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Forensic Radiology In Death Investigations

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Abstract:

Forensic radiology is a new and a developing technique which combines medical imaging and forensics to aid death investigation. In the last 20 years, the development of imaging technologies has provided the possibility of studying the dead person, especially by means of Post Mortem Computed Tomography (PMCT) and Post Mortem Magnetic Resonance imaging (PMMRI). Forensic radiology helps solve legal cases by using imaging to identify victims, detect injuries from accidents or abuse, and analyze things like bite marks or dental patterns. It's also used to estimate age and identify people through unique skull features like the frontal sinuses. The complex skeletal radiological process such as the study of hand-wrist bones, clavicle, bone pelvis, etc enables precise age and sex identification particularly in scenarios where there is skeletal remains. Imaging using X-ray, CT scan, MRI, post mortem angiography and virtual autopsy (Virtopsy) aids in high-resolution inner investigations, 3D reproductions and wound documentations. Forensic radiology has strengths, such as, being culturally sensitive, complete, non-invasive, and having permanent digital records. But it has issues which are a high cost of access, restricted accessibility and special labor requirements. Ethical issues are consent, confidentiality, and respect of culture. Recent surveys have also indicated increasing appreciation of forensics radiology via the digital mediums although there is no formal training. The effective and widespread application of forensic radiology in such countries as India necessitates reasonable investments, interagency collaboration, and national standards to make the best of it in terms of medicolegal investigations..

Keywords: *Forensic radiology, Post mortem angiography, Post Mortem Computed Tomography (PMCT), Post Mortem Magnetic Resonance Imaging (PMMRI), Virtual autopsy*

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1. INTRODUCTION

Forensic radiology is an interdisciplinary science using a convergence of medical imaging and forensic science to support the investigation of dead bodies. The recent 20 years witnessed an amazing breakthrough made in the field of imaging that transformed death investigation to a large degree [1].

Forensic examiners are now in a position to visualize internal trauma, foreign bodies and pathological abnormalities, without harming the still attached person[2]. With this shift, the usage of postmortem imaging, most strikingly postmortem computed tomography (PMCT) and magnetic resonance imaging (PMMRI), has been enhanced both in ordinary forensic practice and in more complex medico-legal cases [3].Such application of forensic radiology engulfs the domains of air crashes, road accidents, gun death, child abuse, identification of corpses, age determination, skeletal studies, death of the fetus, wound evaluation of an individual, and virtual autopsy. Although forensic radiology is useful, it is not without a range of limitations; it should be performed utilizing state-of-the-art technology, highly-skilled staff, and streamlined procedures. It is not always superior to traditional autopsies, particularly when looking to identify microscopic, infectious or toxicological data.

2. SCOPE OF FORENSIC RADIOLOGY

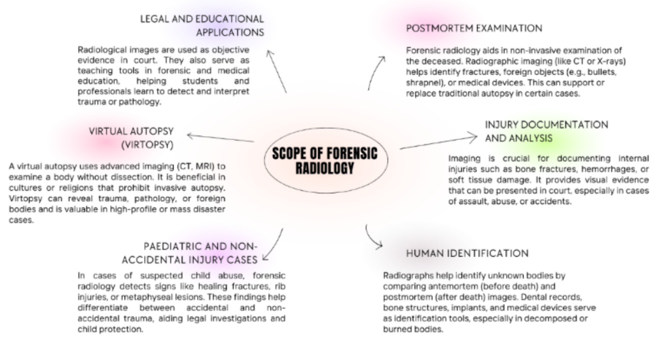

Fig:1 Scope of Forensic Radiology

3. FORENSIC RADIOLOGY IN DENTISTRY

Forensic radiology assists forensic odontology by offering radiographic images (X-rays, CT, MRI) to identify humans and to study trauma as well as analyse the age of an individual and make bite-mark identifications [4]. Figure 1 represents different scope of Forensic radiology. This branch of science started with the discovery of the X-rays (discovered by W.C Röntgen in the year 1895), and by the year 1898, there was already postmortem radiography used forensically.

