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Analyzing orocraniofacial structures for sex estimation using advanced imaging technologies in forensic odontology: a review*

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Abstract

Determining an individual's sex plays a vital role in their identification within forensic investigations. In determining sex especially in cases such as mass disasters, criminal acts, or conditions where visual identification is not possible, teeth and orocraniofacial bones can be used for the identification process due to their resistance to destruction or decomposition. Some parts of the skull that can be used to identify gender in unidentified victims include the mandible (measured from its mandibular ramus height, condylar mandible), maxillary sinus, mastoid process, foramen magnum. Nowadays, the use of advanced imaging in identifying sex as a non - invasive evaluation process during forensic investigation has been used to obtain more accurate information, such as Cone-Beam Computed Tomography (CBCT), Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Facial Reconstruction. The advantages of anatomical imaging applications with advanced imaging technique make it easier to be stored for a longer period of time, faster, and easier portability. Sex estimation through advanced imaging techniques using both morphometric and non-morphometric methods show size differences in male and female skulls. These imaging-based analyses consistently reveal that males exhibit larger cranial dimensions than females, a difference attributed to physiological variations such as muscle mass and body organs.This study discusses an overview of the various methodologies and characteristics of advanced imaging techniques for sex estimation in craniofacial region and concludes that advanced imaging is a potential tool in forensic odontology for sex estimation, with the potency to improve efficiency and accuracy in forensic identification in the future.

Keywords: sex estimation; forensic odontology; advanced imaging

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Introduction

Sexual dimorphism refers to the physical differences between males and females (1). Sex estimation determines whether the skeletal remains belong to a male or female. The estimation can be done by two methods, the non-morphometric method which is only done by visual inspection of tooth and skeletal features and the morphometric method which use measurements of tooth and skeletal dimensions. Sexual dimorphism is rarely visible before puberty (2).

The difference in dimorphism in males and females is influenced by the Y chromosome in males which causes mitotic activity is enhanced so that some anatomy in males is larger than females. This can be seen from the larger crown size and thicker dentin thickness in males (3). The skull also provides sex-related characteristics. The differences in these characteristics are influenced by genetics, nutrition, and environment (4). The increase in muscle mass during puberty in males which affects cranial bones, along with the retention of juvenile traits in females, contributes to the pronounced sexual dimorphism observed in the cranium (5). In general, male's skulls show greater cranial volumes and sturdier jawbone structures highlights the importance of taking sex differences when analyzing skeletal remains in forensic investigations (6).

One of the techniques in determining gender can be done using imaging techniques which are powerful tools in the forensic field. Dental radiographs are essential for recording, identifying and collecting forensic evidence. These data sets are important during comparative dental identification, postmortem profiling, and age-specific estimation. Another advantage is its suitability as an alternative for communities with religious sensitivities that oppose autopsies, as well as for avoiding autopsies on victims with infectious diseases like tuberculosis and coronavirus (7). Dental treatments that are often used for identification using radiographs are restoration, root canal treatment, extraction, and others (8). However, the use of traditional imaging provides fewer effective results due to the lack of dimensional detail, low resolution, and inability to obtain complex craniofacial structures (9).

To overcome the current limitations of using conventional radiographs, the use of advanced imaging in sex estimation as a non - invasive evaluation process during forensic investigation has been used to obtain more accurate information, for instance Cone-Beam Computed Tomography (CBCT), Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and facial reconstruction. The advantages of anatomical imaging applications with advanced imaging technique make it easier to be stored for a longer period of time, faster, and easier portability. The high resolutions results of CT scans can provide good image quality as radiation exposure is negligible at postmortem examination (7). This study attempts to investigate the application of advanced imaging methods, including CBCT, CT scan, MRI, and facial reconstruction for sex estimation in forensic odontology.

Sex estimation in forensic odontology

Sex estimation in forensic odontology can use morphometric methods including direct measurement of dental and cranial structures or indirectly through radiographs, study models. However, sex estimation using morphometric methods with dental media does not have high accuracy (10). The canines showed clear sexual dimorphism, with mandibular canines being larger in males compared to females. Therefore, there is an index to estimate sex that is often used, named Mandibular Canine Index (MCI) which is calculated from the canine mesiodistal width and intercanine distance (11). In addition to the canine teeth, the posterior teeth are also a parameter of sexual dimorphism due to the amount of dentin that is more in males (12).

