How teeth can be used to estimate sexual dimorphism? A scoping review.

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PII: S0379-0738(24)00142-7

DOI: https://doi.org/10.1016/j.forsciint.2024.112061

Reference: FSI112061

To appear in: *Forensic Science International*

Received date: 10 May 2023
Revised date: 4 March 2024
Accepted date: 9 May 2024

Please cite this article as: Tatiana M. Herrera Escudero, David Arboleda Toro and Monica T. Parada-Sanchez, How teeth can be used to estimate sexual dimorphism? A scoping review., *Forensic Science International,* (2024) doi:https://doi.org/10.1016/j.forsciint.2024.112061

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Abstract

Introduction: Teeth are biological structures with a high degree of hardness, density, calcification, and capacity to adapt to extrinsic factors at physical, biological, and physiological levels. Subsequently, they resist for a longer period in deteriorating environmental conditions. With dental analysis, it is possible to acquire biographical data about a person. The aim of this scoping review was to identify publications using human teeth tissues to estimate sexual dimorphism.

Methods: The scoping review was carried out in the following databases: Jstor, Scielo, Science Direct, PubMed, and Scopus, using ten search strategies in English and guaranteeing completeness and reproducibility of the phases stipulated in the PRISMA guide.

Results: 143 studies on sexual dimorphism based on dental tissue traits were included, of which 40.6% (n = 58) were done in Asia and 27.2% (n = 39) in America. 80% of the studies (equivalent to 114 articles) focused their observations and measurements on the dental crown; 4.2% in enamel, dentin, and pulp together; 3.5% in dental pulp; 2.1% in the entire tooth; 2.8% in enamel, root, and the enamel-cementum junction, and only 0.7% in dentin and pulp. In addition, 92.3% of the studies used metric methods, while only 4.9% and 2.8% used biochemical and non-metric method respectively.

Conclusion: For sexual dimorphism establishment, enamel has been the most analyzed dental tissue in permanent canines and molars mainly. Likewise, the most widely and accurately used methods for this purpose are the metrics, with the odontometry as the most implemented (intraoral or by using dental plaster models, digital scanning or software) with prediction percentages ranging from 51% to 95.9%. In contrast to biochemical methods, that can achieve the highest precision (up to 100%), the non-metric methods, to a less extent, reported prediction percentages of 58%.

Keywords: Sexual dimorphism, Teeth, Dental tissues, Odontometry, Scoping review.

1. Introduction

The chemical composition of the teeth, their small size, and their location allow these anatomical structures to have a high preservation and resistance to external conditions, placing them as good candidates for human identification. Moreover, because the integrity of the otherwise normally used bone remains is often compromised and is not always suitable for human identification, teeth become a unique body element providing biological and cultural information about an individual or a human population. Although it must be borne in mind that the morphology of these structures varies among different population groups due to exposure to various environmental conditions [1]. By applying dental analysis, it is possible to acquire biographical data about a person, such as health conditions, age, eating or work-functional habits, evolutionary relationships, and sex. The estimation of a variable of the biological profile like sex plays a transcendental role to know ante-mortem data and reduce the number of individuals that can be taken into consideration and analysis to individualize a person [2, 3, 4, 5].

Biologically, the sex of an individual is classified as male or female and the biological characteristics that differ on average between men and women are evaluated under the concept of sexual dimorphism [2], which is defined as the differences in physical characteristics between adult males and adult females of the same specie [2]. The condition

is reflected in marked or graceful features of the size and shape of body components, which can be evidenced in structures such as bones and teeth [6, 7, 8].

Although bones like the pelvis and skull provide more reliable results of sexual dimorphism through morphological and metric analysis, several studies have also shown the usefulness of teeth in the evaluation of sex [8]. In this way, when analyzing teeth, it is possible to study the sexual dimorphism of an individual based on factors such as patterns of development and dental eruption, dental morphology, and dental dimensions. It has been found that there are dimensions of the permanent dentition that are greater in men compared to women, with the canine being the most dimorphic tooth [7, 8, 9, 10, 11, 12, 13].

The methods used in the analysis of teeth and their tissues can be classified into the following three categories: 1) Biochemical: considered as the method that studies the fundamental molecules for living organisms such as proteins, carbohydrates, lipids, and nucleic acids. [14, 15, 16, 17, 18]. 2) Metric: Known as the method that based the analysis on the dimensions of the teeth, such as mesio-distal (MD), bucco-lingual (BL), dental indices, and diagonal measurements of the teeth to quantitatively assess differences in size and shape between males and females. Various studies have illustrated that odontometric analysis can be used to estimate sexual dimorphism, based on tooth size in various populations [8, 10, 13, 19, 20, 21]. 3) Non-metric: This method performs a qualitative assessment of some dental characteristics that can vary between males and females [13, 22, 23, 24].