3.1 Face recognition of the unknown persons

Frontal sinus patterns, skull X-rays, and dental characteristics such as fillings or canals are distinctive and permanent and help in identifying them. Comparison of antemortem and postmortem images is done by superimposing and measuring. Orthopantomographs find application in mass identification of disasters victims especially.

3.2 Age Estimation

Tooth eruption stages as well as the reduction of pulp chamber together with secondary dentin deposition can be used as criteria of estimating age. Younger people make use of pulp-to-root ratio and hand radiographs (pulp-to-root ratio, middle phalanx) [5]. Figure 2 represents an OPG of Premolar teeth for age estimation.

3.3 Bitemark analysis

Radiographs of dental impressions containing radiopaque materials are used to identify bite marks. Radiographs reveal intentional modification of a tooth-shape in the suspect or an incrusted remains in a victim giving scarce hints of comparative evidence [6].

Fig: 2 OPG of Premolar teeth to identify the age of the person

3.4 Trauma and cause of death analysis

Radiographs are useful in revealing: Fractures, dislocation of the jaw, foreign bodies (e.g. bullets, shrapnel) [7]. Crash victims reveal molten metal of the aircraft as irregular radio-opaque structures. The cases of abuse in children (non-accidental injuries) are registered with the help of CT and MRI. Dental X rays (Fig. 3) can help identify these features in a dental set.

3.5 Mass Disaster victim Identification (MDVI)

Where visual identification cannot be carried out because of burning or decomposition, radiographs such as orthopantomographs and CT scans can be compared with antemortem images. Sophisticated diagnosing such as Dentascan contributes to proper diagnosis as well.

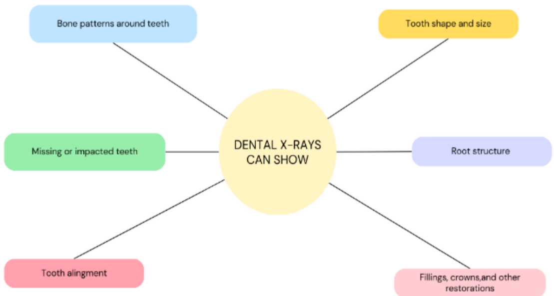

Fig:3 Use of Dental X ray

4. ANATOMICAL IDENTIFICATION

Schuller had provided a typing by frontal sinus radiography obtained in the forehead-nose position for sex and race evaluation. Seven features of radiographs were suggested by him:

4.1 Septum and its displacement: To forensic use, it is possible that comparison of the degree and direction of deviation of the septum on anto-mortem and post-mortem radiographs can be extremely useful to assist a positive identification especially where other methods are illegible in short [8].

4.2 Upper border: The edge of the frontal sinus seen as a radiograph is a very personal design-smooth, interrupted, odd or lobate and does not evolve after the period of adolescence. The uniqueness confers upon it a major trait of forensic identification.

4.3 Partial Septum: Partial septa refers to thin bone plates that form sections in the sinus frontal that are located within the sinus [9]. They are not found in every person, their amount, direction, and incompleteness are personal. These characteristics are also good forensic evidence in comparison of the identification of pre and post-mortems images [10].

4.4 Ethmoidal and supraorbital extensions: The frontal sinus can be projected into the surrounding regions like the ethmoid bone and supraorbital regions of eyes. Such protrusions are called ethmoidal and supraorbital extensions and are not fixed: they differ in individuals and sometimes in one population group compared to another. Their quantity, their size and the ways of assembling them can help establish the race or the origin and include other points of anatomical detail as can be identified in a forensic identification process [11]

4.5 Total breadth: Total breadth refers the maximum lateral width of the frontal sinus. This also is found to be varied according to each person and also it is higher than among the male than among the female. In forensic radiology, the total breadth of the sinus between the known and unknown skulls may help in identification as well as sex determination especially when other cranial measurements accompany it [12].

