, there is no risk of radiation exposure from the treatment, although care must be taken to ensure that the body being inspected is free of any metal objects, such as jewelry, pacemakers, bullets, or prosthetics. The use of MRI is not prohibited by the presence of metal objects per se; however, due to the magnetic field created during the examination, projectiles may move within soft tissue or body cavities, and if they have only penetrated the skin or nearby subcutaneous tissues, they may even exit the body.[41]

Based on the diseases suggested by the case circumstances, external inspection, and baseline postmortem CT, postmortem MRIs should be performed specifically. T1-weighted, T2-weighted, and fluid-sensitive sequences in axial and at least one sagittal or coronal orientation should be part of the usual postmortem MRI protocol. In situations involving blunt trauma or motor vehicle accidents involving walkers, bicyclists, or motorcyclists, postmortem magnetic resonance imaging (MRI) may be utilized to reconstruct the soft-tissue injury caused, as it seems to be more accurate than postmortem computed tomography (CT) in identifying even tiny subcutaneous hematomas. [12]

A brain postmortem MRI protocol (minimum including T1-weighted and T2-weighted axial sequences, FLAIR sequences, and a hemosensitive sequence, such as blood oxygenation level-dependent or susceptibility-weighted imaging) may be relevant for a better depiction of the wound channel and intracranial hemorrhage in cases of head trauma (e.g., gunshot wound or stabbing). [76] It has been suggested that whole fixed brain MRIs be used to demonstrate intracerebral pathology in a way that is appropriate for presentation in court.

of dental evidence is that, similar to other hard tissues, it is frequently preserved until demise. Even a person's dental health varies throughout the course of their life, and the proportion of decayed, missing, and filled teeth is quantifiable and comparative at any given moment in time. The concepts of exclusion and comparison are the cornerstones of dental identification. When antemortem records of other questionable, unidentified individuals are available and need to be ruled out, dental identification is used.[77] Anthropometric measurements, skeletal maturation, dental age estimation, a combination of dental development and anthropometric measurements, mandibular measurement, maxillary sinus measurement, foramen magnum, mastoid foramen evaluation, etc. are some of the methods used in the age estimation and gender identification process.

5.1. Age Estimation

The purpose of determining the age of human remains is to help determine the deceased person's age or biological profile. Since secondary dentin deposition is proportionate to an individual's age, volumetric study of dental features in radiographs, such as pulpal size reduction that results in secondary dentin production, can help estimate an individual's age.[78]

This correlation was first explained by Bodecker in 1925. It is categorized into the following three phases.[79]

(A) Prenatal, neonatal, and postnatal

(B) Children and adolescents:

(C) Adult

Adult age determination has been proposed using morphological changes in teeth in a number of ways, including the following:

(a) Assessment of tooth-pulp volumes

Measuring only the vertical and mesiodistal dimensions of pulp chambers is the extent of two-dimensional (2D) imaging. The analysis of 2D radiographs is challenging and imprecise due to factors like crowding, rotations, superimpositions, magnification or foreshortening, and malpositioning. By offering dimensionally accurate images and simple instruments for measurements and calculation [80] CBCT makes it possible to apply a third dimension—that is, buccolingual measurements—for determining the pulp tooth ratio. Beyond normal wear and tear, enamel is typically resistant to changes; in contrast, as age advances, the pulp–dentin complex exhibits physiologic and pathological changes. However, CBCT offers a non-invasive alternative.[81] Yang et al. discovered a moderate connection with a linear relationship between pulp–tooth volume ratio and age using voxel counting software that was specifically designed for this purpose. Using volumetric reconstruction of their CBCT images, Jagannathan et al. (2011) examined 188 removed mandibular canines to assess whether pulp-tooth volume ratio was appropriate for age estimate in an Indian subpopulation. They concluded that the pulp–tooth volume ratio is a useful indication of age. [82]

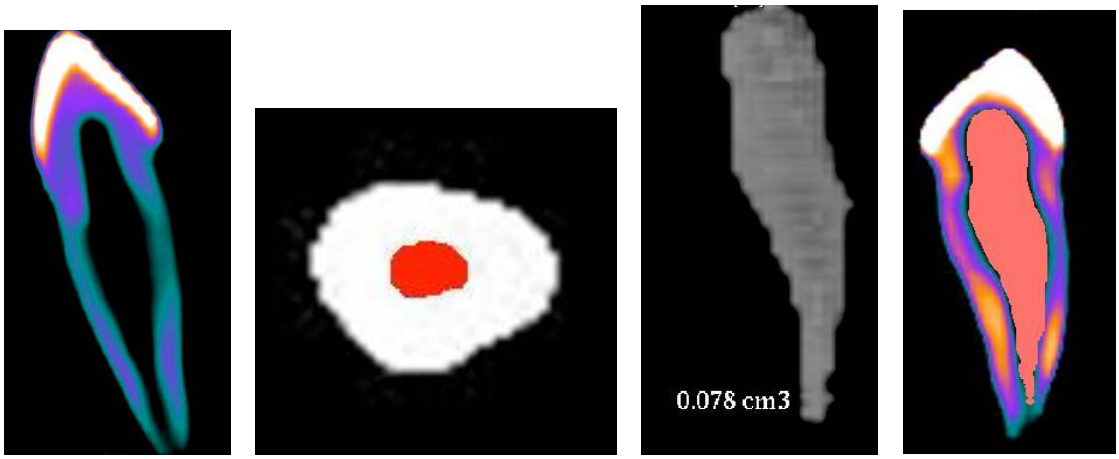


Fig no. 8
a. Reconstructed CT image of tooth with tooth volume marked.
b. A cross-sectional slice of the tooth obtained by CT, outlining the pulp space.
c. Volumetric reconstruction of pulp space.
d. Superimposition of pulp volume reconstruction on tooth volume image.[82]

(b) Third molar analysis

The third molar development, which typically happens after the age of 17, is used as a benchmark for determining an individual's age. Asif et al. (2019) found a significant inverse relationship between the surface area of the developing mandibular third molar apices and chronological age.[83] Third molar development is used to determine age in the context of forensics between the ages of 14 and 21, at which point all other teeth have finished forming. According to the Study Group on Forensic Age Diagnostics' guidelines, the Demirjian method has the highest level of practical and predictive usefulness. The benefits of this age estimation method stem from the well-defined developmental stages as evidenced by radiographs and diagrams.[84]

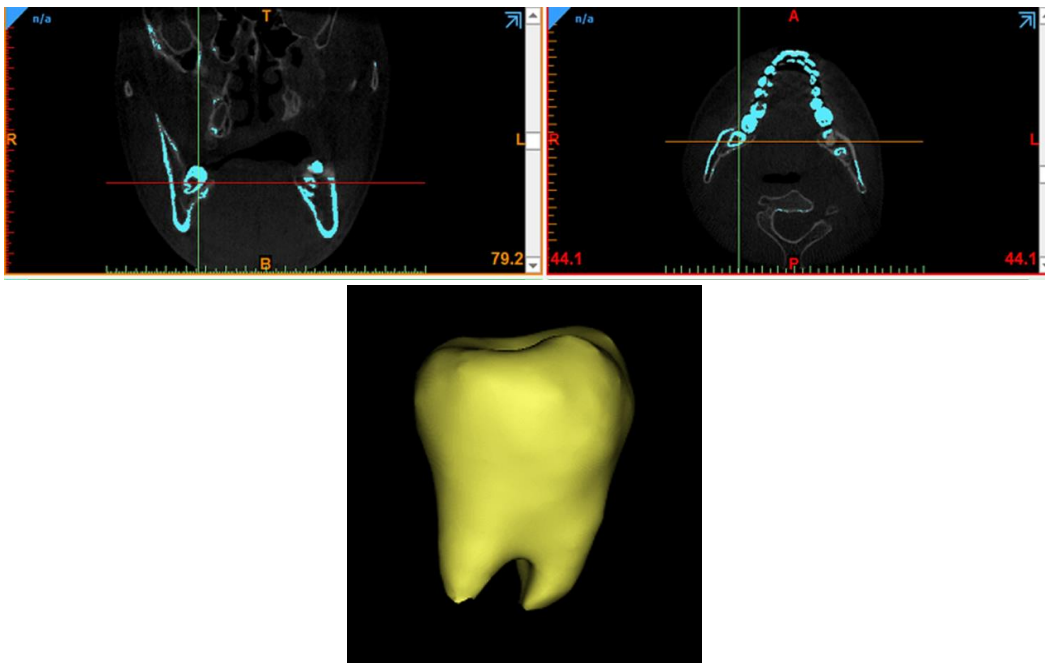
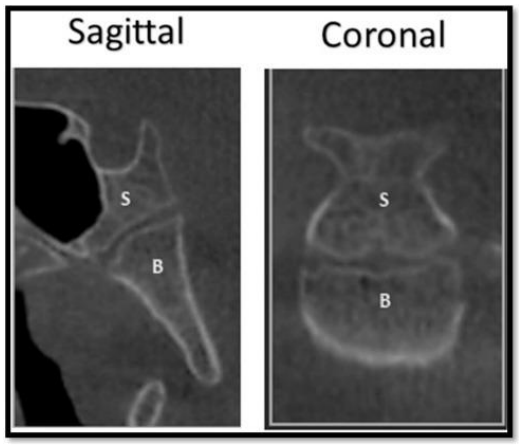


Fig no. 9
During the "multiple slice editing phase," the masks of growing third molars were manually cross-checked to enable precise selection of the calcified tooth structure and to isolate the tooth from the surrounding structures. Next, during the software's "region growing phase," the masks were grown. The program then produced three-dimensional representations of growing mandibular third molars. [83]

(c) Assessment of spheno-occipital synchondrosis

The union of the sphenoid and occipital bones is known as spheno-occipital synchondrosis (SOS), and it occurs in the clivus region at the base of the skull, anterior to the foramen magnum and posterior to the pituitary fossa. It is the primary growth cartilage of the cranial base during childhood and is active until the ages of 12 to 15 years old. It is a skeletal-anthropological marker. SOS is the last location in the skull where growth stops, usually by the time a person reaches the age of 20. [85] For the aforementioned age group, CBCT scans may be the preferred way of age assessment. They can also help establish an individual's legal adulthood in cases involving the age of eighteen. It is assumed that most people of that age are "mature enough to function in society as adults, to care for themselves, and to make their own self-interested decisions," which is reflected in the legal age.[86] Sobh et al. (2020) produced statistically quantified age estimation standards in a sample of the Egyptian populace by visualizing SOS using CBCT in a mid-sagittal view in a neutral head posture. They found that all of the individuals with non-fused SOS were less than 18 years old.[87] In the Indian subpopulation, Sharma et al. (2020) examined SOS in the coronal and sagittal planes using CBCT, and they categorized its closure into six stages. This sexual dimorphism persists until the age of sixteen, at which point 100% of the population exhibits complete closure of SOS. The study's findings showed a linear association between the closure of SOS and age. Therefore, when combined with other age assessment methods like third molar mineralization, cervical vertebrae maturation, etc., SOS is thought to be a more accurate tool for estimating age. [88].



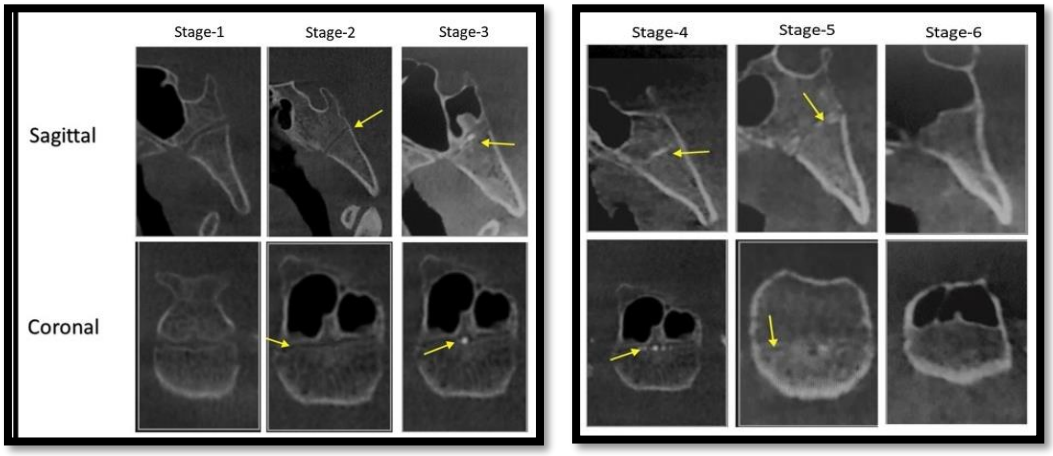


Fig. 10. Sagittal and coronal views of CBCT show spheno-occipital synchondrosis (SOS). S stands for sphenoid bone. B: Basiocciput

Fig 2 scoring tier-.

1. Stage 1: hypodense band between sphenoid and occiput.
2. Stage 2: fusion at the endocranial surface.
3. Stage 3: hyperdense ossification nodule.
4. Stage 4: bony bridging between multiple nodules.
5. Stage 5: SOS is almost fused.
6. Stage 6: complete fusion of the sphenoid and basiocciput. [88]

(d) Maxillary Sinus –

Among the paranasal sinuses (frontal, ethmoid, maxillary, and sphenoid), the maxillary sinus develops first, starting at 10 weeks of intrauterine life [89]. Since the maxillary sinuses have an intriguing history of remaining intact in accidents and tragedies like explosions, war, and airplane crashes, where the skull and other bones are typically horribly scarred, they are thought to be dependable indications for determining age and gender[90]. Numerous physiological and environmental factors, including breathing patterns, dental issues, body anatomy, gender, age, ethnicity, and climate, might have an impact on maxillary sinus volume. When skeletons are partial, sex can be determined by comparing the height and width of the maxillary sinus to other bones. The dimensions of the maxillary sinuses were measured using a brain MRI and was thought to be helpful in assessing the characteristics of the maxillary sinuses that assist in the age estimation.[91]

With panoramic radiographs, the relationship between dental age and chronological age can be approximated, and a number of characteristics can be measured. [92] Radiography pictures can be measured both linearly and angularly using a digital orthopantomograph. It was discussed that radiographic and tomographic pictures are crucial for predicting gender and age in forensic processes involving human identification.[93]

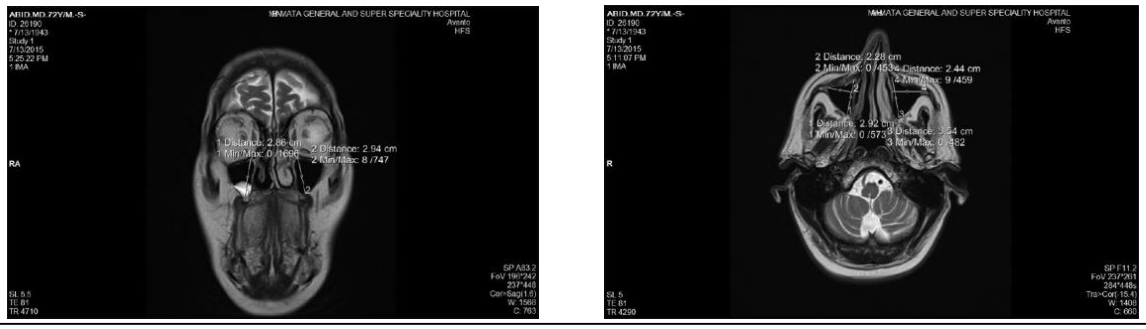


Fig no. 11 A - coronal magnetic resonance imaging image displaying the height of the maxillary sinus

