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REVIEW ARTICLE

Beyond Orthodontics: Role of Cephalometric Indices in Forensic Odontology

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Abstract

Forensic odontology plays a significant role in human identification, particularly in cases involving mass disasters, skeletal remains, and decomposed bodies. Cephalometry, used in orthodontics and craniofacial growth analysis, has increasingly gained attention in forensic investigations. Cephalometric indices derived from craniofacial radiographs provide quantitative data that aid in the determination of sex, ethnicity, and age. These measurements rely on stable anatomical landmarks of the craniofacial skeleton and remain relatively preserved even after postmortem changes. This narrative review summarizes the evidence on their applications, methods, and limitations.

Keywords: Forensic odontology, Cephalometry, Human identification, Craniofacial measurements, Skeletal analysis

Introduction

Human identification is an integral aspect of forensic science, particularly in scenarios involving unknown human remains. Dental structures and craniofacial skeletal components often remain intact even after exposure to extreme environmental conditions. Forensic odontology utilizes dental records, radiographs, and morphological characteristics for identification.[1]

Cephalometry involves radiographic assessment of craniofacial structures using standardized anatomical landmarks. Initially utilized in orthodontics, cephalometric analysis has expanded into other disciplines, including forensic odontology. Cephalometric indices derived from the cephalograms can provide critical information for sex determination, ethnic assessment, and craniofacial pattern analysis.[2]

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Various cephalometric analyses have been developed to aid orthodontic diagnosis and treatment planning. These analyses rely on specific craniofacial landmarks and measurements that quantify skeletal and dental relationships. These cephalometric analyses include ratios as well as linear and angular measurements. These measurements can be used in forensic identification, particularly in cases where conventional methods, such as DNA analysis or fingerprinting, are not feasible.[3]

Cephalometric indices, derived from lateral cephalograms, play a key role in forensic odontology by enabling human identification through stable craniofacial measurements. With the recognition that cranial morphology exhibits population- and sex-related differences, cephalometric measurements have found significance in forensic contexts. These indices measured on antemortem (AM) orthodontic records can be compared to the postmortem (PM) radiographs, particularly in mass disasters where soft tissues are lost.[3]

Advances in digital radiography and imaging software have further improved the accuracy and reproducibility of cephalometric measurements, making them useful tools in forensic investigations. This narrative review summarizes the applications of the cephalometric indices in forensic odontology. The databases PubMed, EBSCO, and Google Scholar were searched using a strategy by combining keywords and MeSH terms such as ‘forensic odontology’, ‘cephalometry’ and ‘cephalometric indices’. Studies till the year 2025 that involved the application of cephalometric indices in forensic odontology were included. Studies that were excluded had either used cephalometric indices

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only for orthodontic treatment planning or had used only panoramic radiographs.

Fundamentals of Cephalometry

Cephalometric analysis depends on the precise identification of anatomical landmarks. These landmarks can be categorized as cranial (e.g., Nasion, Sella, Basion, Porion, etc.), maxillary (e.g., Point A, Anterior Nasal Spine-ANS), mandibular (e.g., Point B, Gonion, Menton), and dental (e.g., incisal edges and root apices). Lateral cephalograms standardize skull projections by tracing these landmarks to derive linear, angular, and proportional indices. Key measurements include anterior cranial base (Sella-Nasion), maxillary length (Ptm-ANS), mandibular body (Gonion-Gnathion), and upper face height (Nasion-ANS).

The cranial base angle (Nasion-Sella-Basion) may express population-specific characteristics and enables ethnic assessment.[4] Mandibular measurements, such as gonial angle and mandibular body length, may aid in sex determination due to sexual dimorphism in mandibular morphology.[5] Condylion–Gonion and Gonion–Menton measurements are used to assess mandibular size and proportions, which show significant sexual dimorphism. The ANB angle measures the anteroposterior relationship between the maxilla and mandible. Population-based norms may help differentiate craniofacial patterns across ethnic groups. The facial index evaluates the proportion between the facial height and the facial width. It is useful in anthropological classification and contributes to ethnicity determination.[6]

Applications in Forensic Odontology

Table 1 depicts the significance of various cephalometric indices/measurements in Forensic Odontology.