5. AGE ESTIMATION

Age estimation is the scientific assessment of an individual's age by the biological properties related to human growth and development (e.g., bones, the emergence of teeth, or other characteristics of a person's anatomy), when there is a lack of legal, documental evidence (birth certificate, etc.) for corroborating that age [13].

5.1 Dental Radiology

The dental age is determined as a qualitative analysis of the development of teeth (or eruption) by clinical, there is accuracy which lies on high-quality radiographs and calibration of the population on the information [19].

5.1.1.4 Gustafson's Method

The Gustafson technique is an approach of calculating dental age depending on adults aged above 21 years. It is anchored under six age-related progressive radiological or microscopically conducted investigations, which are a kind of bench mark, which are used to provide estimates on the biological age of the individual[14].

5.1.1 Methods of dental age estimation

5.1.1.1 Demirjian method

The method that Demirjian uses is a method of dental ages that is performed using the growth of seven permanent teeth within a panoramic X-ray (OPG) of the lower left jaw. The teeth in question in this case, the central incisor to the second molar, are numbered and the numbers are different in the case of males and females. After all the scores are decided upon, they are added to get to the sum and the ages are read off by reference with the charts [15].

5.1.1.2 Willems Method

The Willems Method (2001) is a variation of the Demirjian method, building to the accuracy of age estimation with the use of new scores of males and females of the European origin [16]. Each tooth is assigned one of the levels (A-H), using the Willems method instead of the original method designed by Demirjian, each level is associated with a score that was designed by Willems such as updated Willems scores (boys and girls scores are the updated scores). The person scores are added up to get a total maturity score which can then be transformed into direct estimated chronological age [17].

5.1.1.3 Cameriere Method

The method of Cameriere estimate of dental age is mostly applied to children and adolescence [18]. The Methode uses the references to the roots development and the quantity of visible open apices in the capability of being seen through panoramic radiographs by seven left mandibular teeth. Cameriere Method is very specific and very described to accommodative of living persons in legal or clinical context. Despite this, regressive alteration of a tooth that includes attrition, periodontosis, secondary dentin formation, cementum apposition, root resorption and root transparency [20]. All the above methods are summarized in Table 1.

Table 1: - Different methods of dental age estimation

METHODS	ADVANTAGES	DISADVANTAGES	APPLICATION
Demirjian's Method	Non-invasive and easy to use Consistent, reproducible results No need for tooth extraction	May overestimate age in some ethnic groups Only for ages 5–16	Used to estimate dental age in children (5–16) by assessing 7 left mandibular teeth

	Backed by strong research and data	Accuracy varies by gender and population Not applicable to adults	on an OPG. Common in forensics for age disputes, child labor, and juvenile justice cases.
Willems Method	More accurate than Demirjian's for Europeans Follows same process Non-invasive and easy to use	Population-specific; less suitable for non-Europeans Less accurate near end of dental development Limited use in older teens and adults	The Willems method adapts Demirjian's scoring for improved age accuracy, especially in Belgian and European populations. Used in forensic and clinical dentistry.
Cameriere Method	Uses objective, formula-based assessment Highly accurate for ages 6–15 Supports digital processing and automation	Not usable after age 16 (closed apices) Needs precise measurements and clear X-rays Accuracy affected by landmark and image quality	The Cameriere method measures open apices relative to tooth length in the 7 left mandibular teeth. Used for age estimation in children under 16 in forensics and anthropology.
Gustafson's Method	Gustafson's method estimates age in adults, useful when skeletal methods aren't viable. Applicable to decomposed or skeletonized remains if teeth are intact.	Invasive—requires tooth extraction and sectioning Destructive—not for use in living individuals Time-consuming and can be subjective	Gustafson's method estimates adult age by analyzing tooth regressive changes like attrition, secondary dentin, root transparency, and others.