B - The axial view of magnetic resonance imaging shows the maxillary sinus's width and depth. [91]

5.2. Gender Determination

To estimate a person's biological profile, sex determination is necessary. Conventionally, the pelvis, skull, and long bones are utilized to determine a person's sex. The accuracy rate for determining a person's sex from a skeleton is 100%; from the skull and pelvis, it is 98%; and from the skull and long bones, it is 90–95%. An individual's sex can be determined by anthropometric measurements of several craniofacial components on CBCT scans, including the mandible, mastoid process, foramen magnum, sinuses, and nasal septum. [94]

(a) Mandibular measurements

The size and form of the mandible show sexual dimorphism, which makes it highly accurate in determining sex. Due to factors including sex, diet, and physical activity, the female skeleton has smaller and thinner bones than the male skeleton.[95] The relative development (size, strength, and angulation) of the masticatory muscles is observed to influence the appearance of mandibular dimorphism since the masticatory forces of males and females differ. The jaw of males rotates forward, while the mandible of females has been seen to rotate backward and downward, resulting in larger gonial angle values in females than in males. The gonial angle is obtuse at birth, diminishes as one becomes older, and then increases once more in old age. Using the Planmeca Romexis program, ten mandibular factors were assessed in mandibular radiographs. It has been demonstrated that all nine of the mandibular variables—aside from the gonial angle—are accurate indicators of gender in South Indians.[18]

For the purpose of determining gender, CBCT can be used to measure the mandible's ramus length and breath, gonion-gnathion length, gonial angle, bigonial width, and bicondylar breadth. In a retrospective analysis of 100 CBCT, Gopal et al. (2016) showed that even in cases when the entire mandible could not be recovered for forensic purposes, the ramus could be utilized to determine a person's sex. [96]

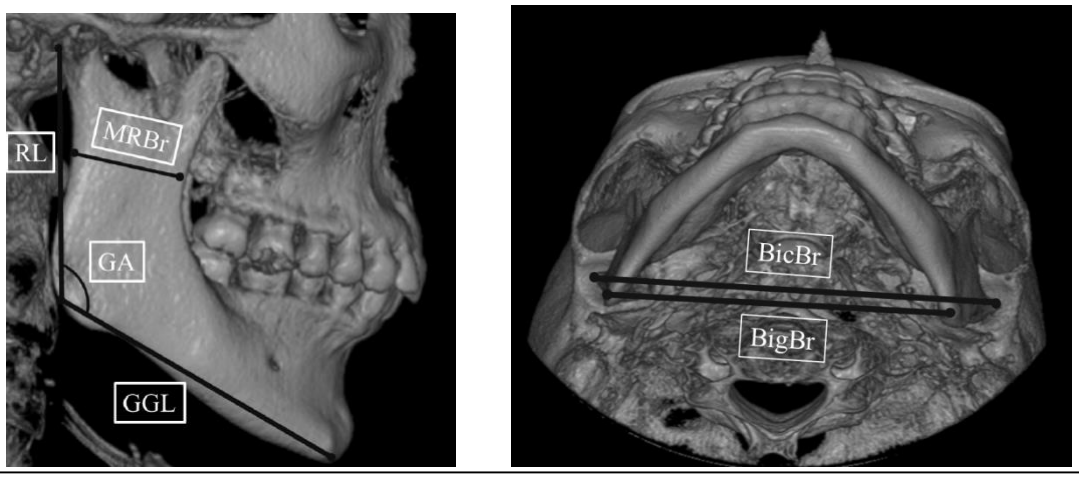


Fig no. 12 - Six measurements were acquired from 3D sagittal views (Fig. 1) of the jaws on CBCT images: bicondylar breadth (BicBr) and bigonial width (Fig. 2) of the jaws, and gonial angle (GA), ramus length (RL), minimum ramus breadth (MRBr), and gonion gnathion length (GGL).[97]

(b) Foramen Magnum

The basal central part of the occipital bone contains the Foramen Magnum (FM), a three-dimensional opening that serves as a transitional space between the skull and spine. Because of its anatomical position, protection, and relative thickness, the cranial base is seen to be a good reference for forensic testing. As such, this region of the skull is more resilient to physical trauma. Foramen length, breadth, and area varied statistically significantly between boys and girls, according to a number of studies. Tambawala et al. (2016) reported that in the forensic evaluation of reformatted axial sections, CBCT showed a 66.4% accuracy rate for sex determination.[98]

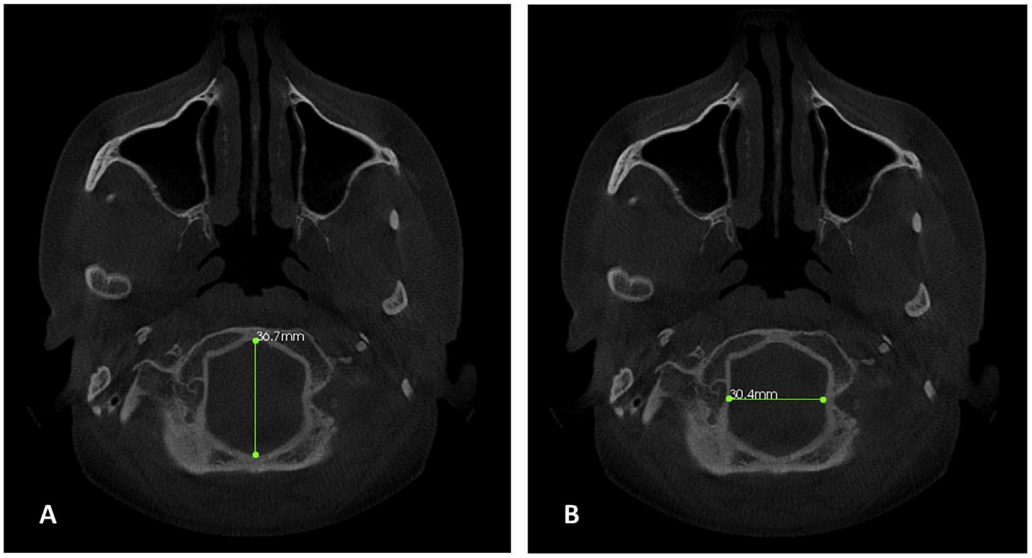


Fig. 13. A displays the foramen magnum's length in an axial cross-sectional image.

B displays the foramen magnum's width in an axial cross-sectional view.[98]

(c) Paranasal sinuses

Even in cases of severe physical trauma to the skull and other cranial bones, the paranasal sinuses (PNS) do not break. Numerous investigations have demonstrated that men's jaw sinuses have a significantly greater area unit than women's. Using CBCT images, Wanzeler et al. (2019) conducted a volumetric analysis of the maxillary, sphenoidal, and frontal sinuses and co-related them with measurements from the foramen magnum. They found that the chances of correctly identifying a person's sex are 96.2% and 92.7% for males and females, respectively, based on the sum of the volumes of the maxillary, sphenoidal, and frontal sinuses. The chances of correctly identifying a person's sex increased to 100% when the sum of the three estimated PNS measurements was correlated with FM measurements. [99]

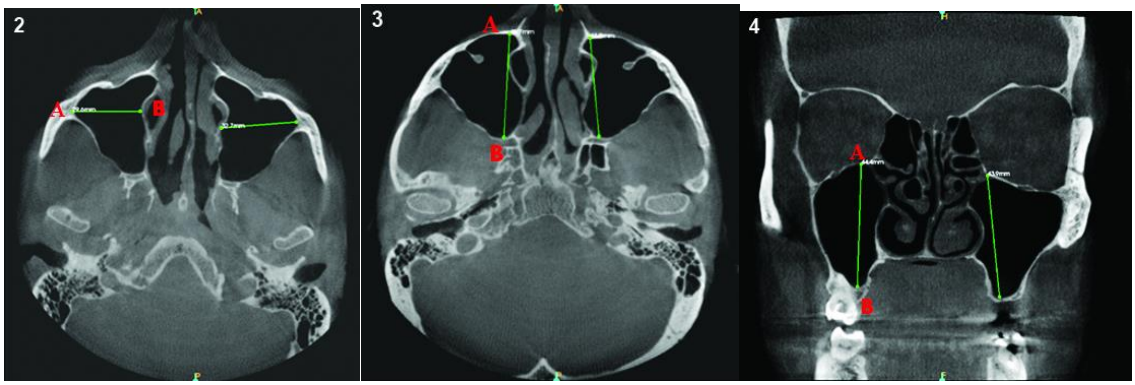


Fig no. 14. Measurement of maxillary sinus width in axial section

POINT A = Most lateral point on lateral wall of maxillary sinus

POINT B = Most medial point on the medial wall of maxillary sinus

Measurement of maxillary sinus length in axial section.

POINT A = Most anterior point of the medial wall of the maxillary sinus

POINT B = Most posterior point of the medial wall of the maxillary sinus

Mesurement of maxillary sinus height in coronal section.

POINT A = Most highest point of the sinus roof

POINT B = Most lowest point of the sinus floor. [99]

i. Frontal sinus comparison

Although frontal sinus (FS) assessment is mostly utilized for personal identification, gender determination can also be made using the considerable sexual dimorphic traits in its measures. Every individual, including monozygotic twins, have them. After the age of 20, they exhibit no change until old age, at which point atrophic changes may eventually result in pneumatization. One tool commonly used for determining sex is the frontal sinus index (FSI) or height/width ratio.[100] Frontal sinus width and height, anteroposterior diameter, total sinus width, inter-sinus width, the separation between the highest points of two FS, and the separation between the left FS's highest point and the maximum lateral limit measurements are the parameters that have been used in CBCT analysis of frontal sinuses.[101] Choi et al. (2018) reported

sexual dimorphism with an accuracy of 80% using reconstructed CBCT images to measure various FS characteristics.[102]

ii. Maxillary sinuses

According to a CBCT study by Tambawala et al. (2016). The greatest predictor of sexual dimorphism was maxillary sinus height. [104]

In the work of Kazuma Otsuki et al. (2023), they used CBCT pictures to assess the maxillary sinus' morphology. The age and sex of an individual can be precisely determined by measuring the sinus diameters and volume, regardless of the kind of maxillary permanent tooth and sinus floor anatomy.[105]

Maxillary sinus dimensions measures are useful in the research of sexual dimorphism, according to a study by Ruhi Sidhu et al. (2021) that examined the precision and dependability of maxillary sinus in gender determination using morphometric parameters. After the second decade of life, they usually settle, and radiographic pictures can give accurate measures for maxillary sinuses that are inaccessible through other channels. Thus, gender determination can benefit from maxillary sinus morphometric study.[106]

(d) Mastoid process

The mastoid region is an area of importance for macroscopic sex identification because of its anatomical location at the base of the skull, which makes it resistant to injury and allows it to remain intact even in the event of a fracture.[107] Males and females differ anatomically in the mastoid process; for example, the male mastoid process tip is vertical, whereas the female mastoid process tip faces inward. Additionally, males have greater mastoid measures than females. The size, surface area, flare, and medial convergence angle of the mastoid process were examined in 192 CBCT skull images by Amin et al. (2015). They found that these characteristics of the mastoid process can accurately identify the sex in 90.6% of the subjects.[108]

(e) Mental foramen :-

By drawing tangents to the superior and inferior borders of the foramen and perpendiculars from the tangents to the lower border of the mandible, the distances between the mental foramen and the mandibular border were calculated. In the population of northern India, this measure demonstrated appropriate gender dimorphism.[109] 2019's Shanmugasundaram K et al studied radiographic markers, such as the mental foramen in dental panoramic radiographs of the Chennai population, and suggested that it can be used to determine sex. Two tangents were made to the traced mental foramen, one inferior and one superior. The mandible's lower border was traced in a similar manner. On both the right and left sides, the lengths (in millimeters) between the perpendiculars drawn from the tangents to the lower border were measured (SL and IL). The measured lengths were counted and examined. In this study, they come to the conclusion that mental foramen can serve as a marker for human sexual dimorphism. They discovered In comparison to females, males had considerably larger distances between the inferior tangent and the lower border of the mandible and between the superior tangent and the lower border of the jaw.population of Chennai Two tangents were made to the traced mental foramen, one inferior and one superior. The mandible's lower border was traced in a similar manner.[110]

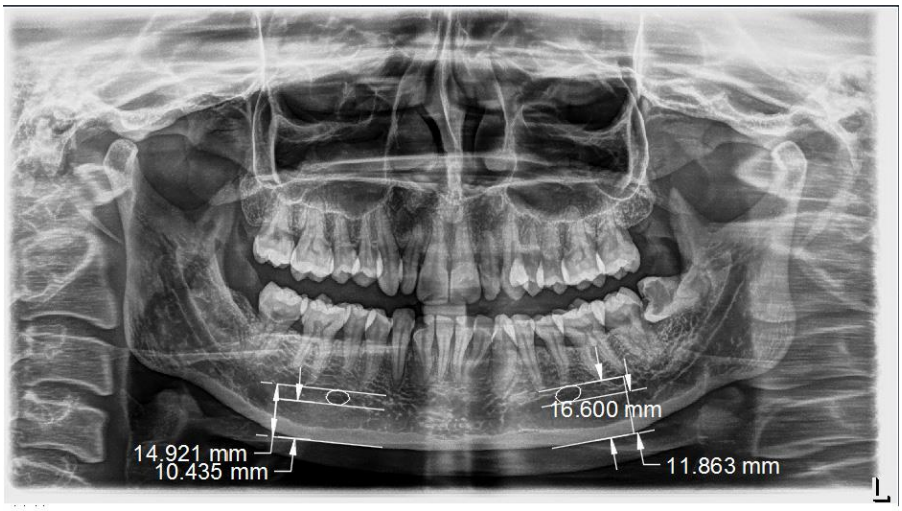


Fig no. 15. Tracing the mental foramen, measuring distance superior tangent and the lower border of the mandible and the inferior tangent and the lower border of mandible. [110]

6. Advance approach in forensic radiology

6.1. Facial reconstruction

One method for constructing a "alive" face from skeletal remains is facial reconstruction. The thicknesses of the soft tissues covering the skull's underlying bone structure determine how facial characteristics are replicated. It should be aware that the reconstruction process itself does not identify the subject; rather, it serves as a last resort by helping to recall a lost detail.[111] When no AM records or presumptive identification are available, reconstructive identification is taken into consideration, particularly when the bones have been severely burned or macerated.

It includes the coordinated use of 3D imaging (CT, CBCT, and MRI), anthropology, forensic dentistry, and forensic medicine. [112] Thanks to developments in computer graphics, three-dimensional reconstructed pictures from CT scans, or 3D-CT, have been utilized for anthropometric studies, dental implant planning, tumor assessments, and assessment of craniofacial abnormalities, among other clinical uses. With the goal of identifying humans by craniofacial analysis, it is suggested that 3D-CT is a more repeatable approach because craniometry necessitates the precise location of points and determination of measures. It has been demonstrated that 3D-CT imaging yields more precise measurements than 2D-CT image reconstruction and imaging directly on CT slices.

In 1990, Hildelbolt and Vannier conducted direct measurements on standard CT slices and 3D reconstruction. They then compared their results with caliper measurements and concluded that 3D-CT measures were more accurate than CT slice measurements. And it is thought that the advent of this technology and methodology constitutes a significant advancement in the field of forensic dentistry for human identification, particularly in large urban centers where there is a high population density and where the method's objectivity and speed are crucial considerations.

