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Historical evolution of sex and age estimation techniques through the skull

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ABSTRACT
The estimation of sex and age through cranial measurements is a fundamental practice in various fields such as physical anthropology, archaeology, and forensic medicine. Over the centuries, techniques and methodologies have been developed and refined to increase the accuracy of these estimates, reflecting advances in anatomical knowledge, imaging technology, and statistical analysis. This article aims to explore the historical evolution of these techniques, highlighting the major changes and innovations from the rudimentary methods used in early anthropological investigations to the sophisticated contemporary approaches incorporating cutting-edge technologies like computed tomography and machine learning algorithms. In addition to reviewing traditional methods, this study examines how the application of new technologies has contributed to greater accuracy and reliability in sex and age estimations, as well as the implications of these improvements for population studies and forensic investigations. By tracing this evolution, it seeks not only to provide a comprehensive overview of the historical development of these techniques but also to contextualize future trends and the challenges that still need to be addressed.

Keywords: Cranial Measurements; Sex and Age Estimation; Historical Evolution; Forensic Anthropology; Imaging Technology.

1 INTRODUCTION

Estimating sex and age through cranial measurements is vital in various fields, including physical anthropology, archaeology, and forensic medicine. This technique helps identify fundamental biological characteristics, contributing to understanding the demographics of ancient populations, analyzing skeletal remains in archaeological contexts, and solving modern forensic cases. Over time, the accuracy of these estimates has improved significantly due to advancements in anatomical science, imaging technology, and statistical analysis. The development of increasingly sophisticated methods has enhanced the precision and reliability of determining sex and age, expanding knowledge about human life, health, and behavior throughout history and providing essential tools for justice and criminal investigation.

2 DEVELOPMENT

Sex estimation from osteological remains can be performed using three primary methods: morphological assessment (non-metric) of teeth and bone traits that exhibit sexual dimorphism,

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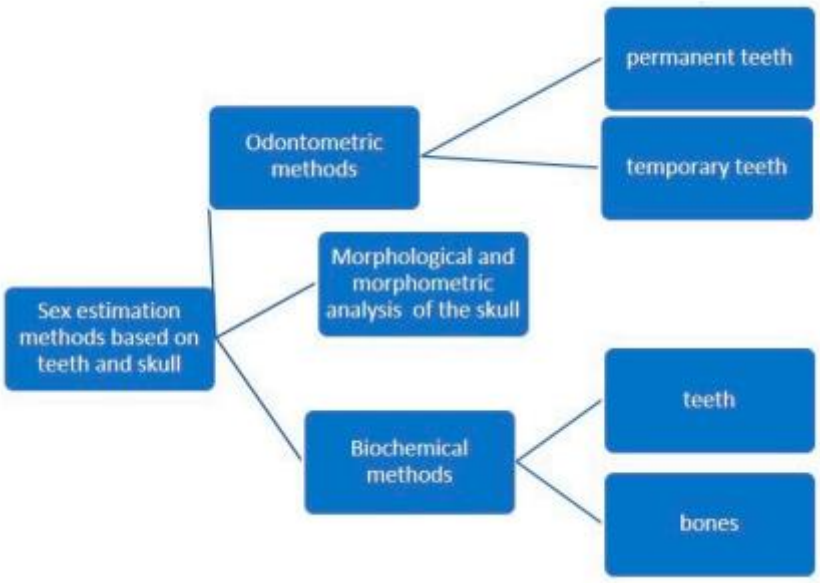
morphometric assessment (involving the measurement of specific quantifiable features of bones and teeth), and biochemical analysis, such as DNA or Barr bodies analysis. Among these, DNA analysis is the most accurate, although it is also the most expensive and may not be practical for examining large numbers of specimens (BESCHIU et al., 2022).

Figure 1: Odontological and cranial sex estimation methods



Source: Beschiu et al. (2022).

Present-day quantitative methods for estimating ancestry and sex from skulls typically require extensive manual data collection and specialized recording tools, often limiting the analysis to a laboratory setting. Caple, Byrd, and Stephan (2018) explored overcoming this limitation by developing a quicker, more user-friendly, and automated data protocol using elliptical Fourier analysis (EFA). They found that lateral skull outlines could successfully estimate ancestry and sex with accuracy comparable to other methods, laying the groundwork for future cross-validation testing. Additionally, relying on a single, easy-to-take photograph and a user-friendly, open-source R script facilitates straightforward application and use in the field.