5.2 Skeletal Radiology

Skeletal X-rays or scans the skeletal X-rays or scans include a study of bone formation and fusion of growth plates in forensic age estimation. Growth plates close at measurable ages during maturation, so their appearance can be used to identify the biological age of a person (child, adolescent, adult), assisting, e.g. in situations involving the rule of law or forensics [21].

5.2.1 Hand and wrist

Multi-exposure X-ray by comparing the X-ray against some standard guides such as the Greulich and Pyle Atlas or the Tanner-Whitehouse method, forensic experts are able to determine the stage of bone maturity level to certain age groups [22]. The technique is particularly sensitive among children aged between 1 and 18 years, when epiphyseal plate activity is highest and therefore, an effective modality of forensic testing of children [23].

5.2.2 Clavicle (Collarbone)

The clavicle is also an excellent skeletal element in the provision of age estimations (especially, between late adolescence and early adulthood), because the study of its stemal (medial) epiphysis provides the most comprehensive information about its age, since it closes together after the age of 18-22 years, close to the bone union. Albeit being used commonly, CT scans and MRIs give much clear representation of partial or total fusion and thus this method is quite effective in approximating whether the adult age has been on an individual or not as far as forensic investigation is concerned [24].

5.2.3 Pelvis and long bones

When determining the age using forensic sciences, iliac crest, femoral head, distal radius, and proximal tibia are the bones that are usually analyzed using X-rays to determine epiphyseal fusion. As the timing of fusion differs according to individual biology, sex, and type of bone, assessment of several parts of the skeleton is more accurate, especially in adolescents and younger adults who are close to the age of legal importance [25].

6. SEX DETERMINATION

Unobtrusive radiological footage into skeletal morphology is accessible in forensic research through radiography, CT scans and MRI [26]. These instruments have the capacity of showing the clear anatomical differences like form and angle of pelvic bones or the solidity of the skull which helps ensure that the forensic experts are able to guess the sex of the deceased [27].

6.1 Pelvis (Most Accurate Indicator):

The pelvis is the most sexually differentiated part of the human skeleton since it is used by a female to give birth [28]. Radiological analysis normally involves evaluating a set of measurements and morphology [29] as mentioned in table 2.

Table 2: - Sexual Dimorphism of pelvis

CHARACTERISTICS	FEMALE	MALE
Size and shape	Smaller, slender	Larger, stronger
Supraorbital ridge	Less projecting, flatter	More projecting, prominent
Glabella	Flatter	More prominent
Mastoid process	smaller	More extensive, stronger
Nuchal crest	Less prominent	Sharper and more rough
Mandible	Smaller	Larger
Orbits	Rounded or oval in shape	More squareish
Frontal siinus	Less developed	More developed
Zygomatic arches	Less developed	More robust and flared

6.2 Skull:

The skull is also highly dimorphic sexually, but less trustworthy, in general, in the determination of sex and especially among prepubescents [30]. A lot of features and measurements can be measured by the use of radiological methods [31] as mentioned in table 3.

Table 3:- Sexual Dimorphism of Skull

CHARACTERISTICS	FEMALE	MALE
Size and shape	Smaller, slender	Larger, stronger
Supraorbital ridge	Less projecting, flatter	More projecting, prominent
Glabella	Flatter	More prominent
Mastoid process	smaller	More extensive, stronger
Nuchal crest	Less prominent	Sharper and more rough
Mandible	Smaller	Larger
Orbits	Rounded or oval in shape	More squareish
Frontal siinus	Less developed	More developed
Zygomatic arches	Less developed	More robust and flared

6.3 Long Bones:

Long bones (femurs, humerus, tibias and so on), are less informative than the pelvis or the skull, but can provide some degree of sex indication by general dimensions, robusticity, and specific measurements [32] as mentioned in table 4.