The purpose of Sara dos Santos Rocha et al.'s study is to evaluate the accuracy of linear measures made in 3D-CT utilizing craniometric patterns for forensic dentistry individual identification. Anthropometric measures such as nasal breadth, skull length, facial height, and nasal height were measured on five cadaver heads using axial slices in a spiral computed tomography scan. Using computer graphics tools and the volume rendering approach, 3D-CT reconstructions were produced. After determining ten craniometric measurements in 3D-CT pictures, the researchers came to the conclusion that forensic facial reconstruction can identify an individual through the examination of 3D-CT images in soft tissue and bone.[113]

In order to ascertain whether soft tissue thickness measurements can aid in forensic identification, Tanushri Saxena et al. conducted a study on persons in the north Indian population. Every subject underwent a CT scan, and measures were obtained. In order to determine the soft tissue thickness measurement, a tangential line was drawn to the outer surface curve of the body landmarks. The length of the line from the bone to the junction with the skin surface was considered the comparable soft tissue thickness at that landmark. The line was drawn perpendicular to the tangent at the bony landmark and extended outward to meet the facial profile. They came to the conclusion that regular scanning techniques for CT scans of the face provide a good representation of the soft tissue depth in the face and are a dependable way to measure the thickness of the soft tissue in that location. [114]

Fig no. 16.
A-end point of nasal bone
B-supra-canine
C-ramus
D-zygomatic bone
E-temporal bone
F-lateral orbital
G-malar prominences. [113]

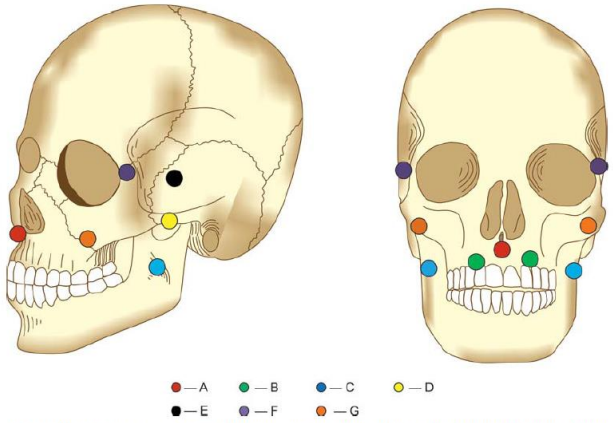


Fig. 1: (A) End point of nasal bone, (B) supra-canine, (C) ramus, (D) zygomatic bone, (E) temporal bone (F) lateral orbital, (G) malar prominence

However, compared to multi-slice CT, cone-beam CT (CBCT) reports a significantly lower radiation dosage and allows us to collect images of people while they are upright. CBCT provides us with information on both soft and hard tissues, as well as the thickness of the ST, whereas forensic facial reconstruction reconstructs the soft tissues of the face onto the surface of an unknown skull. Hwang, Hyeon-Shik, and colleagues demonstrate the repeatability of measurements of the thickness of the facial soft tissue (ST) by contrasting three distinct techniques that were applied at 32 landmarks on three-dimensional cone-beam computed tomography (CBCT) images. Using CBCT scan data, they quantify the face ST thickness of 20 adult subjects, and the inter- and intra-observer repeatability was assessed. The findings suggest that locating the landmarks on hard tissue images as opposed to ST images could improve repeatability. Additionally, the landmark description employed in this study can be applied to the creation of trustworthy tissue depth data utilizing CBCT images.[115]

The mouth is an essential component of the rebuilt face, and its placement indicates the proper facial proportions. Since there are no objectively validated effective methods for reconstructing the face, several researchers have observed a bias in mouth reconstruction. Few studies have examined the link between hard and soft tissues, despite study in this area—within the field of anthropometrics—helping to understand the morphology of the mouth among various populations.[116]

In order to improve forensic facial reconstruction's accuracy. According to the, a forensic radiologist should collaborate with a forensic anthropologist and an odontologist, utilizing the most recent tissue depth data relevant to various ethnic groups and modern techniques that summarize the qualifications and characteristics of Indian dentists that are useful for forensic facial reconstruction..[117]

There are certain restrictions in facial repair or approximation. The soft tissues of the face and the skeletal elements of the skull still have little in common. The presence and shape of the face muscles vary greatly, and it is challenging to reconstruct them from hard tissues. Furthermore, subcutaneous fat in the face affects look, and fat levels are unpredictable. Furthermore, tissue depth varies from person to person and sample references are used to calculate the average tissue depth. In order to generate fresh leads that may result in a provisional identification, facial reconstruction is helpful. Facial reconstruction techniques should be applied carefully for validation.
Some of the limitations are – a) Insufficient tissue thickness data, b) Lack of methodological standardization, c) Subjectivity.

Forensic reconstruction is still relatively new in India. When it comes to unidentifiable dead bodies, forensic facial reconstruction is particularly helpful for victim identification. To increase the success of facial reconstruction, it is advised that India build cutting-edge forensic laboratories, more infrastructure, and skilled and experienced forensic professionals. Furthermore, standard operating procedures (SOP) instructions for forensic facial reconstruction must be provided by the Ministry of Home and Family Welfare. It is also proposed that the use of odontology in facial reconstruction aims to create a scientific foundation for the artistic sculpting of facial features in addition to providing hands-on expertise with a variety of dental devices and materials. [118]

6.2. Image Guided Virtual Autopsy - An Important Tool in Forensic Identification

The words "virtual" and "autopsy" were combined to produce the term "virtopsy." The Latin word virtus, which meaning "useful, efficient, and good," is the source of the former phrase. The Greek phrases autos, which means "self," and opsomei, which means "I will see," are combined to form the word "autopsy." Autopsy, then, is defined as "to see with one's own eyes." We combined the phrases "virtual" and "autopsy"—deleting autos—to form the term "virtopsy" because we wanted to remove the subjectivity that was conveyed by autos.
The two main components of virtopsy are (a) 3D body surface documentation utilizing forensic photogrammetry and 3D optical scanning, and (b) body volume documentation and analysis using CT, MR imaging, and microradiology.

The final data collection includes 3D volume documentation of the body's inside and high-resolution 3D color-encoded documentation of the body's surface. The new technique ought to assist in ascertaining whether a death was caused by an accident, suicide, homicide, or natural causes.[119]

The identity of the deceased must be established and proven prior to any postmortem examination; if not, one of the objectives of the investigation will be to restore the identity of the unidentified body. In this context, multi-detector row CT can be quite beneficial. The only methods of secure postmortem identification that remain are dental status, DNA profiles, and fingerprinting. The more widely used methods include fingerprinting and dental identification, while DNA is the most costly and time-consuming. Any antemortem radiographic projection can be reconstructed for comparison using cranial CT data taken from a body. It is possible to produce panoramic images that are similar to antemortem orthopantograms.[120] Furthermore, antemortem dental records of people who are believed to be lost can be compared with postmortem CT data to determine the restorative material that was employed.

Death can have many different causes, regardless of how it occurs (natural causes, accidents, suicide, violence, or iatrogenic causes, for example). A few of these reasons are exclusive to particular body parts, such the heart, brain, or lungs. The cause of death may also be indicated by a number of systemic abnormalities. Postmortem imaging can depict typical trauma findings just as effectively as clinical radiology can. Postmortem imaging makes it possible to see a gross pathologic finding in the brain in depth. When a deceased person is originally discovered laying injured on the ground, it is crucial for forensic examination to ascertain whether the injury was the result of a blow to the head or a fall to the ground. This conclusion can be drawn from contrecoup lesions in the brain, typical skull fracture systems, and the morphologic characteristics of the crush wound.

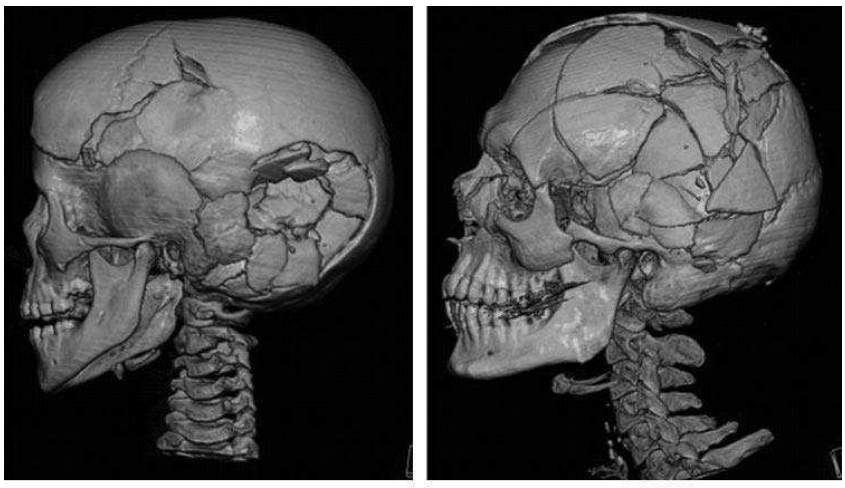


Fig. no. 17
(a) A head injury brought on by blows. The oblique left lateral 3D VR CT scan displays a ring fracture of the occipital skull as a result of hammer strikes, together with a characteristic local impression.
(b) A head injury brought on by a high-altitude fall. Comminuted burst fractures beginning at the posterior prominent area of the skull (place of impact) are visible in the oblique left lateral 3D VR CT picture.[119]

Forensic application of a minimally invasive, image guided biopsy procedure on corpses made it possible to obtain tissue specimens for histopathological investigation. With this method, samples of blood, bile, or urine can be obtained in addition to tissue specimens for use in toxicological or DNA analyses.[119]

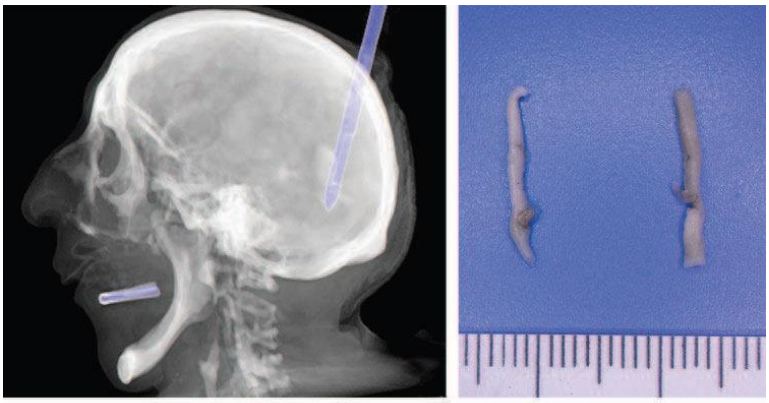


Fig. no. 18
Postmortem imaging-guided biopsy.
(a) A biopsy needle that was put into the brain through a hole cut into the skull is clearly seen in the left lateral 3D CT scan. A metallic component of a denture is represented by the linear blue object on the left side of the picture.
(b) A photograph displaying brain specimens that were removed and stained histologically.[119]

Sometimes the clinical CT scans' and MR images' spatial resolution is insufficient to provide useful information for forensic wound analysis inquiries. High spatial resolution pictures are produced by emerging technologies like micro-MR imaging and high-resolution CT (micro-CT). Since its introduction to medicine in the mid-1990s, micro-CT has been employed in research on osteoporosis and transgenic mouse follow-up.[121] It has previously been shown that micro-CT is helpful in evaluating bone damage.

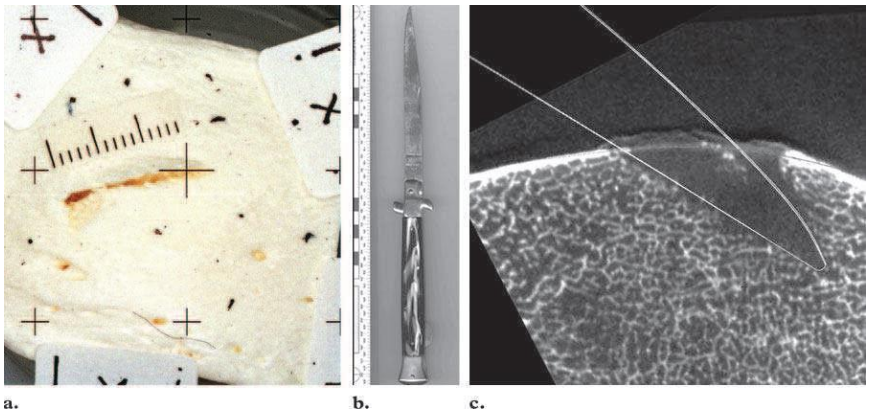


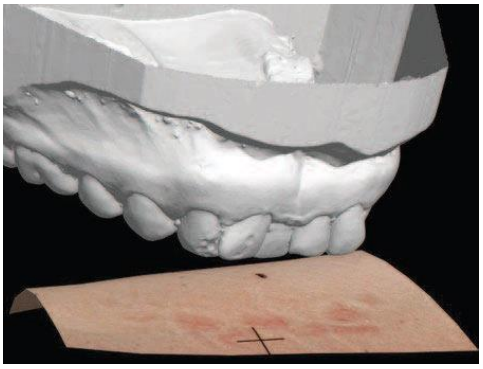
Fig .no. 19
Forensic micro-CT in a case of sharp-force injury.
(a) Photograph shows a bone defect that was to be investigated and compared with a knife that was suspected to have caused the injury.
(b) Photograph shows the knife.
(c) On a micro-CT scan obtained orthogonal to the bone lesion, the knife's dimensions are superimposed, allowing inclusion of the knife in the group of possible injury-causing instruments.

In the sense that micro-CT and micro-MR imaging may be utilized to perform microvirtopsy on forensic tissue specimens prior to destructive sectioning, CT and MR imaging are predicted to turn standard autopsy into minimally invasive imaging guided virtual autopsy.[122]

3D Color-encoded Surface Scanning

The TRITOP/ATOS II system (GOM) is utilized in forensic applications where 3D documentation of the weapon (instrument that caused the harm) and the produced injury on the body (skin, bone) is used.[123] This 3D data collection is referred to as a "morphologic fingerprint" or "patterned injury." Correlation attempts are undertaken in a virtual three-dimensional environment after the weapon is scanned. Potential morphologic relationships include those between minor bite wounds and potential perpetrators' teeth or between a traffic accident victim's patterned injuries and the potential vehicle involved.

Fig no. 20shows study of a bite wound in three dimensions.
A 3D surface image of the offender's teeth is linked with a color-encoded 3D surface image of the bite mark on the victim's skin. Based on the precise locations of teeth, the study in this instance enabled a positive match between the bite mark and the dentition that caused the injury.[119]



Unlike the previous generation of CT scanners, the entire body may be documented in a matter of minutes thanks to the new MSCT method. Compared to traditional radiological documentation, which involves taking separate standard images for the head, neck, thorax, abdomen, and limbs, as well as any autopsy procedure, this is substantially faster. Fast isotropic documentation and the resulting great possibilities for 2D and 3D post-processing are the key advantages of MSCT. In the near future, radiological techniques like MRIs and MSCTs may be used as a "virtual autopsy" tool. Afterwards, bullets and pertinent histology samples may be obtained using image-guided percutaneous biopsy procedures in a minimally invasive manner, and they could be examined, for instance, using high-resolution micro-radiological techniques like micro-CT and micro-MR. [124]

One benefit of virtopsy is that it can quickly and painlessly visualize an area of interest while accurately identifying any damaged organs or foreign bodies. additionally It offers human intervention-free sample, comprehensive 3D records that show the cause or method of death with intact tissue, and contamination-free sampling. In times of mass disasters where bodies sustain significant damage, it is a simple means of identification. Forensic facial reconstruction in three dimensions using virtopsy methods is applicable to medicolegal scenarios. The highly accurate data that has been digitally preserved can be useful for additional case inquiry. The drawbacks of virtopsy include its inability to reveal details regarding infection status, tissue texture, and color changes, as well as its cost-effectiveness, technique sensitivity, and need for highly qualified radiologists. Its viability and judicial acceptance are limited.