The use of dental radiographs has increased in clinical dental practice. It is useful for forensic odontology in providing dental victim information. Measurements can be made through tooth height, width, or length, root length, amount of dentin, size of pulp chamber, and mandibular bone structure. The scale benchmark uses ABFO (American Board for Forensic Odontology) No.2 (3). In addition to teeth, the use of radiographs can also be used in measuring skeletal dimensions in cases of decayed victims (2).

In addition to morphometric methods, sex estimation can also be done through non-morphometric methods using hard tissue morphology such as dental and skeletal, and soft tissue through cheiloscopy and rugoscopy analysis. However, compared to morphometric methods, non-morphometric methods provide more subjective interpretation of the analysis results. Distal accessory ridge of canine teeth is the only morphology that shows sexual dimorphism with more prevalence on males than females (13). Skull is one of the bone parts in the

human body that shows the most sexual dimorphic (14). Application of cheiloscopy in estimating sex based on Suzuki and Tsuchihashi classification shows types I and I' dominant in females in quadrants 3 and 4, while type II is dominant in males in quadrant II (15). Sex estimation by rugoscopy method based on the Thomas-Kotze method showed primary, wavy, backward, and divergent unification rugae patterns are often found in males, meanwhile secondary, curvy, forward, and convergent unification rugae patterns are dominant in females (16).

Advanced imaging technologies in forensic odontology

To overcome the limitations of 2D radiographs such as dimensional variations and vertical and horizontal angulation differences, 3D radiographs in the form of advanced imaging are required. The application of advanced imaging including CBCT (Cone-Beam Computed Tomography) in maxillofacial 3D imaging contributes to dental age estimation, bitemark analysis, race and gender determination. Data obtained from CBCT can be transferred to third-party image enhancement software such as Mimics and 3-Matics for 3D volumetric analysis in forensic (17). The advantages provided by CBCT are low metallic artifacts, easy portability, dose reduction (96% lower than conventional CT).

Another application of advanced imaging is facsimile imaging of the post mortem phase that can be created using the information available in CT-Scan (Computerized Tomography Scan) (18). CT-scan and CBCT can also be used to assess the severity of wounds in cases of skull injury. Meanwhile, the use of MRI in forensic odontology plays a role in evaluating soft tissue injuries, chronicity of bleeding, and bone bruising. In addition, the implementation of facial reconstruction is useful for determining gender in forensic odontology.

Advanced imaging technologies method for sex estimation - CBCT (Cone-Beam Computed Tomography)

Sex estimation by morphometric method through CBCT can use craniofacial structures such as mandible, mastoid process, foramen magnum, and maxillary sinus. The accuracy of sex determination through skull is 98% (18).

1. Mandible: Measured from the distance between the vertex of the mandibular condyle and the junction of its posterior and inferior planes. Masar et al investigated that ramus height in males was 61.88 mm and 56.33 in females. The same results was also found in research from Alime et al was detected that ramus height was 53.91 in males and 48.00 in females (19,20). Mandible projective height of ramus measurements were found to be larger in males than females due to differences in chewing activity by the masticatory muscles.

2. Mastoid process : measured from both mastoid process distances. Previous research from Ozlem et al reported that bimastoid diameter in males was 110.69 mm while 101.65 mm in females. It was also found in research from Ferat et al was detected that bimastoid diameter as 108.53 mm in males and 100.82 in females. It was found that the bimastoid distance in males greater than females because the males cranium was larger due to the activity of the longissimus capitis, splenius capitis, and sternocleidomastoideus muscles (5,21,22).

3. Foramen magnum: measured from the sagittal diameter (anteroposterior) and transverse diameter (largest width) of the foramen magnum and then analyzed with the formula 2 x 3.14 x transverse diameter/2 (circumference). The study conducted by Junaid et al found that foramen magnum circumference was 100.06 mm in males and 94.43 mm in females. Another study by Jaitley et al also evaluated that foramen magnum for males was 115 mm and for females was 109.23 mm. Research conducted by Subhasish et al demonstrated the same result that was 100.26 mm in males and 95.04 mm in females for foramen magnum circumference. Measurements of foramen magnum circumference in males higher than that of the females (23–25).