In another study, Imaizumi et al. (2020) introduced an innovative method for sex estimation utilizing three-dimensional skull shapes and machine learning technology. Researchers obtained 100 skull shapes from post-mortem computed tomography data, creating homologous models of the whole skull, the cranium only, and the mandible only. They reduced the dimensionality of the models' 40,962 vertices using principal component analysis (PCA) and partial least squares regression (PLS). Known sex data and component scores were used to train a support vector machine for sex estimation, achieving accuracy rates through a 10-fold double-looped cross-validation procedure. Although validation on six casework skulls yielded less satisfactory results than anticipated, indicating a need

for further research with larger sample sizes, this method offers a promising approach for objective identification of skeletal remains, crucial in forensic anthropology.

Grabherr et al. (2009) explored the capabilities of multi-detector computed tomography (MDCT) in estimating bone age and sex of deceased individuals. They scanned 22 deceased persons with known ages using MDCT, employing a protocol for high-resolution imaging of specific skeletal regions, including the skull, shoulder girdle, symphysis pubis, and upper femora. Using the resulting two- and three-dimensional reconstructions of bone and soft tissue, three anthropologists with varying expertise analyzed the data. Sex determination relied on three-dimensional models of the skull and pelvis, while age estimation followed the Nemeskéri method, supplemented by additional parameters like dental condition and spinal degeneration, tailored individually by each observer. This study demonstrated the feasibility of MDCT for accurate sex and age estimation, highlighting virtual skeletons as valuable tools for non-invasive anthropological research with extensive investigative potential.

Darmawan et al. (2015) conducted a study on sex estimation in forensic anthropology, focusing on children under 19 years old. They used X-ray images of the left hand from an Asian population dataset and measured the lengths of 19 hand bones using Free Image software. Three classification techniques—Discriminant Function Analysis (DFA), Support Vector Machine (SVM), and Artificial Neural Network (ANN) multilayer perceptron—were applied using MATLAB. The study found that the age groups "16-19" years old and "7-9" years old showed the highest accuracy rates, above 80%, for sex estimation. Among the techniques tested, the ANN model demonstrated the highest average accuracy percentage across both age groups compared to DFA and SVM. The results underscored the effectiveness of these methods in sex estimation, highlighting their potential application in forensic contexts where precise age and sex determination from skeletal remains are crucial.

Ogawa et al. (2013) conducted a study to develop discriminant functions for estimating the sex of modern Japanese skulls. They analyzed anthropological measurement data from 113 individuals (73 males and 40 females) collected from forensic anthropological records at the National Research Institute of Police Science in Japan. The individuals, born between 1926 and 1979 and all over 19 years old at death, were measured on ten anthropological dimensions: maximum cranial length, cranial base length, maximum cranial breadth, maximum frontal breadth, basion-bregmatic height, upper facial breadth, bizygomatic breadth, bicondylar breadth, bigonial breadth, and ramal height. The study established nine discriminant functions, with classification accuracy ranging from 79.0% to 89.9% using the initial dataset. When a leave-one-out cross-validation procedure was applied, the accuracy ranged from 77.8% to 88.1%. Testing the functions on 50 new individuals (25 males and 25 females) unrelated to the initial dataset yielded accuracy rates between 86.7% and 93.0%.

Finally, Gillet et al. (2020) aimed to assess how the skull and mandible contribute to sex estimation within the entire cranium using metric and geometric morphometric methods alongside multislice computed tomography (MSCT) analysis. They reported that the mandible demonstrated higher accuracy in individuals over 40 years old compared to those under 40, although there was no significant difference in geometric morphometric accuracy between age groups. In contrast, the cranium consistently showed superior predictability across all parameters examined.

3 CONCLUSION

In conclusion, the studies reviewed highlight the significant advancements and diverse methodologies in the field of sex and age estimation from cranial measurements. From traditional manual techniques to cutting-edge machine learning and imaging technologies, the evolution of these methods has vastly improved the accuracy and reliability of determining biological characteristics from skeletal remains. The integration of sophisticated tools such as elliptical Fourier analysis, multi-detector computed tomography, and artificial neural networks demonstrates a promising future for forensic anthropology, archaeology, and related disciplines. These innovations not only enhance our understanding of historical population demographics and health patterns but also provide crucial support in modern forensic investigations. Continued research and the development of more user-friendly, automated protocols will further refine these techniques, ensuring they remain indispensable tools for both scientific inquiry and the pursuit of justice.

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