New Uses for Virtopsy Applications include an automated postmortem and three-dimensional surface scanning are two features of robotic virtual autopsy, a multipurpose technology that improves the quality of forensic investigation results.[125] The use of volume-analysis software during virtopsy aids in the precise measurement of internal organ masses. A useful virtopsy approach for visualizing the system is postmortem angiography, which involves infusing contrast material using a peristaltic pump and contrast medium.[126]

In the future, it's possible that more deceased people may get a preliminary external examination and CT scan, and an autopsy will be performed based on the findings. This would result in a far higher proportion of post-mortem examinations, a higher rate of homicide detection, and more examinations overall.[127]
A minimally intrusive strategy could be beneficial in a variety of ways. First, in recent years, there has been a sharp decline in the acceptance of traditional autopsy. One can perform a triage by scanning the bodies. However, a more comprehensive triage approach is now feasible since non-invasive forensic techniques are becoming more widely accepted. In cases where postmortem imaging reveals evidence of a third party's participation, the case for an autopsy becomes considerably stronger. In certain situations, post-mortem angiography, image-guided biopsies, and surface scanning—all minimally invasive methods—have the potential to replace traditional autopsies.[128]

Virtual autopsy has recently advanced to become a new specialism in radiology. Therefore, using these investigation approaches calls for specialized and concentrated skills from both radiologists and forensic radiologists. Most importantly, the credibility of virtual autopsy can only be ensured by close collaboration between forensic pathologists and radiologists who are knowledgeable with standardizing indications and methods.[129].

In a survey conducted by Yadukul S ET AL (2022), they investigated the understanding, perspective, and adoption of virtual autopsy among Indian forensic experts and scientists. A pre-validated cross-sectional questionnaire research involving 65 Indian forensic experts and scientists was conducted. The questionnaire asked questions about the fundamentals, attitudes, and practices of virtual autopsy in the hospital or institute15.4% of them were familiar with the Virtual Autopsy process in its entirety. 78.5% of interviewees said that virtual autopsies may supplement traditional autopsies. The majority of participants believe that the biggest obstacle to the adoption of virtual autopsies in India is money. The National Medical Council (NMC) and other Institutes of National Importance should take the lead and introduce Virtual Autopsy as a required curriculum, eventually making its implementation mandatory. It was determined that Virtual Autopsy is an urgent need to be implemented in all Medical and Dental Institutes across the nation.[130]

6.3. 3D printing

Cone Beam Computed Tomography (CBCT) is the most modern digital radiological technology to be used in forensic radiology, having progressed from plain film radiography. In many parts of the world, post-mortem identification involves the use of high resolution radiographs, such as Computed Tomography (CT), when dental identification becomes problematic. In many areas of medicine and dentistry, fast prototyping has replaced earlier digital procedures in recent years.[131]. Rapid prototyping, sometimes

known as 3D printing, requires sophisticated equipment. Rapid prototyping makes it possible to create full-scale models that accurately represent anatomy; as a result, it will be highly beneficial in the fields of forensic dentistry and medicine. [132]

Mr. Chuck Hull, who is regarded as the Father of 3D printing, is the brains behind this rapid prototyping. In the year 1984, he created the first 3D printer. Since then, the field of 3D printing has experienced rapid expansion. The digital photos are used to construct 3D models. The raw image can be obtained using many imaging modalities, including as Magnetic Resonance Imaging (MRI), CT, and CBCT. Radiographic pictures from Digital Imaging and Communications in Medicine (DICOM) are exported to the Standard Triangular Language (STL) format so that quick prototyping may take place. Various types of scanners, including photogrammetry, structured light, laser, and related technologies, are used in 3D digitizing systems. Layer-by-layer models are created using a variety of materials, including metals, ceramics, liquid resins, and specific powders, in order to generate three-dimensional things from two-dimensional image data.[133. 134]

3D printing is useful in forensic orthodontia for a number of purposes, including the analysis of bite marks, the recording, documentation, and analysis of lip prints, the analysis of palatal rugae pattern, facial reconstructions, post mortem reconstruction of the skull and other bones, the identification and reconstruction of weapons used during crimes, and more. [135, 136]
A Johnson et al. (2021) assessed the metric accuracy validity and reliability of 3D printed replicas using manual measurements and a digital mesh comparison. Twelve removed teeth were among them, and an Intra-oral portable laser scanner was used to scan them. After the scan data were analyzed, the obtained 3D model was post-processed and converted to a stereolithography file format. Five distinct 3D printing technologies—Fused Deposition Modeling (FDM), Stereolithography (SLA), Selective Laser Sintering (SLS), Multijet Fusion Technology (MJF), and Digital Light Processing (DLP)—were used to print the final files on separate printers. After comparing the teeth manually, they came to the conclusion that the 3D printed teeth were correct to within 0.5 mm (with one exception). This suggests that the validity and dependability of 3D printed replicas as demonstrative evidence in the forensic sciences, and forensic odontology in particular, is good. [137]

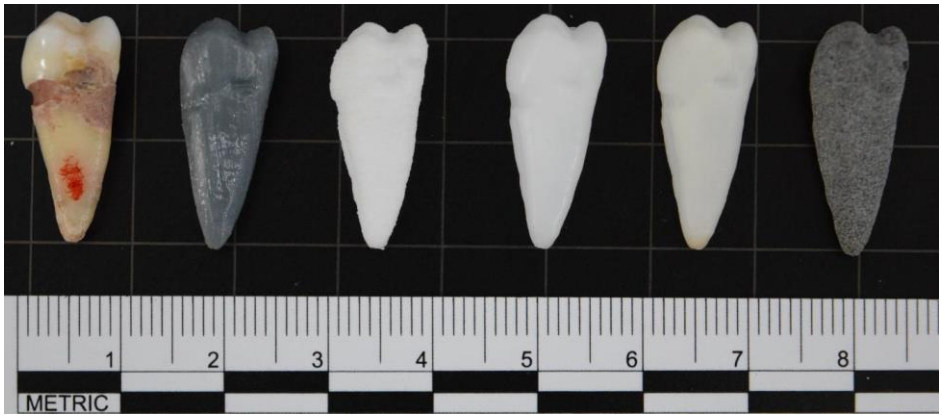


Fig. no. 21

3D printed teeth and original tooth from left to right: Natural tooth, FDM printed tooth, SLS printed tooth, DLP printed tooth, SLA printed tooth and MJF printed tooth. [137]

Ballistics, anthropology, forensic medicine, and ortopedology are among the disciplines that actively employ this technology. Better evidence visualization, interpretation, preservation, and analysis are made possible by 3D printing. Situation In India, 3D printing for forensics is still a relatively new technique. In India, there aren't many examples of 3D scanning being used for documentation. recognizing the various forensic fields in which 3D technology can be applied successfully and forming a multidisciplinary team to create best practices in 3D forensics. Establishing standard operating procedures to acquire 3D scans and configure 3D modeling settings for printing and other purposes is also necessary. creation of moral and legal standards for using 3D technology and presenting proof that has been rebuilt.[138] Bones, organs, and veins, along with associated diseases, can be shown anatomically thanks to the use of 3D printing and medical imaging technologies. Virtual data is transformed into actual models through 3D printing technology. These models are so intuitive that even non-medical people can understand them, which makes this technology useful for courtroom presentations and other instructional uses.[139]

The forensic sciences have seen a transformation thanks to the adoption of 3D digitizing technology as laser scanners, structured light scanners, photogrammetry, etc. It permits the presenting of three-dimensional models of any proof originating from humans without introducing prejudice into the legal system. The use of these technologies also enables quick data collecting with low degradation and a decrease in human error. The delivery of forensics education is a significant additional use for 3D printing. Therefore, forensic sciences can be advanced by carefully adapting these 3D digitizing technologies. [140]
The development of 3D printing technology has been extremely beneficial to forensic odontology. It is evident that 3D printing has a wide range of uses, from the development of tools and biomechanical modeling to the production of anatomical models that aid in pathology identification and surgical planning. 3D printing in forensics is only getting begun in India; proof-of-concept studies and early research are paving the way for later, more sophisticated uses. The impact that 3D printing will have on forensic medicine in India and elsewhere in the future will be greatly impacted by cross-disciplinary cooperation, measurement validation, and ethical norm observance. With further advancements in technology, forensic investigations and medical procedures could potentially become more accurate, efficient, and effective in the future.[141]

6.4. X-ray fluorescence and Energy dispersive x-ray spectrography (EDs)

The fluorescence radiation that a surface emits upon exposure to x-rays is measured via EDXRF spectroscopy. Determining the radiation allows for the determination of the basic composition of the surface. It is thought that X-ray fluorescence spectrometry (XRF), a method for identifying the major, minor, and trace elemental elements in a sample, will be useful in these kinds of investigations. [142]

EDXRF extracts electrons from their orbitals by means of ionizing radiation in the form of high-energy x-ray photons Energy is released in the form of secondary x-ray photons, or "fluorescence," as a result of

this transition towards a lower energy state. Every element, orbital, and electron has a different fluorescence emission energy, which allows one to determine the atomic makeup of a surface. The amount of fluorescence is then measured by a silicon drift detector (SDD), which transmits the data to a PC for processing and display. The only substances that can be recognized on an EDXRF spectrum are supplements, like radiopaque fillers. contrary to equipment used in laboratories.

EDXRF equipment is portable, affordable, and simple to use. They can also offer a quick and accurate way to find out if restorative ingredients are present. They can promptly furnish details regarding the quantity of various filler components utilized in a victim. Composite filler material identification using energy-dispersive .

A non-destructive elementary study of a surface called X-ray fluorescence (EDXRF) spectroscopy can distinguish or identify specific filler materials. The combined application of EDXRF spectroscopy on repaired dental surfaces and a post mortem CT scan may show to be more effective than either technique alone and a more accessible and affordable substitute for chemical analysis.[143]

The X-ray fluorescence spectrometer is studied in human cadavers by Mary A. Bush et al. (2002). A portable X-ray fluorescence spectrometer (XRF) was used to identify the resin brand and its location in the dentition following the insertion of the resin restoration. This study demonstrated the value of restorative resins in victim identification even after cremation, as well as the effectiveness of XRF as an analytical technique for forensic odontology. [144]

6.5. Bite marks identification - Computerized Axial Tomography

In forensic dentistry, biting mark analysis is the most challenging and commonly employed method. Both the attacker and the victim have bite marks. It might be challenging to distinguish violent attacks because many of them involve many bites. A bite mark will resemble an oval, round, or U-shaped arch. Each case has a different description of this bite pattern, and the skin changes throughout time. Given that each person's bite mark is unique, it is often a useful identification tool in cases of violence.[145]

There are two main categories of bite marks: those caused by animals (which are non-human) and those caused by people. According to the mode of causation, bite marks can be defined as either criminal or non-criminal, with the latter grouping into defensive (on the part of the attacker) and offensive (against the victim by the attacker) bite marks. Examples of non-criminal bite markings are love bites. [146]
There are seven types of bite marks,
‘Haemorrhage’ (a small bleeding spot),
‘Abrasion’ (undamaging mark on skin),
‘Contusion’ (ruptured blood vessels, bruise),
‘Laceration’ (near puncture of skin),
‘Incision’ (neat punctured or torn skin),
‘Avulsion’ (removal of skin), and
‘Artefact’ (bitten-off piece of body).

These further can be classified into four degrees of impressions;
'Clearly defined' that results from the application of significant pressure, 'Obviously defined' which is the effect of first degree pressure,
'Quite noticeable' due to violent pressure and
'Lacerated' when the skin is violently torn from the body.[147]

The following classes that are of proven significance in practical application regarding bite marks are:

Class I: It includes diffused bite marks, which is having limited class characteristics and lacks individual characteristics. Such as bruise, diffused bite mark, a smoking ring or, a faint bite mark.

Class II: This pattern of injury referred to as a single arch bite or the partial bite mark as it has some individual and some class characteristics.

Class III: This classification includes both individual as well as class characteristics. This bite has great evidentiary value and used mostly for the comparison purposes. The main sites for this type of bite on the body are buttocks, shoulder, an upper arm or the chest. The pressure and deep penetration of tissue is held to record the lingual surface of anterior teeth.

Class IV: Mainly, avulsion or laceration of the tissues is caused by the bite. In this class, class characteristics and individual characteristics are not present. This type of bite is commonly found where there is avulsion of an ear or finger.[148]

A bitemark is characterized as a "pattern produced by a human or animal dentition and associated structures capable of being marked by these means" in the field of forensic science. A bitemark is an oval or circular lesion that is made up of two symmetrical U-shaped arches that are either separated at their bases or not. The precision with which teeth record the bitten substrate and the dentition's specificity are the foundations of bitmark analysis. There are now photographic protocols in place that demand the existence of a reference scale (ABFO n°2, for instance) that is in the same plane as the bitemark. The digital camera and these two components must be perpendicular to one another. However, certain distortions may develop and obstruct accurate analysis if protocols are not properly followed. Scanners can be used to obtain bitemarks data when the three-dimensional component is visible.

An intraoral scanner can be used in forensic odontology to capture a suspect's teeth and scan bitemark indentation reliefs other than skin. 3D point processing software can then compare these two items. A few bitemarks from cheese and chocolate, as well as those from wax and apple, were compared and lined up. Even though the bitemarks were created by the same dentition, several of them did not match up between the various materials. The physical characteristics of the support and the bite force were the parameters that affected the bitemark analysis's accuracy. Shape, density, hardness, and water content of the material are some of the physical attributes of the support.