Table 4 :- Sexual Dimorphism of Long Bones

CHARACTERISTICS	FEMALE	MALE
Size and length	Smaller, shorter	Larger, longer
Robusticity/thickness	More gracile, less robust	More robust
Bone density	Lower bone density	More bone density
Muscle attachment sites	Smoother, less pronounced	Rugged muscle, more pronounced

7. IMAGING MODALITIES IN FORENSIC RADIOLOGY

7.1 X-ray Imaging

Standard radiography remains essential despite the introduction of advanced diagnostics and in particular, in the diagnosis of fractures, foreign bodies (e.g., bullets), dental history, child abuse, etc. It is cheap, quick, and easily available and this makes it suitable as a primary forensic screen [33].

7.2 Computed Tomography (CT)

CT scans also have high-resolution cross-sectional imaging that lets one obtain an image of internal structures in exquisite detail [34]. PMCT is especially meaningful in estimating skeletal trauma, inner hemorrhage, gas embolisms and the path of the penetrating injury. Virtual autopsy also depends on the CT to obtain 3D reconstruction [35].

7.3 Magnetic Resonance Imaging (MRI)

MRI has a superior resolution of soft tissue as compared to CT. The use of MRI is useful in identifying a minor brain trauma, ischemia, and damage to soft tissues that are difficult to identify in CT scans [36]. However, due to long acquisition time and cost MRI is not used that often during uncomplicated forensic examination [37].

7.4 Postmortem Angiography

This goes together with intravenous injection of contrast substances into the vascular system when necessary to enable the veins and arteries to be visualized after death [38]. It is effectively applicable in diagnosing vascular lesion, traumatic rupture of vessel and areas of haemorrhage that cannot be seen using the conventional scans [39].

7.5 Virtopsy and 3D reconstruction

To create an entire digital image of the body, virtual autopsy combines data obtained by CT, MRI, and the surface scanning [40]. The method allows larger inspection without invasive cut up and is especially helpful in cultures or religions that prohibit autopsies [41

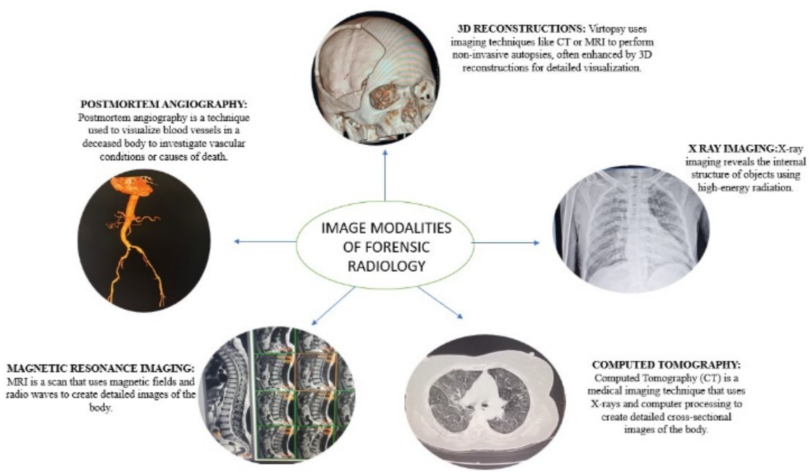

Fig: 4 Imaging Modalities of Forensic Radiology

8. ADVANTAGES OF FORENSIC RADIOLOGY

8.1 Precise Injury Recording: It helps in the correct imaging and recording of injuries such as fractures, gunshot injuries and internal injury which are very crucial in the determination of cause and manner of death [42].

8.2 Production of Permanent Records: The radiological pictures make a permanent computer record that can be maintained, checked and used as representable evidence in the court [43].

8.3 3D Reconstruction Capability: With high-level imaging such as CT scans, it is possible to reconstruct a body region or the area of trauma in the form of 3D, which useful in drawing trauma diagrams or recreating crime scenes [44].

8.4 Multidisciplinary application: Forensic radiology also aids in aligning the efforts of other disciplines related to forensics such as; the forensic pathologists, anthropologists, odontologists and legal experts that would enhance accuracy and effectiveness in the whole investigation [45].