Sex determination

Sex estimation is a crucial step in building a biological profile of unidentified remains. Cephalometric measurements, particularly mandibular dimensions and cranial base relationships, demonstrate measurable sexual dimorphism.[5] Sex estimation utilizes dimorphism observed in various parameters, including gonial angle, maxillary depth, and sinus indices.[7] A recent systematic review[8] found lateral cephalometric radiography to be useful in sex estimation of adults in settings with limited resources. However, there were variations in measurement methods, hence the accuracy varied from 56.3 to 99%.[8]

Ethnic assessment

Certain cephalometric patterns vary across populations due to genetic and environmental influences. These differences may assist forensic investigators in estimating population affinity. Cephalic index, facial index, and dental parameters such as inter-canine width are being explored for application in the determination of ethnic groups.[6]

Age estimation

Developmental changes in craniofacial structures may assist in estimating age in adolescents. Skeletal age assessment can be done through the cervical vertebrae maturation stage[9] and the hand wrist maturation. Other skeletal methods may include the gonial angle, frontal sinus, clavicle, etc.[10]

Identification using antemortem records

Superimposition of antemortem orthodontic cephalograms onto postmortem radiographs identifies individuals through unique geometric patterns. Comparison of frontal sinuses on antemortem radiographs and postmortem radiographs has been utilized for human identification. Different classification systems have been proposed for the assessment of the frontal sinus, including the FSS system by Tatlisumak *et al*.[11], which was found to be a reliable tool for the identification of victims in mass disasters.[12] Reddy G *et al*.[13] concluded that orthodontists can utilize available software to reconstruct a victim's facial features to a considerable extent using superimposition techniques on lateral cephalograms.

Methodological Advances

Recent developments in radiographic imaging as well as computational techniques are enhancing the utility of cephalometric analysis. Three-dimensional imaging modalities such as cone-beam computed tomography (CBCT) allow more precise evaluation of craniofacial structures. Digital tools reduce radiation and enable Artificial Intelligence-driven landmark detection.

Artificial intelligence and machine learning algorithms are being developed to automate landmark detection and improve the accuracy of sex and ethnic estimation. An algorithm was developed that encodes cranial patterns into a database for future matching with postmortem cephalograms, which accurately identifies an individual through comparison of cranial structures with 97.5% accuracy.[3]

The use of deep learning algorithms has recently become an efficient way of image processing and analysis. Convolutional neural networks (CNNs) based on DenseNet121 were used for automated sex determination on lateral cephalometric radiographs, with a 90% overall prediction accuracy.[7] A study by Prabha PS found potential in machine learning models, Random Forest and GXBoost, to determine sex through mandibular measurements on lateral radiographs, thereby demonstrating its practicality in forensic assessments.[14]

Handayani *et al*.[15] used a dataset of 274 cephalometric radiographic pictures to build a gender classification model using the VGG16 and VGG19 architectures and found a gender identification accuracy of 93% for females and 73% for males with the VGG16 model, whereas the VGG19 model achieved an accuracy of 0.95% for females and 0.80%

Table 1: Role of various cephalometric measurements in forensic odontology

Index / Measurement	*Cephalometric landmarks*	*Description*	*Forensic significance*
Cranial Base Angle	Nasion (N) – Sella (S) – Basion (Ba)	Angle between anterior and posterior cranial base	Helps evaluate cranial morphology and population variation
ANB Angle	Point A – Nasion – Point B	Measures maxilla–mandible anteroposterior relationship	Useful in identifying skeletal pattern differences among populations
SNA Angle	Sella – Nasion – Point A	Indicates anteroposterior position of maxilla relative to cranial base	May show population-specific craniofacial morphology
SNB Angle	Sella – Nasion – Point B	Indicates mandibular position relative to cranial base	Used for skeletal profile assessment
Facial Index	Nasion – Menton / Bizygomatic width	Ratio of facial height to width	Used in anthropological classification and ethnic estimation
Gonial Angle	Articulare – Gonion – Menton	Angle formed at mandibular angle	Demonstrates sexual dimorphism
Mandibular Body Length	Gonion – Menton	Linear length of mandibular body	Useful for sex determination
Ramus Height	Condylion – Gonion	Vertical height of mandibular ramus	Sexual dimorphism
Co–Gn Length	Condylion – Gnathion	Total mandibular length	High reliability in sex determination
Maxillary Sinus Index	Maxillary sinus height / width	Ratio of sinus dimensions	Useful for sex estimation in forensic identification
Lower Anterior Facial Height (LAFH)	ANS – Menton	Vertical lower facial height	Used in craniofacial pattern analysis
Mandibular Plane Angle	Gonion – Menton to Sella – Nasion	Angle representing mandibular plane inclination	Useful for skeletal pattern differentiation