The thickness and hardness of the support that is bitten determine how strong the bite is. Periodontal mechanoreceptor data provides the basis for biting force adaptation. The principal distortions are caused

by these two factors: biting force and material properties. Then, when time passes and bitemarks are recorded as proof, the technicalities create the secondary distortions. Bitemarks and dentitions can be quickly recorded with intraoral scanning devices. By transferring the 3D images to surface comparison software, bitemarks may be directly analyzed and compared. Preserving the 3D aspect makes analysis easier and less biased. As a result, 3D analysis is more impartial than previous techniques.[149]

Bite mark analysis is a relatively new and potentially useful part of forensic dentistry. A bite mark can be documented in situations of child abuse and sexual offenses. The examination of bite marks is mostly dependent on the uniqueness of a suspect's dentition. Bite mark evidence is a useful technique for identification in many criminal cases because it has been used in the legal system.[145]

It is now appropriate to think about using less intrusive, digitally transferable, and similarly accurate alternative approaches, including three-dimensional (3D) scanning technologies. A three-dimensional scan is a moment in time that freezes and captures visuals that we already know are distorted. Point clouds are produced by a 3D scanner using geometric information acquired from an object's surface. Using digital data on the known spatial position of each measurement point, the shape of the object is recreated. Dental casts and scanned dentition are compared using various scanning and processing software packages.[150] Accurate and quick bite mark recording is made possible by 3D digital scanning. Keeping up a digital trail of evidence is much easier to maintain. To facilitate instant communication between the members of the forensic team, a digital file might be uploaded to a cloud server.[151] It was thought that the CBCT-assisted bite mark analysis was straightforward, accurate, and nondestructive. According to Ali et al., bite mark CBCT images showed no distortion artifacts and allowed for precise 3D measurements.[152] Bite mark digital analyses can only improve on aspects that already exist and make these features more effectively presented. There are useful benefits to using 3D image technology in the courtroom, particularly in terms of juror comprehension of technical jargon. 153 The possibility for precise portrayal of bite marks in three dimensions, comparison of the dentition of the suspected biter with the evidence, and matching of the corresponding biter with the bite-mark among multiple suspects has been demonstrated by computer-aided graphics and animations. The automatic computation of the deviation between the two meshes made possible by ATOS software makes it possible to analyze and interpret the results with ease and accuracy. The animated act of biting may be compared dynamically using 3D Studio Max software, allowing for the obvious detection of 3D matches or nonmatches. [154]

7. 3-D SCANNING AND COMPUTER-ASSISTED DENTAL IDENTIFICATION SOFTWARE

CAPMI

Since the late 1980s, Lorton, Langley, and Weed have developed Computer Assisted Post Mortem Identification (CAPMI), a program that helps forensic odontologists identify victims of mass disasters by generating potential matches. Forensic odontologists have used computers for data collection and documentation of various evidences collected.

DVI System International

Software called DVI (Disaster Victim Identification System International) can handle identification-related tasks in the event of a mass disaster. This is especially useful when victims of many nationalities are involved. The forms are divided into two sets of data sheets: a pink form set that records all finds related to a deceased body, and a yellow form set that records the most recent information available about a missing individual. One benefit is that comparable antemortem and postmortem pages can be displayed simultaneously in the same window as part of a Microsoft Office Word function. On the other hand, comparable digital images and radiographs can be displayed simultaneously as part of a Microsoft Office Picture Manager function. (Torpet,2005)

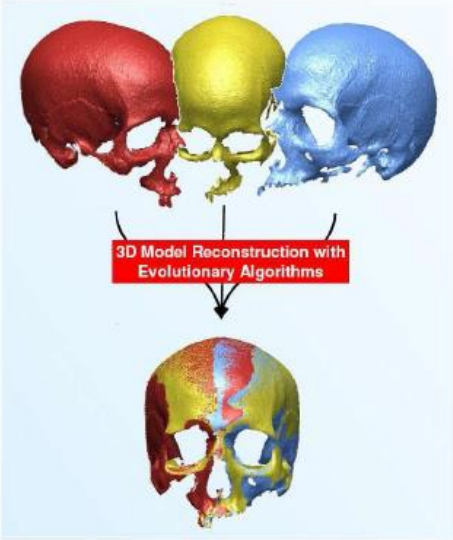
WinID3

Dr. James McGivney created WinID, a free computer-assisted dental identification program. This program was utilized in a number of large-scale incidents, including as terrorist attacks. WinID3 employs an understandable approach that allows it to correct identify changes brought about by reasonable and explicable discrepancies in references, in addition to sorting for requested identifiers. DEXIS, a digital radiography program, has been integrated with WinID3 to enable the management and capturing of dental radiographs in addition to all other photos and documents. This makes it possible for WinID3 to seamlessly connect radiographic and photographic records with dental charting to create an integrated system for case evaluation and comparison. (Berman et al., 2013) [155]

Craniofacial superimposition

Techniques for improving 2D face images using commercial software that is operated by humans will be regarded as non-automatic. Such 2D image augmentation is carried out automatically by computer programs. However, current methods of craniofacial superimposition require a precise three-dimensional model of the skull. With the resources available in a conventional forensic anthropology lab, there aren't many opportunities to record 3D forensic items. Computed tomography scanning pictures are the initial data used in the biomedical sector to reconstruct the skull. [Singare et al. 2009; Fantini et al. 2008].

The production of a 3D model requires the use of 3D image reconstruction software to align the images in a shared coordinate frame. Typically, this procedure is known as range image registration. To match the obtained views of the item, the optimal 3D rigid transformation—which is made up of a rotation and a translation—must be determined. Figure displays three separate views of a skull together with the 3D model that was rebuilt.



Three different views of a skull and the reconstructed 3D model.[156]

Among the many beneficial prospective uses of image processing techniques to forensic sciences are the automatic localization of anthropological landmarks on 3D skull models and 2D face photos. There is a genuine need for precise and automatic registration methods for constructing 3D models and superimposing them on 2D photographs, and computer graphics techniques can fulfill this demand. Using the imaging capabilities offered by the Adobe PhotoshopTM and Corel DrawTM software products, the most sophisticated approach is based on computer-aided craniofacial superimposition [Al-Amad et al. 2006; Bilge et al. 2003; Ross 2004]. We concur with these authors that using digital images for work is unquestionably easier and less expensive than using equipment for photo-graphic or video superimposition.[156]

Determining definite identification required careful consideration of the computer-assisted superimposition used in the comparison. By using a CT scan and superimposing various bone landmarks and photos with comparable features from antemortem photographs, it is feasible to positively identify a deceased person. It has been demonstrated that for the superimposition test, a 3D reconstruction of the skull is just as helpful as a skeletonized skull. [158]

Laser range scanners

Based on the optical principle of triangulation, laser range scanners rapidly and non-contactly gather a dense set of three-dimensional point data [Bernardini and Rushmeier 2002]. Fortunately, some laser range scanners come with a rotational table—an extra positioning tool—as well as the software needed to enable 3D reconstruction.[156]

Forensic BioRobots

Deoxyribonucleic acid (DNA) has a long history of being a dependable source for human identification, and its application in criminal investigations has increased dramatically in recent years. The extraction, measurement, and dilution steps of the DNA sample procedure have been automated in labs thanks to

forensic robots. BioRobot M 48 has proven to be highly successful in extracting DNA from most specimens in most forensic labs, according to Parys Proszek et al. These are mainly intended to increase productivity and free up the forensic scientist to concentrate on analysis and interpretation instead of processing duties. As a result, they save time by expediting the DNA profiling procedure and minimizing human error. [157]

8. Role of consultant in forensic radiology

Due to weakened infrastructure, lost communication lines, and destruction of antemortem records from nearby dental clinics, forensic odontologists may encounter particular challenges. All of these things have the potential to hinder or delay the timely victim identification. In their analysis of the role forensic odontologists play in victim identification after mass disasters, Ghevaram Prajapati et al. (2018) came to the conclusion that forensic odontologists are among the most cost-effective and dependable scientific approaches for managing mass disasters. However, the availability of antemortem records is a major factor in the success of forensic odontologist-mediated identification. Therefore, having sufficient understanding of forensic odontology and maintaining proper dental records are essential.[159]

It is possible to compare the dental characteristics that were present before and after death. As ante-mortem data, all of these records are available from teaching dental hospitals or general dentists.[160] Therefore, we think it is crucial that general dentists and/or dental hospitals preserve their patients' dental records. Any general dentist practicing their profession has a need to comprehend the forensic ramifications of doing so. Part of the dentist's professional duty is to create, maintain, and disseminate clear and accurate patient records. Regretfully, general dentistry practitioners in India lack the necessary training and experience to properly maintain patient records. Numerous studies have indicated that there is an urgent need to educate practitioners about maintaining dental records properly and how they can be used in the future to identify victims.[161]

The most frequent reason for requesting a formal radiologist evaluation for radiological consultation is for the postmortem radiographic assessment of infants and children who have passed away from a variety of causes, where it is necessary to ascertain whether nonaccidental or intentional trauma was present. [162]
A consultant in forensic radiology is responsible for determining fracture age, helping to identify and assess skeletal trauma, and offering expert interpretation of radiographic data. By bridging radiologic and forensic investigations through imaging techniques, consultants may even be involved in virtual autopsies. Additionally, by offering their specific radiological skills, they might aid in the investigation of criminal cases.[163]

The lack of standards for training and certification, the cost, availability, and quality of imaging equipment, the subjective interpretation of radiological images, and increased error rates that may lead to erroneous convictions are some of the difficulties faced by consultants in forensic radiology. Furthermore, as they become less trustworthy, some older forensic procedures are becoming less valuable and are As a branch of forensic science and medicine, forensic radiography aids in court investigations. To ensure quality images are produced, radiologists practicing forensic radiography must have proper training. It is

essential that the person doing the process has received training in radiation safety for both themselves and their employees.[165] Modern imaging technologies have a great deal to offer the forensic autopsy community. Advanced sectional imaging technologies are predicted to revolutionize forensic pathology practice. This change is probably being driven by the expectations and attitude of the public as well as legal orders and federal funding. Fellowships in forensic radiology for pathologists and radiologists would promote a convergence of abilities and aid in bridging the disciplines.[166]

Dentistry records tend to be a very helpful tool in circumstances where antemortem records are unavailable, as forensic dentistry investigation primarily depends on their availability. They are also kept up to date for dental insurance and as consumer court documents. According to one of the survey results, only 12 percent of dentists kept comprehensive dental records. As a result, it demands that every dentist fulfill their social obligation to maintain their patients' dental records, which might be a crucial source of information in the event of an accident.[167] Rahman Juber et al. (2017) The study's objective was to assess dental surgeons in Bhubaneswar, East India, on their knowledge, awareness, and practice of forensic odontology. The findings also indicated that all three groups had appropriate levels of forensic odontology knowledge and awareness. On individual correlation, however, the groups performed poorly in practice when it came to specific questions, such the required retention period for dental data.[168]

Legal practitioners who are not knowledgeable in forensic odontology will not be able to evaluate and manage scientific evidence in a competent manner, which could substantially hinder the pursuit of justice and result in factual errors.[169]

9. Knowledge and awareness in India

Forensic odontology has emerged as a new promise in supporting forensic medicine in recent times, although this essential and crucial area of forensic medicine is still undeveloped in India. There are four main areas of interest within the field of forensic dentistry:

a. Dental identification,
b. Bite mark, Cheiloscopy (study of lip prints)
c. Rugoscopy (study of palatal rugae patterns).

Natural and man-made calamities are happening more regularly in India these days, and there is also a rise in crime, including child abuse and gang rape. In these circumstances, victims' bodies become severely disfigured, and dental surgeons play a crucial role in identifying those who have suffered such injuries. The field of forensic odontology has grown in prominence in some wealthy nations, but it has not yet reached its full potential in developing nations like India.

According to Namrata Harchandani et al.'s 2014 study, "Awareness of Forensic Odontology among General Dental Practitioners in Pune - A Cross-sectional Study," general dentists in Pune lack knowledge about maintaining dental records, including what kind and how long to keep them up to date and how to testify.[170] Although India does not currently have any fully functional forensic odontology labs, there are numerous institutes that do offer formal forensic odontology training, including those in Delhi, Mumbai, and Karnataka. Our academic curriculum did not contain forensic odontology until recently. Parul Khare

et al. (2013) seek to assess dentists' understanding and expertise in forensic odontology in a tier 2 and metropolitan area. There were 774 dentists that participated in this poll. The purpose of the questionnaire was to evaluate forensic odontology practitioners' knowledge, skills, and state of practice. stated that there was a lack of awareness among respondents on the clinical applications of forensic odontology; hence, measures to educate dental professionals about these applications must be taken.[171]

In 2016, Gambhir et al. carried out Regarding the knowledge, awareness, and practical application of forensic odontology among dentists in India, a systematic review of pertinent cross-sectional studies was carried out. The results suggested that there is a significant variation in the practice of forensic odontology among dentists and that the subjects' knowledge and awareness levels were inadequate.[172]

For the first time in India's criminal prosecution history, an accused person was granted the death penalty; in this case, dental forensics was crucial in supplying evidence. The forensic odontologist connected the bite marks on the victim with the teeth of the two defendants in the Delhi gang rape case.[173]

Dental professionals in India have sufficient understanding of forensic odontology; what they lack is the mindset and application of that information. Practitioners have limited access to forensic odontology journals and are unaware of them. A considerably higher percentage of respondents connected to academic pursuits indicated knowing that forensic odontology is recognized as a field of study.[170]

In every study, very few dentists had any prior expertise solving forensic odontology problems. According to the results of the Preethi et al. study, 40% of dentists lacked the necessary skills to recognize child abuse, and the remaining 60% would do so based on physical harm, scars, behavior, attire, etc. Additionally, 60% of dentists agreed that parents/children should receive counseling and that any incident should be reported to the child care authorities. [169]

Current Scenario in India:

The Indian Association of Forensic Odontology (IAFO) was established in 2000, and registration was completed in 2001. Since then, the organization has hosted yearly national conferences, greatly advancing the field in India. A significant step toward the advancement of the subject was made in 2007 when the Dental Council of India (DCI) revised the Bachelor of Dental Surgery Regulations to include Forensic Odontology in the curriculum for third and final year students. This allowed for the subject's exposure to undergraduate students.

Dr. Ashith B. Acharya contends that it is incorrect to presume that every medico-legal case will necessitate a thorough medical investigation, much less forensic odontology, and that routine usage of forensic odontology is not a reality in India at this time. In addition to the ongoing work of established organizations like the IAFO, persistent efforts by individual dentists with an interest in the subject are needed for this to become a reality in IndiaIt is necessary for the media to participate and to engage with the judiciary, law enforcement, and the forensic community in a variety of platforms and activities, including conferences, instructional programs, and practical workshops.[174]

Dr. Ajit Dinakar claims that there is a greater need for skilled forensic dentists in the nation, but there are two things that need to be considered: first, the need for forensic odontologists in the nation needs to be quantified; second, the skills needed by a forensic dentist who wants to work for the army, a law firm, a crime lab, or any other law enforcement agency need to be properly defined. There are relatively few dental professionals in India with formal training in forensic dentistry due to the absence of postgraduate programs in the nation. The majority of them got it from nations like Australia or the UK.[175] Numerous educational institutions in India, including JSS University in Mysore, D.Y. Patil University in Navi Mumbai, and SDM College of Dental Sciences in Dharwad, have begun to provide master's degree, fellowship, and postgraduate diploma programs in forensic orthodontia, respectively. In addition, Gujarat Forensic Science University (GDSU) launched an M. Sc. degree in forensic orthopaedics in 2014.[176]

There are a number of reasons why India lacks consultant radiologists: insufficient training opportunities; scarce medical seats; higher attrition rates; excessive workloads; and burnout. The chairman of Aasra Hospitals, Dr. Jagadish Hiremath, claims that the unequal distribution is caused by a shortage in Tier 2 and 3 cities and none in rural areas. The average ratio of radiology seats to all clinical seats combined is approximately 1:15, which suggests that there are not enough medical facilities offering radiology training programs. A major obstacle is also the requirement for over 20,000 radiologists to guarantee that the benefits of imaging are available throughout India. The increasing number of patients in rural areas who do not have access to specialized medical treatment adds to the load and is driving up demand for teleradiology services. [177]

The Indian government has taken significant action to alleviate the scarcity of forensic radiologists. The government has been working on programs to solve the overall shortfall of healthcare workers, although it is well known that India has a severe deficit of healthcare experts, especially forensic specialists.[178] Among these efforts are the creation of medico-legal institutes in each state and the use of AI to forensic medicine. The scarcity of forensic experts is a component of India's greater scarcity of healthcare workers, and resolving it could necessitate taking extensive steps to fortify the healthcare system and enhance medical education and training initiatives. [179] The broader initiatives to fortify the healthcare workforce and enhance the forensic medicine infrastructure in India are pertinent to the overall context of addressing the shortage of forensic radiologists, even though the specific initiatives to address the shortage of forensic radiologists are not specifically mentioned in the search results.[174]

The lack of specialized training institutions, low public knowledge of forensic radiography, and the requirement for well-equipped forensic laboratories and training facilities in every state are among the difficulties faced by forensic radiologists in India. There are other medico-legal concerns as well, like radiologic misconduct and the requirement for specific knowledge when managing medico-legal matters. Other major obstacles include the shortage of professionals qualified to handle forensic evidence and the creation of medico-legal institutes in every state. These difficulties underscore the need for more knowledge, specialized education, and the development of infrastructure in India's forensic radiology sector. [180]

10. Future of forensic radiology

Forensic dentistry is a relatively new field with a lot of room for growth in India. The Dental Council of India has incorporated it into the Bachelor of Dental Surgery (BDS) curriculum. Although forensic dentistry is not currently offered as a stand-alone subject in the Dental Council of India's curriculum, it is connected to two other branches: oral medicine and radiology and oral and maxillofacial pathology.[167]

Dr. Acharya, one of the pioneers of forensic odontology in India, proposed a plan for its introduction, and the DCI accepted it in 2007 when they revamped their dental curriculum. The majority of people who were not specialists were allowed to teach the topic. This was carried out with the issue of the nationwide shortage of certified forensic odontologists in mind. Due to some material overlap, dental specialists from fields like oral pathology/oral biology and oral medicine/radiology were selected to teach forensic odontology. The course was separated into two streams: oral medicine/radiology for the para-clinical stream and oral pathology/oral biology for the preclinical stream.[168]

Like in the West, forensic odontology in India will undoubtedly become its own dental specialty in the near future. Numerous national and international organizations, including the recently founded Indo Pacific Academy of Forensic Odontology and the Indian Association of Forensic Odontology, are registered, operational, and actively involved in advancing this field in India.