9. LIMITATIONS AND CHALLENGES

9.1 Exclusive and Expensive Access

The requirement of up-to-date radiology technology such as digital X-rays, panoramic radiographs and cone-beam computed tomography (CBCT) required by forensic radiology, is difficult and expensive to acquire and is high maintenance. The forensic units lack technology due to budgetary reason or non-existence of infrastructure in most parts of the world especially in less-developed countries or in remote regions [46].

9.2 Specialist knowledge required

Interpretation of dental radiographs in a forensic setting must be carried out by qualified forensic odontologists or radiologists, as general dentists or radiographers are unlikely to diagnose subtle dental alteration which is paramount in the legal comparison situations.

9.3 Source Postmortem Artifacts

Artificial changes in a dental radiograph due to postmortem alteration may include displacement of tissues, or heat damage on dental materials, or movement of bones which may distort any important identification that may not be able to match easily with any antemortem records.

9.4 Incomplete viewing of some pathologies

In other situations, such as deep lesions of the bone, damage of the tooth roots, or craniosteal fracture, common dental X-rays could not identify any serious damages. Although CBCT or CT produce relatively clearer images, these more developed tools are not always available at our disposal in forensic work.

10. DISCUSSION

Forensic radiology is a new development in which medicine and law meet and offers a non-surgical, high resolution and often socially more acceptable alternative to the traditional autopsy. This combination of imaging modalities such as CT, MRI, and postmortem angiography, enhances the range of forensic medical diagnosis capabilities especially at circumstances where the traditional autopsy is not possible or is prohibited altogether. Moreover, foreign coordination and standardization of protocols activities will be vital towards the enhancement of the scientific and legal integrity of forensic radiology. Both training and cross-disciplinary education should be prioritized, and the generation of the budding forensic specialists should be prepared to make the best of such devices.

11. SURVEY STUDIES: -

A purposive survey was conducted to gain information about the participants knowledge on the use and importance of the forensic radiology in death studies. The increase in the knowledge of most participants about forensic radiology was mainly on the internet and through social media, with the limited source being formal education (Fig. 5). Few attended it through workshops or seminars and this shows lack of such professional development activities.

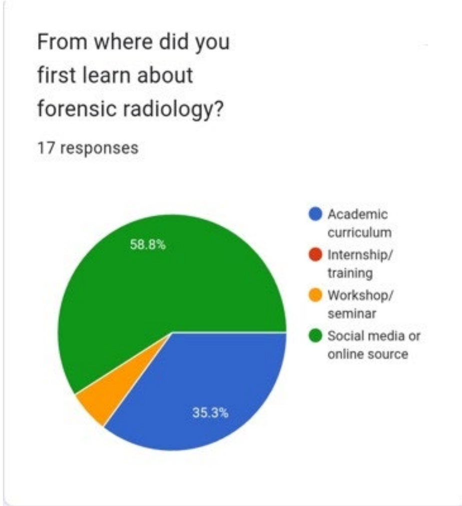

Fig: 5 Response indicate where they first learned about forensic radiology

The survey indicated that X-ray was the most generally identified forensic radiology practice since it is handy and efficient (Fig. 6). CT or MRI were discussed less in spite of their developed treatments possibilities as they are rather expensive and do not have wide accessibility. PET scan and ultrasound were least mentioned probably because the participants were not quite aware of them.