Table 2: Reported accuracy of cephalometric indices for specific studies

Index type	*Examples*	*Significance in Forensic Odontology*	*Reported Accuracy*
Linear3	Sella-Nasion, Articulare-Gonion (mandibular ramus)	Cranial base matching	92-98%
Angular17	Gonial Angle (Go-Gn:Ar-Go;) SNA	Sex dimorphism	80-97%
Ratios/ Proportions6	Facial index (N-Gn/N-ANS), maxillary sinus index	Racial/age estimation, reconstruction	70-89%
Sinus-Specific18	Frontal sinus area/height ratio	Uniqueness even in fragments	90-100%

for males. Porto SF *et al.*[16] developed an artificial neural network classification system for the determination of age and sex using photo-anthropometric indexes, generated from frontal faces cephalometric landmarks of the Brazilian population.

Table 2 demonstrates the accuracy of different cephalometric indices in Forensic odontology as reported in a few studies.[3,6,17,18]

Girdhar A *et al.*[19] reported higher accuracy with digital methods as compared to manual methods for gender estimation, but it remains insufficiently reliable to be an independent factor in gender prediction of an individual.

Critical Appraisal of included studies

The studies included in this review demonstrate the growing application of cephalometric indices in forensic odontology; however, their methodology and generalizability vary considerably. Most of the included studies are cross-sectional or retrospective in design, which reduces the quality of evidence. A major limitation across studies is the small and population-specific sample sizes, restricting the external validity of findings.

Variability in landmark identification and measurement techniques further affects reproducibility, with manual methods prone to observer bias and a lack of standardized protocols across studies. Although some studies have incorporated digital and AI-based tools to minimize these errors, standardization of measurement protocols remains lacking across the literature.

Moreover, few studies assess real-world forensic applicability, with most evidence derived from controlled settings that do not reflect practical challenges such as fragmented remains, poor radiographic quality, or absence of antemortem records. While systematic reviews provide higher-level evidence, they also reveal significant heterogeneity, limiting comparability. Overall, current evidence is restricted by methodological variability, population bias, and lack of standardization.

Challenges and Limitations

The use of cephalometric indices in forensic odontology has advantages in terms of quantitative and reproducible measurements, stability of craniofacial structures, comparison with antemortem orthodontic records, applicability even when soft tissues are absent, and compatibility with digital imaging and AI-based analysis.

Despite these advantages, certain challenges remain, such as severe trauma cases and variability in manual identification of the landmarks. The limitations can be summarized as

- Need for good-quality radiographs
- Population variability may affect accuracy
- Difficulty in identifying landmarks in damaged remains
- Limited availability of antemortem cephalograms
- Potential measurement errors due to projection distortion
- Lack of a global database

Future Directions

Advances in digital imaging and three-dimensional radiography are enhancing the reliability and applicability of cephalometric analysis in forensic investigations. Future research and population-specific studies are necessary to establish standardized reference lines and improve the forensic applicability of cephalometric indices.[20]

Validated artificial intelligence (AI) models should be incorporated in forensic identification, including the detection of cephalometric landmarks to improve the accuracy and automation of cephalometric data analysis. Advanced machine learning and deep learning models, like Convolutional Neural Networks (CNNs), need to be trained on extensive datasets of cephalometric images to enhance precision. These AI models, such as DenseNet121 and YOLO, automate cephalometric analysis with high accuracy. However, most of these models are not readily applicable in practice as they need further development due to limited and population-specific datasets, lack of external validation, and risk of overfitting and bias.[21]

Furthermore, national antemortem cephalogram repositories should be developed to ensure a database of records for comparison with postmortem cephalograms for identification in case of mass disasters.

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