Before beginning their service, every soldier enlisting in the armed forces must pass a rigorous medical check. In order to maintain a thorough record of the recruit in the database for any future referral, a number of medical tests are conducted and samples are gathered. A body that has been mutilated or disoriented is identified by comparing it with the database's entries. The DNA and fingerprints of an individual are among the samples that are typically preserved as documentation. In the worst situations, though, the bodies may have to remain unidentified because the DNA and fingerprints may be lost owing to inaction. If the recruits' dental records are also obtained in addition to these information, it might help identify the bodies even after a considerable period of time has passed. Forensics would be useful in both identifying the remains of their warriors and defending the country from terrorists who pose as national security threats by spreading false information and impersonating them.[170]

While forensic medicine departments exist at medical colleges throughout the state, there isn't a specific facility for medico-legal cases. A better platform for medico-legal work that benefits both living and deceased patients will be made available by the medical college's medico-legal institute. Establishing the Medico-legal Institute at Medical Colleges will better meet its goals of providing construction space, qualified labor, a working environment, and case availability for the institute's successful operation.[175]
Similar to doctors in other specialties, radiologists are more likely to face legal action for their professional misconduct. Legal concerns now play a big role in the life of a practicing radiologist. The PCPNDT Act and radiologic malpractice are two significant areas where Indian radiologists should exercise caution. The majority of doctors are ignorant of these legal matters and the regulations that now regulate them. Therefore, it is imperative to possess fundamental understanding and expertise on these matters in order to shield oneself from professional liability. [181]

Artifact-related issues can be significantly decreased in the future if all of the centers that are permitted to utilize the radiography units begin employing digitalized radiography. Images that include data can be stored and reprinted at any moment, even after a long period of time. Nonetheless, a forensic odontologist should rule out image tampering during an inquiry. When all of these factors are taken into account, digital radiography has to be the best method available, provided that it is maintained under tight guidelines and leaves no room for image manipulation. In the future, it's also feasible that virtual autopsy may frequently take the role of surgical autopsy, utilizing radiography to its maximum potential.[182]

11. CONCLUSION

In the interest of justice, forensic odontology handles the administration, review, assessment, and presenting of dental evidence in criminal or civil procedures. The conduct, interpretation, and reporting of radiographic tests and processes related to the legal system are all included in forensic maxillofacial radiology. Dental radiographs, which are vital to the forensic sciences, have reportedly been identified as one of the most often used Ante mortem evidences for human identity. The acquired evidence from dental remains must be processed, reviewed, and evaluated by forensic dentists in order to produce objective, scientific facts that may be presented to legal authorities. Forensic dentistry has evolved greatly from being sporadically utilized to becoming essential to identification processes. Radiographic Techniques Used in Forensic Identification are Extraoral radiographic technique which include OPG, CBCT CT and MRI. With the help of these techniques age estimation, sex determination, bite mark analysis, facial reconstruction, implant retracking, and tissue damage analysis can be done. Anthropometric measurements, skeletal maturation, dental age estimation, a combination of dental development and anthropometric measurements, mandibular measurement, maxillary sinus measurement, foramen magnum, mastoid foramen evaluation, etc. are some of the methods used in the age estimation and gender identification process. Advances in forensic radiology field are facial reconstruction, virtual autopsy, 3D-Printing, X-ray fluorescence and Energy dispersive x-ray spectrography (EDs).

3-D scanning and computer-assisted dental identification software include Capmi, Dvi system international, Craniofacial superimposition, Laser range scanners, Forensic biorobots.
In India A consultant in forensic radiology is responsible for determining fracture age, helping to identify and assess skeletal trauma, and offering expert interpretation of radiographic data. The lack of specialized training institutions, low public knowledge of forensic radiography, and the requirement for well-equipped forensic laboratories and training facilities in every state are among the difficulties faced by forensic radiologists in India. The Indian government has taken significant action to alleviate the scarcity of forensic radiologists. The government has been working on programs to solve the overall shortfall of healthcare workers, although it is well known that India has a severe deficit of healthcare experts, especially forensic specialists.

References

1. Rai S, Misra D, Misra A, Kalita P, Krishna A. Forensic outlook of Maxillofacial Radiology–An inevitable tool revisited. UNIVERSITY JOURNAL OF DENTAL SCIENCES. 2022 May 17;8(3).

2. Issrani R, Prabhu N, Sghaireen MG, Ganji KK, Alqahtani AM, ALJamaan TS, Alanazi AM, Alanazi SH, Alam MK, Munisekhar MS. Cone-beam computed tomography: a new tool on the horizon for forensic dentistry. International journal of environmental research and public health. 2022 Apr 28;19(9):5352.
3. Chiam SL. A note on digital dental radiography in forensic odontology. Journal of Forensic Dental Sciences. 2014 Sep;6(3):197.
4. Kahana T, Hiss J. Forensic radiology. The British Journal of Radiology. 1999 Feb;72(854):129-33.
5. Avon SL. Forensic odontology: the roles and responsibilities of the dentist. Journal-Canadian Dental Association. 2004 Jul 1;70(7):453-8.
6. Jawaid M, Amir A, Shahnawaz K, Qamar Y, Upadhay P, Singh J. Maxillofacial imaging in forensic science: a newer approach. Int J Contemp Med Res. 2016;3(8):2491-5.
7. Jeddy N, Ravi S, Radhika T. Current trends in forensic odontology. Journal of forensic dental sciences. 2017 Sep;9(3):115.
8. Senn DR, Weems RA, editors. Manual of forensic odontology. CRC press; 2013 Jan 22.
9. Lagalla R. A brief history of forensic radiology. Radiology in Forensic Medicine: From Identification to Post-mortem Imaging. 2020:1-2.
10. Kaleelullah RA, Hamid P. Forensic odontology, a boon and a humanitarian tool: A literature review. Cureus. 2020 Mar 24;12(3).
11. Brogdon BG, Lichtenstein JE. Forensic radiology in historical perspective. Brogdon's forensic radiology. 2010 Nov 22:9-23.
12. Flach PM, Thali MJ, Germerott T. Times have changed! Forensic radiology—a new challenge for radiology and forensic pathology. American Journal of Roentgenology. 2014 Apr;202(4):W325-34
13. Boger D. Role of the Consultant in Forensic Radiology. InMultidisciplinary Medico-Legal Death Investigation 2018 Jan 1 (pp. 35-68). Academic Press.
14. Bruce-Chwatt RM. A brief history of forensic odontology since 1775. Journal of forensic and legal medicine. 2010 Apr 1;17(3):127-30.
15. Aalders MC, Adolphi NL, Daly B, Davis GG, De Boer HH, Decker SJ, Dempers JJ, Ford J, Gerrard CY, Hatch GM, Hofman PA. Research in forensic radiology and imaging; Identifying the most important issues. Journal of Forensic Radiology and Imaging. 2017 Mar 1;8:1-8.
16. Sinha S, Singh C, Chandra S, Singh SK, Mehta P. Role of maxillofacial radiology in expediting forensic odontology. International Journal of Oral Care and Research. 2018 Oct 1;6(4):89-92.
17. Tarani S, Kamakshi SS, Naik V, Sodhi A. Forensic radiology: An emerging science. Journal of Advanced Clinical and Research Insights. 2017 Mar 1;4(2):59-63.
18. Yazdanian M, Karami S, Tahmasebi E, Alam M, Abbasi K, Rahbar M, Tebyaniyan H, Ranjbar R, Seifalian A, Yazdanian A. Dental radiographic/digital radiography technology along with biological agents in human identification. Scanning. 2022 Jan 18;2022.
19. Ali HJ, Choudhari M, Hande A. Scope and Relevance of Forensic Odontology in India–A Review. Journal of Indian Academy of Forensic Medicine. 2022 Oct 12;44(3):75-7.
20. Avon SL. Forensic odontology: the roles and responsibilities of the dentist. Journal-Canadian Dental Association. 2004 Jul 1;70(7):453-8.

21. Jeddy N, Ravi S, Radhika T. Current trends in forensic odontology. Journal of forensic dental sciences. 2017 Sep;9(3):115.
22. Kumar R, Athota A, Rastogi T, Karumuri SK. Forensic radiology: An emerging tool in identification. Journal of Indian Academy of Oral Medicine and Radiology. 2015 Jul 1;27(3):416-22.
23. Pallagatti S, Sheikh S, Aggarwal A, Singh R, Gupta D, Kaur A. Maxillofacial imaging: An emerging tool in forensic science. J Forensic Res. 2011;2(6):2-4.
24. Eckert WG, Garland N. The history of the forensic application in radiology. The American journal of forensic medicine and pathology. 1984 Mar 1;5(1):53-6.
25. Carvalho SP, Silva RH, Lopes-Júnior C, Peres AS. Use of images for human identification in forensic dentistry. Radiologia Brasileira. 2009;42:125-30.
26. Schuller A. A note on the identification of skulls by X-ray pictures of the frontal sinuses. Medical Journal of Australia. 1943;1(25):554-6.
27. Shahin KA, Chatra L, Shenai P. Dental and craniofacial imaging in forensics. Journal of Forensic Radiology and Imaging. 2013 Apr 1;1(2):56-62.
28. Pretty IA, Sweet D. A look at forensic dentistry–Part 1: The role of teeth in the determination of human identity. British dental journal. 2001 Apr;190(7):359-66.
29. Appelbaum PS. Law & psychiatry: Through a glass darkly: Functional neuroimaging evidence enters the courtroom. Psychiatric Services. 2009 Jan;60(1):21-3.
30. Castillo RF, Ruiz MD. Assessment of age and sex by means of DXA bone densitometry: application in forensic anthropology. Forensic science international. 2011 Jun 15;209(1-3):53-8.
31. Hinchliffe J. Forensic odontology, Part 1. Dental identification. Br Dent J 2011;210:219-24.
32. Raitz R , Fenyo-Pereira M, Hayashi A S , Melani R . Dento-maxillo-facial radiology as an aid to human identification. J Forensic Odontostomatol 2005;23:55-9.
33. Adams BJ. Establishing personal identification based on specific patterns of missing, filled, and unrestored teeth. J Forensic Sci 2003;48:487-96.
34. Delattre VF. Antemortem dental records: Attitudes and practices of forensic dentists. J Forensic Sci 2007;52:420-2.
35. Thali MJ, Vock P (2003) Role and techniques in forensic imaging. In Payne-James J, Busuttil A, Smock W, eds., Forensic Medicine: Clinical and Pathological Aspects. Greenwich Medical Media, London, pp. 731-746.
36. Hiss J, Kahana T (2000) Trauma and identification of victims of suicidal terrorism in Israel. Mil Med 165, 889-893.
37. Rai S, Misra D, Tyagi K, Prabhat M, Gangwal P. Image guided virtual autopsy: An adjunct with radiographic and computed tomography modalities-An important tool in forensic identification. Journal of Indian Academy of Oral Medicine and Radiology. 2017 Oct 1;29(4):368-70.
38. Kumar R, Athota A, Rastogi T, Karumuri SK. Forensic radiology: An emerging tool in identification. Journal of Indian Academy of Oral Medicine and Radiology. 2015 Jul 1;27(3):416-22.
39. Jawaid M, Amir A, Shahnawaz K, Qamar Y, Upadhay P, Singh J. Maxillofacial imaging in forensic science: a newer approach. Int J Contemp Med Res. 2016;3(8):2491-5.