4. Maxillary sinus: measured from the width and length of the maxillary sinus in the axial view and its height in the coronal view. Then the volume of the maxillary sinus is calculated using the formula length x width x height x ½ (26,27). Research by Arathi et al assessed that the maxillary sinus volume in males was 18.86 - 19.22 mm3, while in females it was 15.10 - 15.21 mm3. The same findings were also found in the study of Sivasamy et al has reported that male had a maxillary sinus volume of 14.90 - 16.14 mm3 while in female it was 12.97 - 12.98 mm3.

Measurement in males shows larger maxillary sinus than females. It was initially explained by the need for larger lungs in males to accommodate their comparatively bigger muscles and body organs. Additionally, physiological changes in the size and shape of the nasal cavity occur to facilitate breathing, such as warming and humidifying the air inhaled. As a result, the maxillary sinus also expands to occupy the remaining space within the nasomaxillary complex (28). In addition, the size difference is also due to increased skull dimensions and pneumatization in males (27).

CT-Scan (Computed Tomography Scan)

CT-Scan can be used to determine gender by analyzing the maxillary sinus, specifically the anteroposterior (AP) dimensions and the width of the sinus in the axial view. Study from Massarat et al assessed that sinus AP diameter in males was 3.64 mm and 3.49 mm in females, while sinus width in males was 2.40 mm and 2.39 mm in females. Another research Bangi by et al demonstrated the same result that sinus AP diameter was 3.57 – 3.55 in males and 3.37 – 3.38 in females, while sinus width in males was 3.30 – 2.61 in males and 2.48 – 2.44 in females. Measurements demonstrate that the dimensions of the maxillary sinus are larger in males compared to females. This is due to the size of the male's skull larger than the female's then affects the size of the maxillary sinus which is part of the skull (29,30).

MRI (Magnetic Resonance Imaging)

The implementation of MRI (Magnetic Resonance Imaging) technology can also play a role in determining gender by comparing the morphology of the right and left TMJ (Temporo Mandibular Joint). The aspect of interest is the shape of the mandibular condylar. The condyle size in males tends to be larger than in females. Other studies have found an increase in medial condylar length and mediolateral disc length in males, while anteroposterior disc length in females is greater (31). Based on its shape, eminence with flattened and sigmoid shapes is more common in females, because TMJ dysfunction and joint degeneration and androgenic hormones are more prevalent in females (32). Whereas box-shaped eminence is more frequent in males (33). Apart from its shape, the size of the glenoid fossa shows differences between males and females, with a study conducted by Melo et al found that the glenoid fossa in males is higher than females (34).

Facial reconstruction

Each individual has different facial characteristics. In case of a mass disaster that causes destruction to the victim's face, the skull of the victim will remain intact. This can be used in forensics to determine gender because the skull is helpful in sexual dimorphism. Craniofacial reconstruction is performed when there are no photographs or other information about the missing person (35). The implementation of facial reconstruction using a laser video camera assisted by a computer system through CT scanning, can demonstrate a fully 3D skull surface. An example of computer software-aided facial reconstruction is Vitrea 2.3 version volumetric visualization software (36).

There are guidelines in the image acquisition process to optimize face recognition accuracy, such as the Standard Guide for Postmortem Image Capture (Scientific Working Group on Face Identification (FISWG) (37). The process of facial reconstruction starts with a skull model characterized by tissue depth markers as guides for construct head and neck structure, then a model of the muscles attached to the skull is made, and the final result is a resemblance of the deceased person before the disaster (38). The facial parts used as parameters for facial reconstruction to distinguish between male and female are nose height, nose depth, nose inclination, nasolabial inclination, upper and lower lip height and thickness, chin thickness. It was found that males have a larger size of facial features than females (39).

Conclusion

Sex estimation remains a vital component in the identification of unidentified individuals in forensic odontology. The integration of advanced imaging techniques such as CBCT, CT, MRI, and facial reconstruction has significantly enhanced the accuracy of sex determination. Both morphometric and non-morphometric methods have proven effective, particularly when applied to sexually dimorphic cranial structures like the mandible, foramen magnum, maxillary sinus, and mastoid process. These imaging-based analyses consistently reveal that males exhibit larger cranial dimensions than females, a difference attributed to physiological variations such as muscle mass and body organs.

Declaration of interest
None

Author Contribution
NS, EIA contributed to the study's conceptualization. NS contributed to writing the initial draft of the manuscript. EIA supervised the study, and together with RSP critically reviewed and wrote the final draft of the manuscript. All authors have contributed and approved the final draft of the manuscript.

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Artificial intelligence was not used in the preparation of this manuscript.

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