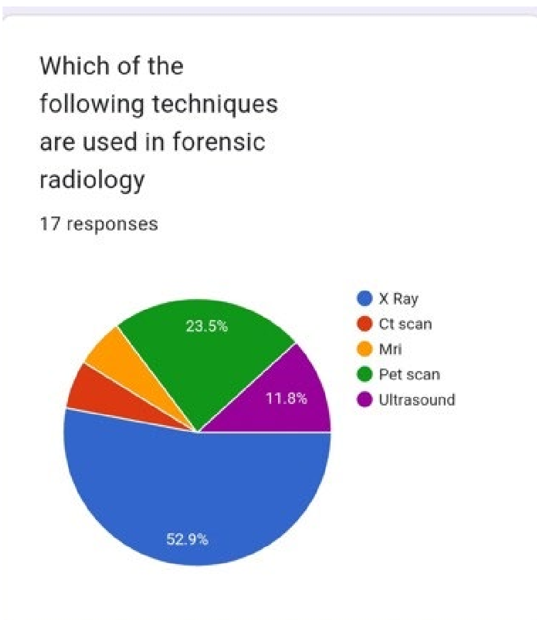

Fig: 6 Response of the survey for the techniques that are used in Forensic Radiology

Forensic radiology is considered essential in the death investigation based on a recent poll. It helps to identify unknown bodies by skeletal analysis, dental analysis or implant analysis and also in gunshot cases and traffic accidents when internal damage can be determined (Fig. 7). It is also significant in large nurse-disaster when the conventional identification methods are not useful.

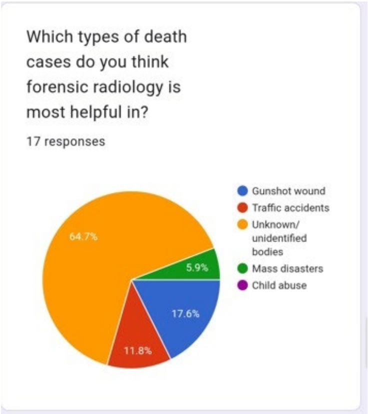

Fig: 7 Response for Identifying cases where forensic radiology is most useful

The majority of the respondents felt that in some cases forensic radiology can take the place of the conventional autopsy where cultural, religious, or legal limitations are present (Fig 8). Though not applicable in every scenario such as that which requires tissue analysis, it commonly makes the cut in cases of traumas in order to identify cause of death through CT or MRI.

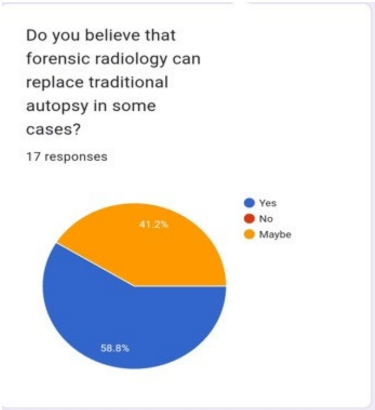

Fig: 8 Opinion if forensic radiology can replace traditional autopsy

Improved forensic radiology integration in India demands a more affordable access to imaging, access to rural imaging, need of more trained experts, improved institutional coordination and national directives on forensic imaging and enhanced awareness and education in the area.

12. CONCLUSION

Forensic radiology is a high-tech form of modern forensic science which provides some accurate non-invasive ancient alternatives to the autopsy by utilizing imaging techniques such as X-rays, CT scan, MRI and post mortem angiography. It is beneficial in medico-legal investigations for analysis and identification of trauma, age and sex determination, but it has also the advantage of preserving the dignity of a deceased-particularly in mass disasters, gunshot, and abuse investigations. It also takes into consideration cultural and religious sensitivities because it minimized invasive procedures that are required. But its disadvantages are expensive nature, shortage of equipment in different regions and requirement of qualified personnel. The issues concerning ethics, such as consent, privacy, and cultural respect, should be taken into consideration. Although there is increased awareness and optimism, particularly among the younger professionals, a country such as India still needs improved training, infrastructure and policy support. To conclude, forensic radiology is revolutionizing forensic medicine and, through commitment to education, technology and laws, allows forensic radiology to be a beneficial instrument of justice-be a light in the dark murky cases and a breath of fresh air in highly sensitive cases.

The future promises to increase the scope of forensic radiology with improved AI, portable imaging and international standardization and, therefore, become a significant part of accurate, non-invasive and interdisciplinary death investigations.

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