40. Sarment DP, Christensen AM. The use of cone beam computed tomography in forensic radiology. Journal of Forensic Radiology and imaging. 2014 Oct 1;2(4):173-81.
41. Swift B, Rutty GN. Recent advances in postmortem forensic radiology: computed tomography and magnetic resonan
42. Alwohaibi RN, Almaimoni RA, Alshrefy AJ, AlMusailet LI, AlHazzaa SA, Menezes RG. Dental implants and forensic identification: A systematic review. Journal of Forensic and Legal Medicine. 2023 Mar 5:102508.ce imaging applications. Forensic pathology reviews. 2006:355-404.
43. Senn DR, Weems RA, editors. Manual of forensic odontology. CRC press; 2013 Jan 22.
44. Gopal, S.K. Role of 3D cone beam computed tomography imaging in forensic dentistry: A review of literature. Indian Forensic Odontol. **2018**, 11, 75–82.
45. Jeddy, N.; Ravi, S.; Radhika, T. Current trends in forensic odontology. J. Forensic Dent. Sci. **2017**, 9, 115–119. [CrossRef]
46. Carvalho, S.P.M.; Silva, R.H.A.; Lopes, C., Jr.; Sales-Peres, A. Use of images for human identification in forensic dentistry. Radiol. Bras. **2009**, 42, 125–130.
47. Stuehmer, C.; Blum, K.S.; Kokemueller, H.; Tavassol, F.; Bormann, K.H.; Gellrich, N.-C.; Rücker, M. Influence of different types of uns, projectiles, and propellants on patterns of injury to the viscerocranium. J. Oral Maxillofac. Surg. **2009**, 67, 775–781. [CrossRef]
48. Von See, C.; Bormann, K.H.; Schumann, P.; Goetz, F.; Gellrich, N.C.; Rucker, M. Forensic imaging of projectiles using cone-beam computed tomography. Forensic Sci. Int. **2009**, 190, 38–41.
49. Jain, S.; Choudhary, K.; Nagi, R.; Shukla, S.; Kaur, N.; Grover, D. New evolution of cone-beam computed tomography in dentistry: Combining digital technologies. Imaging Sci. Dent. **2019**, 49, 179–190
50. Manhaes-Caldas, D.; Oliveira, M.L.; Groppo, F.C.; Haiter-Neto, F. Volumetric assessment of the dental crown for sex estimation by means of cone-beam computed tomography. Forensic Sci. Int. **2019**, 303, 109920
51. Da Costa, E.D.; Peyneau, P.D.; Roque-Torres, G.D.; Freitas, D.Q.; Ramírez-Sotelo, L.R.; Ambrosano, G.M.B.; Verner, F.S. The relationship of articular eminence and mandibular fossa morphology to facial profile and gender determined by cone beam computed tomography. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. **2019**, 128, 660–666. [CrossRef]
52. Mowafey, B.; Van de Casteele, E.; Youssef, J.M.; Zaher, A.R.; Omar, H.; Politis, C.; Jacobs, R. Can mandibular lingual canals be used as a forensic fingerprint? J. Forensic Odontostomatol. **2015**, 33, 26–35.
53. Gopal, S.K.; Vardhan, H.B.G.; Kumar, N. Implant backtracking—A valuable tool in forensic identification—An advanced radiological CBCT study. Asian J. Sci. Technol. **2017**, 8, 4787–4789.
54. Von See, C.; Bormann, K.H.; Schumann, P.; Goetz, F.; Gellrich, N.C.; Rucker, M. Forensic imaging of projectiles using cone-beam computed tomography. Forensic Sci. Int. **2009**, 190, 38–41.
55. Jain, S.; Choudhary, K.; Nagi, R.; Shukla, S.; Kaur, N.; Grover, D. New evolution of cone-beam computed tomography in dentistry: Combining digital technologies. Imaging Sci. Dent. **2019**, 49, 179–190

56. Thali MJ, Vock P (2003) Role and techniques in forensic imaging. In Payne-James J, Busuttil A, Smock W, eds., Forensic Medicine: Clinical and Pathological Aspects. Greenwich Medical Media, London, pp. 731-746.
57. Thali MJ, Yen K, Vock P, et al. (2003) Image-guided virtual autopsy findings of gunshot victims performed with multi-slice computed tomography and magnetic resonance imaging and subsequent correlation between radiology and autopsy findings. Forensic Sci lnt, 138, 8-16.
58. Persson A, Lindblom M, Jackowski C. A state-ofthe- art pipeline for postmortem CT and MRI visualization: from data acquisition to interactive image interpretation at autopsy. *Acta Radiol* 2011; 52:522–536
59. Ruder TD, Hatch GM, Ebert LC, et al. Whole body postmortem magnetic resonance angiography. *J Forensic Sci* 2012; 57:778–782
60. Aghayev E, Christe A, Sonnenschein M, et al. Postmortem imaging of blunt chest trauma using CT and MRI: comparison with autopsy. *J Thorac Imaging* 2008; 23:20–27
61. Ross SG, Flach PM, Thali MJ. Postmortem angiography. In: Thali MJ, Viner MD, Brogdon BG, eds. *Brogdon's forensic radiology*, 2nd ed. BocaRaton, FL: CRC Press, Taylor and Francis Group, 2010:449–460
62. Ross SG, Thali MJ, Bolliger S, Germerott T, Rud-er TD, Flach PM. Sudden death after chest pain: feasibility of virtual autopsy with postmortem CT angiography and biopsy. *Radiology* 2012; 264:250–259
63. Flach PM, Ross SG, Bolliger SA, Preiss US, ThaliMJ, Spendlove D. Postmortem whole-body computed tomography angiography visualizing vascular rupture in a case of fatal car crash. *Arch Pathol Lab Med* 2010; 134:115–119
64. Saukko P, Knight B, eds. *Knight's forensic pathology*, 3rd ed. London, UK: Edward Arnold, 2004
65. A.L. Brough, B. Morgan, G.N. Rutty, Postmortem computed tomography (PMCT) and disaster victim identification, La Radiol. Med. 120 (9) (2015) 866–873.
66. Heinemann, H. Vogel, M. Heller, A. Tzikas, K. Puschel, Investigation of medical intervention with fatal outcome: the impact of post-mortem CT and CT angiography, La Radiol. Med. 120 (9) (2015) 835–845.
67. H. Hyodoh, R. Terashima, M. Rokukawa, J. Shimizu, S. Okazaki, K. Mizuo, et al., Experimental drowning lung images on postmortem CT - Difference between sea water and fresh water, Leg. Med. (Tokyo Japan) 19 (2016) 11–15.
68. S.M. Kirchhoff, E.F. Scaparra, J. Grimm, M. Scherr, M. Graw, M.F. Reiser, et al., Postmortem computed tomography (PMCT) and autopsy in deadly gunshotwounds–a comparative study, Int. J. Leg. Med. 130 (3) (2016) 819–826.
69. P. Fais, C. Giraudo, A. Viero, D. Miotto, F. Bortolotti, F. Tagliaro, et al., Micro computed tomography features of laryngeal fractures in a case of fatal manual strangulation, Leg. Med. (Tokyo Japan) 18 (2016) 85–89.
70. L.C. Ebert, W. Schweitzer, D. Gascho, T.D. Ruder, P.M. Flach, M.J. Thali, et al., Forensic 3D visualization of CT data using Cinematic volume rendering: a preliminary study, AJR Am. J. Roentgenol. (2016) 1–8.

71. D. Wittschieber, L. Beck, V. Vieth, M.L. Hahnemann, The role of 3DCT for the evaluation of chop injuries in clinical forensic medicine, Forensic Sci. Int. 266 (2016) e59–e63.
72. G. Ampanozi, D. Zimmermann, G.M. Hatch, T.D. Ruder, S. Ross, P.M. Flach, et al., Format preferences of district attorneys for post-mortem medical imaging reports: understandability, cost effectiveness, and suitability for the courtroom: a questionnaire based study, Leg. Med. (Tokyo Japan) 14 (3) (2012) 116–120.
73. Sushil Kumar et al. Skeletal maturation evaluation using mandibular second molar calciication stages. Angle Orthod. 2012;82:501–506.
74. Aprajita Sikka, Anjali Jain. Sex determination of mandible: a morphological and morphometric analysis. International Journal of Contemporary Medical Research. 2016;3:1869- 1872.
75. Levy RA, Rosenbaum AE, Kellman RM, Bailey GL, Aravapalli SR (1991) Assessing whether the plane of section on CT affects accuracy in demonstrating facial fractures in 3-D reconstruction when using a dried skull. AJNR Am J Neuroradiol 12, 861–866.
76. Yen K, Lövblad KO, Scheurer E, et al. Post-mortem forensic neuroimaging: correlation of MSCT and MRI findings with autopsy results. *Forensic Sci Int* 2007; 173:21–35
77. Spitz WU. Spitz and Fischer's medicolegal investigation of death: guidelines for the application of pathology of crime investigation. Springfield, Ill: Charles C. Thomas; 1993.
78. Kauser, S.; Chatra, L.; Shenai, P. Dental and craniofacial imaging in forensics. J. Forensic Radiol. Imaging **2013**, 1, 56–62.
79. Bodecker, C.F. A consideration of some of the changes in the teeth from young to old age. Dent. Cosm. **1925**, 67, 543–549.
80. Gustafson, G. Age determinations on teeth. J. Am. Dent. Assoc. **1950**, 41, 45–54.
81. Yang, F.; Jacobs, R.; Willems, G. Dental age estimation through volume matching of teeth imaged by cone-beam CT. Forensic Sci. Int. **2006**, 159 (Suppl. 1), S78–S83.
82. Jagannathan, N.; Neelakasntan, P.; Thiruvengadam, C.; Ramani, P.; Premkumar, P.; Natesan, A.; Herald, J.S.; Luder, H.U. Age estimation in an Indian population using pulp/tooth volume ratio of mandibular canines obtained from cone beam computed tomography. J. Forensic Odontostomatol. **2011**, 29, 1–6.
83. Asif, M.K.; Nambiar, P.; Ibrahim, N.; Al-Amery, S.M.; Khan, I.M. Three-dimensional image analysis of developing mandibular third molars apices for age estimation: A study using CBCT data enhanced with Mimics and 3-Matics software. Leg. Med. **2019**, 39, 9–14.
84. Odzhakov, F.; Apostolov, A. Dental age estimation–Literature review. J. Transl. Sci. **2019**, 6, 1–5.
85. Iyyer, B.S.; Bhalaji, S.I. Orthodontics, the Art and Science, 3rd ed.; Arya (Medi) Publishing House: New Delhi, India, 2006; pp. 21–35.
86. Sinanoglu, A.; Demirturk, H.; Noujeim, M. Age estimation by an analysis of spheno-occipital synchondrosis using cone-beam computed tomography. Leg. Med. **2016**, 18, 13–19.
87. Sobh, Z.K.; Mohamed, A.S. A computed tomographic analysis of spheno-occipital synchondrosis ossification for age estimation in a sample of Egyptians. Am. J. Forensic Med. Pathol. **2020**, 42, 235–242.
88. Sharma, A.; Kumbhare, S.P.; Kalaskar, A.R.; Motghare, P.; Gondivkar, S.; Upmanyu, A. Age estimation in an Indian subpopulation by cone-beam computed tomographic analysis of spheno-occipital synchondrosis fusion. Forensic Sci. Int. Rep. **2020**, 2, 100085.

89. B. B. Bangi, U. Ginjupally, L. K. Nadendla, and B. Vadla, "3D evaluation of maxillary sinus using computed tomography: a sexual dimorphic study," International journal of dentistry, vol. 2017, Article ID 9017078, 4 pages, 2017.
90. S. U. Rani, G. V. Rao, D. R. Kumar, T. Sravya, Y. Sivaranjani, and M. P. Kumar, "Age and gender assessment through three-dimensional morphometric analysis of maxillary sinus using magnetic resonance imaging," Journal of forensic dental sciences, vol. 9, no. 1, p. 46, 2017.
91. S. U. Rani, G. V. Rao, D. R. Kumar, T. Sravya, Y. Sivaranjani, and M. P. Kumar, "Age and gender assessment through three-dimensional morphometric analysis of maxillary sinus using magnetic resonance imaging," Journal of forensic dental sciences, vol. 9, no. 1, p. 46, 2017.
92. P. G. Limdiwala and J. S. Shah, "Age estimation by using dental radiographs," Journal of forensic dental sciences, vol. 5, no. 2, pp. 118–122, 2013.
93. V. Poongodi, R. Kanmani, M. S. Anandi, C. L. Krithika, A. Kannan, and P. H. Raghuram, "Prediction of age and gender using digital radiographic method: a retrospective study," Journal of pharmacy & bioallied sciences, vol. 7, Supplement 2, pp. S504–S5S8, 2015.
94. Gopal, S.K. Role of 3D cone beam computed tomography imaging in forensic dentistry: A review of literature. Indian Forensic Odontol. **2018**, 11, 75–82.
95. Sahithi, D.; Reddy, S.; Divya Teja, D.V.; Koneru, J.; Sai Praveen, K.N.; Sruthi, R. Reveal the concealed—Morphological variations of the coronoid process, condyle and sigmoid notch in personal identification. Egypt. J. Forensic Sci. **2016**, 6, 108–113. [CrossRef]
96. Gopal, S.K.; Kshatri, J.K.S.; Kumar, M.P. Sex determination with mandibular ramus—A retrospective CBCT study. Int. J. Inf. Res. Rev. **2016**, 3, 2328–2329.
97. de Oliveira Gamba T, Alves MC, Haiter-Neto F, Mandibular sexual dimorphism analysis in CBCT scans, *Journal of Forensic and Legal Medicine* (2016), doi: 10.1016/ j.jflm.2015.11.024.
98. Tambawala, S.S.; Karjodkar, F.R.; Sansare, K.; Prakash, N.; Dora, A.C. Sexual dimorphism of foramen magnum using Cone Beam Computed Tomography. J. Forensic Leg. Med. **2016**, 44, 29–34. [CrossRef]
99. Urooge, A.; Patil, B.A. Sexual dimorphism of maxillary sinus: A morphometric analysis using cone beam computed tomography. J. Clin. Diagn. Res. **2017**, 11, 67 70.
100. Saraswathi, G.K.; Prakash Vijayan, B. Frontal sinus and nasal septum patterns in personal identification in forensics. Int. J. Oral Health Med. Res. **2016**, 2, 2395–7387.
101. Benghiac, A.G.; Thiel, B.A.; Haba, D. Reliability of the frontal sinus index for sex determination using CBCT. Rom. J. Leg. Med. **2015**, 23, 275–278.
102. Choi, I.G.G.; Duailibi-Neto, E.F.; Beaini, T.L.; da Silva, R.L.B.; Chilvarquer, I. The frontal sinus cavity exhibits sexual dimorphism in 3D cone-beam CT images and can be used for sex determination. J. Forensic Sci. **2018**, 63, 692–698.
103. Tambawala, S.S.; Karjodkar, F.R.; Sansare, K.; Prakash, N. Sexual dimorphism of the maxillary sinus using cone beam computed tomography. Egypt. J. Forensic Sci. **2016**, 6, 120–125.
104. Paknahad, M.; Shahidi, S.; Zarei, Z. Sexual dimorphism of maxillary sinus dimensions using cone-beam computed tomography. J. Forensic Sci. **2017**, 62, 395–398
105. C. L. Queiroz, A. S. Terada, T. U. Dezem et al., "Sex setermination

106. of adult human maxillary sinuses on panoramic Scanning 25 radiographs," Acta stomatologica Croatica, vol. 50, no. 3, pp. 215–221, 2016.
107. Sidhu R, Chandra S, Devi P, Taneja N, Sah K, Kaur N. Forensic importance of maxillary sinus in gender determination: A morphometric analysis from Western Uttar Pradesh, India. European Journal of General Dentistry. 2014 Jan;3(01):53-6.
108. Farhadian, M.; Salemi, F.; Shokri, A.; Safi, Y.; Rahimpanah, S. Comparison of data mining algorithms for sex determination based on mastoid process measurements using cone-beam computed tomography. Imaging Sci. Dent. **2020**, 50, 323–330.
109. Amin, W.; Saleh, M.W.; Othman, D.; Salhab, D.; Thunaibat, H. Osteometric assessment of the mastoids for gender determination in Jordanians by discriminant function analysis. Am. J. Med. Biol. Res. **2015**, 3, 117–123.
110. Chandra, A. Singh, M. Badni, R. Jaiswal, and A. Agnihotri, "Determination of sex by radiographic analysis of mental foramen in North Indian population," Journal of forensic dental sciences, vol. 5, no. 1 pp. 52–55, 2013.
111. Shanmugasundaram K, Prasanthi S. Sex Determination using Mental Foramen in Chennai Population. Prof. RK Sharma. 2019 Jan;13(1):63.
112. Stavrianos C, Stavrianou I, Zouloumis L, Mastagas D. An introduction to facial reconstruction. Balkan Journal of Stomatology. 2007 Jan;11(2):76-83.
113. Tarani, S.; Kamakshi, S.S.; Naik, V.; Sodhi, A. Forensic radiology: An emerging science. J. Adv. Clin. Res. Insights **2017**, 4, 59–63.
114. Rocha SD, Ramos DL, Cavalcanti MD. Applicability of 3D-CT facial reconstruction for forensic individual identification. Pesquisa Odontológica Brasileira. 2003;17:24-8.
115. Saxena T, Panat SR, Sangamesh NC, Choudhary A, Aggarwal A, Yadav N. Facial soft tissue thickness in North Indian adult population. Journal of Indian Academy of Oral Medicine and Radiology. 2012 Apr 1;24(2):121-5.
116. Hwang HS, Choe SY, Hwang JS, Moon DN, Hou Y, Lee WJ, Wilkinson C. Reproducibility of Facial Soft Tissue Thickness Measurements Using Cone-Beam CT Images According to the Measurement Methods. Journal of forensic sciences. 2015 Jul;60(4):957-65.
117. Dias PE, Miranda GE, Beaini TL, Melani RF. Practical application of anatomy of the oral cavity in forensic facial reconstruction. PloS one. 2016 Sep 9;11(9):e0162732.
118. Chowdhry A, Kapoor P, Popli D, Sircar K, Miglani R. Inclusion of forensic odontologist in team of forensic facial approximationa proposal and technical note. J Clin Diagn Res. 2018 Sep 1;12.
119. Manikyam KS, Charan JL. Forensic Facial Reconstruction in Rape-Cum-Murder Cases in India: An Emerging Arena of Forensic Identification. INTERNATIONAL JOURNAL OF RESEARCH AND ANALYTICAL REVIEWS. 2023 Mar 14;10(1).
120. Dirnhofer R, Jackowski C, Vock P, Potter K, Thali MJ. VIRTOPSY: minimally invasive, imaging-guided virtual autopsy. Radiographics. 2006 Sep;26(5):1305-33.
121. Jackowski C, Lussi A, Classens M, et al. Extended CT scale overcomes restoration caused streak artifacts— 3D color encoded automatic discrimination of dental restorations for identification. J Comput Assist Tomogr 2006;30(3):510–513.
122. Engelke K, Karolczak M, Lutz A, Seibert U, Schaller S, Kalender W. Micro-CT: technology and application for assessing bone structure [in German]. Radiologe 1999;39:203–212.

123. Ruegsegger P, Koller B, Muller R. A microtomographic system for the nondestructive evaluation of bone architecture. Calcif Tissue Int 1996;58: 24–29.
124. Thali MJ, Braun M, Buck U, et al. VIRTOPSY: scientific documentation, reconstruction and animation in forensics: individual and real 3D data based geometric approach including optical body/ object surface and radiological CT/MRI scanning. J Forensic Sci 2005;50:428–442.
125. Thali MJ, Yen K, Vock P, Ozdoba C, Kneubuehl BP, Sonnenschein M, Dirnhofer R. Image-guided virtual autopsy findings of gunshot victims performed with multi-slice computed tomography (MSCT) and magnetic resonance imaging (MRI) and subsequent correlation between radiology and autopsy findings. Forensic science international. 2003 Dec 17;138(1-3):8-16.
126. Tejaswi KB, Periya EA. Virtopsy (virtual autopsy): A new phase in forensic investigation. J Forensic Dent Sci 2013;5:146-8.
127. Rai S, Misra D, Tyagi K, Prabhat M, Gangwal P. Image guided virtual autopsy: An adjunct with radiographic and computed tomography modalities-An important tool in forensic identification. Journal of Indian Academy of Oral Medicine and Radiology. 2017 Oct 1;29(4):368-70.
128. Bolliger SA, Thali MJ. Imaging and virtual autopsy: looking back and forward. Philosophical Transactions of the Royal Society B: Biological Sciences. 2015 Aug 5;370(1674):20140253.
129. Bolliger SA, Thali MJ, Ross S, Buck U, Naether S, Vock P. Virtual autopsy using imaging: bridging radiologic and forensic sciences. A review of the Virtopsy and similar projects. European radiology. 2008 Feb;18:273-82.
130. Filograna L, Pugliese L, Muto M, Tatulli D, Guglielmi G, Thali MJ, Floris R. A practical guide to virtual autopsy: why, when and how. InSeminars in Ultrasound, CT and MRI 2019 Feb 1 (Vol. 40, No. 1, pp. 56-66). WB Saunders.
131. Yadukul S, Parmar P, Srirambhatla A, Arora AJ, Mada P, Reddy D. Virtual autopsy in India: The need of the hour. Journal of Forensic Medicine and Toxicology. 2022;39(2):4-7.
132. Gavli N, Venkatesh R, More CB. Forensic odontology and rapid prototyping: Adding 3 dimension for investigation rd. Journal of Indian Academy of Forensic Medicine. 2019 May 12;41(1):57-8.
133. Ramya A. and Vanapalli S. 3D Printing Technologies in Various Applications. 2016:1-14.
134. Khanna S, Dhaimade P. Exploring the 3rd Dimension: Application of 3D Printing In Forensic Odontology. J Forensic Sci Criminal Inves.2017;3:001- 3.
135. Dawood A, Marti B, Jackson V, Darwood A. 3D Printing in Dentistry. Br Dental J. 2015; 219:521-29.
136. Chaudhary RK, Doggalli N, Chandrakant HV, Patil K. Current and evolving applications of three-dimensional printing in forensic odontology: A review. Int J Forensic Odontol 2018;3:59-65.
137. Dedhia JP, Pawar AM. 3D Scanning and Printing in Forensic Odontology- Revolutionizing Forensics. Int J Curr Med Pharmaceutical Res. 2017; 3(8): 2190-2192.
138. Johnson A, Jani G, Carew R, Pandey A. Assessment of the accuracy of 3D printed teeth by various 3D printers in forensic odontology. Forensic Science International. 2021 Nov 1;328:111044.

139. Jani G, Johnson A, Marques J, Franco A. Three-dimensional (3D) printing in forensic science–An emerging technology in India. Annals of 3D Printed Medicine. 2021 Mar 1;1:100006.
140. Ebert LC, Thali MJ, Ross S. Getting in touch—3D printing in forensic imaging. Forensic science international. 2011 Sep 10;211(1-3):e1-6.
141. Khanna S, Dhaimade 3rd P. Exploring the 3rd dimension: Application of 3D printing in forensic odontology. J Forensic Sci Crim Investig. 2017;3(3):1-3.
142. Shakya NK, kumar Arya A, Shakya P, Dev R. 3-Dimensional (3D) Printing Technology in Forensic Medicine-An Overview of Indian Scenario. Journal for ReAttach Therapy and Developmental Diversities. 2023 Sep 29;6(9s):759-69.
143. Christensen AM, Smith MA, Thomas RM. Validation of x-ray fluorescence spectrometry for determining osseous or dental origin of unknown material. Journal of forensic sciences. 2012 Jan;57(1):47-51.
144. Merriam T, Kaufmann R, Ebert L, Figi R, Erni R, Pauer R, Sieberth T. Differentiation of dental restorative materials combining energy-dispersive X-ray fluorescence spectroscopy and post-mortem CT. Forensic Science, Medicine and Pathology. 2018 Jun;14:163-73.
145. Bush MA, Miller RG, Prutsman-Pfeiffer J, Bush PJ. Identification through X-ray fluorescence analysis of dental restorative resin materials: a comprehensive study of noncremated, cremated, and processed-cremated individuals. Journal of forensic sciences. 2007 Jan;52(1):157-65.
146. Jimsha VK, Shakila R, Jonathan DM, Ramesh V, Marak F. Bite mark analysis: A case report. Journal of Indian Academy of Forensic Medicine. 2020;42(1):66-9.
147. Webster G (1982) A suggested classification of bite marks in foodstuffs in forensic dental analysis. Forensic Sci Int 20: 45-52.
148. Bowers CM, Bell G (1995) Manual of Forensic Odontology. American Society of Forensic Odontology.
149. Kaur S, Krishan K, Chatterjee PM, Kanchan T. Analysis and identification of bite marks in forensic casework. Oral Health Dent Manag. 2013 Sep 1;12(3):127-31.
150. Fournier G, Savall F, Galibourg A, Gély L, Telmon N, Maret D. Three-dimensional analysis of bitemarks: a validation study using an intraoral scanner. Forensic science international. 2020 Apr 1;309:110198.
151. Molina A, Martin-de-las-Heras S (2015) Accuracy of 3D scanners in tooth mark analysis. J Forensic Sci 60(Suppl 1):S222–S226
152. Patzelt, S.B., et al., The time efficiency of intraoral scanners: an in vitro comparative study. Journal of the American Dental Association (1939), 2014. **145**(6): p. 542–51.
153. Ali IK, Sansare K, Karjodkar FR (2018) Analysis of intercanine distance and dimensional changes in bite marks on foodstuffs using cone beam computed tomography. Am J Forensic Med Pathol 39(3):213–217. https:// doi. org/ 10. 1097/ paf. 0000000000 000399
154. Vilborn P, Bernitz H. A systematic review of 3D scanners and computer assisted analyzes of bite marks: searching for improved analysis methods during the Covid-19 pandemic. International Journal of Legal Medicine. 2022 Jan;136(1):209-17.
155. Naether S et al (2012) The examination and identification of bite marks in foods using 3D scanning and 3D comparison methods. Int J Legal Med 126(1):89–95
156. Shetty SS. Advanced technologies an aid in forensic odontology: An update. Int J Adv Res. 2015;3:1615-20.

157. Damas S, Cordon O, Ibanez O, Santamaria J, Alemán I, Botella M, Navarro F. Forensic identification by computer-aided craniofacial superimposition: a survey. ACM Computing Surveys (CSUR). 2011 Oct 18;43(4):1-27.
158. Nagi R, Aravinda K, Rakesh N, Jain S, Kaur N, Mann AK. Digitization in forensic odontology: A paradigm shift in forensic investigations. Journal of forensic dental sciences. 2019 Jan;11(1):5.
159. Lorkiewicz-Muszyńska D, Kociemba W, Żaba C, Łabęcka M, Koralewska-Kordel M, Abreu-Głowacka M, Przystańska A. The conclusive role of postmortem computed tomography (CT) of the skull and computer-assisted superimposition in identification of an unknown body. International Journal of Legal Medicine. 2013 May;127:653-60.
160. Prajapati G, Sarode SC, Sarode GS, Shelke P, Awan KH, Patil S. Role of forensic odontology in the identification of victims of major mass disasters across the world: A systematic review. PloS one. 2018 Jun 28;13(6):e0199791.
161. Dutta SR, Singh P, Passi D, Varghese D, Sharma S. The role of dentistry in disaster management and victim identification: an overview of challenges in Indo-Nepal scenario. J Maxillofac Oral Surg. 2016; 15: 442±448. https://doi.org/10.1007/s12663-016-0896-4 PMID: 27833335
162. Gambhir RS, Singh G, Talwar PS, Gambhir J, Munjal V. Knowledge and awareness of forensic odontology among dentists in India: a systematic review. J Forensic Dent Sci. 2016; 8: 2±6. https://doi.org/10.4103/0975-1475.176954 PMID: 27051215
163. Boger D. Role of the Consultant in Forensic Radiology. InMultidisciplinary Medico-Legal Death Investigation 2018 Jan 1 (pp. 35-68). Academic Press.
164. Boger, Donald. (2018). Role of the Consultant in Forensic Radiology. 10.1016/B978-0-12-813818-2.00003-X.
165. Forensic Radiology: A Path Forward in Strengthening Forensic Science by Kristin Beinschroth, MPH, BSRS, RT(R), CHES on Apr 14, 2023
166. Horn-Lodewyk J, van der Merwe B, Kali GM, Munro L. Evaluating the knowledge and training of forensic pathologists and registrars performing forensic radiography at a forensic pathology mortuary in the Free State province, South Africa. Health SA. 2022 Oct 27;27:2014. doi: 10.4102/hsag.v27i0.2014. PMID: 36337446; PMCID: PMC9634712.
167. Elifritz, Jamie & Nolte, Kurt & Hatch, Gary & Adolphi, Natalie & Gerrard, Chandra. (2014). Forensic Radiology. 10.1016/B978-0-12-386456-7.06706-X.
168. Gambhir RS, Singh G, Talwar PS, Gambhir J, Munjal V. Knowledge and awareness of forensic odontology among dentists in India: A systematic review. Journal of Forensic Dental Sciences. 2016 Jan;8(1):2.
169. Rahman J, Routray S, Mishra SS, Mohanty I, Mohanty N, Sukla N. Knowledge, awareness, and practice of forensic odontology among dental surgeons in Bhubaneswar, India. Journal of Unexplored Medical Data¦ Volume. 2017 May 21;2:27.
170. Selvajothi P, Lavanya C, Joshua E, Rao UK, Ranganathan K. Awareness of forensic odontology among legal professionals, Chennai, India. North American journal of medical sciences. 2014 Nov;6(11):553.

171. Harchandani N, Marathe S, Hebbale M, Ul Nisa S, Hiremutt D. Awareness of forensic odontology among general dental practitioners in Pune A cross-sectional study. J Adv Med Dent Sci Res. 2014 Jul;2(3):10-6.
172. Khare P, Chandra S, Raj V, Verma P, Subha G, Khare A. Status of forensic odontology in metro and in tier 2 city in urban India. Journal of Forensic Dental Sciences. 2013 Jul;5(2):134.
173. Vannala V, Shetty SR, Reddy S, Khazi S, Laxminarayanan A, Shetty P. Forensic odontology in India key milestones and missed opportunities. Eur J Forensic Sci● Jul-Sep. 2017;4(3):1.
174. Arora KS, Kaur P. Role of forensic odontology in the Indian Armed Forces: An unexplored arena. Journal of Forensic Dental Sciences. 2016 Sep;8(3):173.
175. Wankhade TD, Ingale SW, Mohite PM, Bankar NJ. Artificial Intelligence in Forensic Medicine and Toxicology: The Future of Forensic Medicine. Cureus. 2022 Aug 25;14(8):e28376. doi: 10.7759/cureus.28376. PMID: 36168339; PMCID: PMC9506671.
176. Kumar B, Kumar A, Kumari V, Rastogi A. Medico-legal Institute: A Need of State. Medico-Legal Update. 2021 Jul 1;21(3).
177. Ali HJ, Choudhari M, Hande A. Scope and Relevance of Forensic Odontology in India–A Review. Journal of Indian Academy of Forensic Medicine. 2022 Oct 12;44(3):75-7.
178. Jankharia GR. Commentary - radiology in India: the next decade. Indian J Radiol Imaging. 2008 Aug;18(3):189-91. doi: 10.4103/0971-3026.41868. PMID: 19774153; PMCID: PMC2747440.
179. Kumar A. The Transformation of The Indian Healthcare System. Cureus. 2023 May 16;15(5).
180. Grewal H, Sharma P, Dhillon G, Munjal RS, Verma RK, Kashyap R. Universal Health Care System in India: An In-Depth Examination of the Ayushman Bharat Initiative. Cureus. 2023 Jun 21;15(6).
181. Jeddy N, Ravi S, Radhika T. Current trends in forensic odontology. Journal of forensic dental sciences. 2017 Sep;9(3):115.
182. Singh, Shoibam, and Naveen Jayaram. "Medico-legal issues in radiology: Indian context." *Journal of Medical Society*, vol. 29, no. 3, Sept.-Dec. 2015, p. 129. *GaleAcademicOneFile*,link.gale.com/apps/doc/A437022512/AONE?u=googlescholar&sid=bookmark AONE&xid=8a55456b. Accessed 6 Feb. 2024.
183. Samuel SG, Pandey A, Dahiya MS. A report on the current status of radiology in forensic odontology in the Indian scenario. International Journal of Forensic Odontology. 2017 Jan 1;2(1):34