This scoping review seeks to investigate the methods/techniques most implemented to estimate sexual dimorphism in teeth as well as to find out which dental tissues have been most frequently analyzed (and incidentally, which ones have not) for this purpose. This is done in order to delve into the potential of biological information stored in teeth. This could be important and useful to areas such as bioarchaeology, forensic anthropology, and forensic odontology in aspects related to the application of methods for the purpose of human identification, considering the high level of resistance to taphonomic factors and deterioration by environmental agents in general, which enables the preservation of dental structures for a longer time compared to bone remains [5, 6, 9].

2. Materials and methods

2.1. Study design and protocol

A scoping literature review was designed according to the guidelines of PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) [25].

2.2.Focused question and eligibility criteria

We aimed to answer the following PECO (Patient/Population, Exposure, Comparison, Outcomes) question: How dental tissues are accurately evaluated to estimate sexual dimorphism? (Table 1). This framework helped to structure our study design and research objectives by identifying key elements of our research question.

The inclusion criteria consisted of a) Observational studies articles that investigated sexual dimorphism in human teeth. b) Deciduous and permanent teeth. c) No restriction of the year (from inception to search date), and d) Articles in English, Spanish, and Portuguese.

The exclusion criteria consisted of studies that: a) Focus on other topics, out of the scope of the study (age estimation, dental pathologies, bone studies, maturation). b) Non-original studies: reviews, mini-reviews, scoping reviews, case reports, short communications, letters to the editor, systematic reviews and reports. c) Book chapters or encyclopedias, abstracts of conferences. d) Populations with known systemic diseases, syndromes, or other pathologies, and e) Articles that contain abstracts and no full-text articles.

2.3. Information sources and search strategy

Identification of studies for this scoping review was performed through detailed search strategies developed for each database: Jstor, Scielo, Science Direct, PubMed, and Scopus. Descriptors in Health Sciences (DeCS) were used to build up a search string. Boolean operators “AND” and “OR” were implemented to combine and restrict the following terms: "teeth" AND "sexual dimorphism" OR "estimating sex" OR "sex estimation" OR "sex characteristics" OR "sex assessment" OR "sexual difference" OR "determining sex" OR "sexing" OR "sex patterns" OR "odontometric". The details of the initial search strategy and then filtering by the presence of the terms in the title, abstract, and/or keywords of the studies, performed in each database, are illustrated in Table 2. Studies till 29 October 2022 that met the eligibility criteria were included in this scoping review.

2.4. Selection of studies

Study selection was assessed independently by two investigators (TMHE and MTPS), who performed the assessment of titles and/or abstracts of retrieved studies. Any disagreements were resolved by discussion with a third author (DAT).

2.5. Data extraction

Data were extracted and tabulated in Excel. The following variables were extracted: title, author, year of publication, country, sample number (indicating the number of men and female or indeterminate), tooth/teeth analyzed, tooth region analyzed, and method/technique used for sex estimation. In order to establish standards for data extraction, titles and abstracts were independently reviewed by the authors for possible inclusion based on the aforementioned criteria. Disagreements among the authors (TMHE and MTPS) were resolved through discussions and consensus, with mediation by a third reviewer (DAT). The final decision was made based on the opinion of two out of the three reviewers.

2.6. Data analysis

A qualitative synthesis of the variables predefined in the search protocol was performed. To do so, descriptive statistics were used. Data were presented using percentages for each of the variables evaluated (year, country of publication, type of dentition, dental tissue analyzed, method/technique, and accuracy to estimate sexual dimorphism).

3. Results

3.1 Study selection

Through the search protocol described above, 1568 possibly relevant publications were retrieved. After removing duplicates and excluding articles by titles and/or abstracts review, 179 articles and one article more (included by expert indication) were assessed for full paper review eligibility, 37 articles were excluded with the respective reasons for exclusion detailed in Figure 1. As a result, a final number of 143 observational studies were included in this review.

3.2 Characteristics of the studies

The year of publication of the included studies ranged between 1966 and 2022. 2017 was the year in which more articles on the subject were published with a total of 12 articles. It is important to highlight that sexual dimorphism has been mainly studied on permanent teeth with 83.9% (n = 120) of the total studies. The remaining studies, which correspond to 9.1% (n = 13) concentrated their analysis on temporary teeth, and only 7% (n = 10) of the investigations were in both types of dentitions. Furthermore, most of the studies, 93.7% (n = 134), independently of the type of dentition analyzed, were able to estimate sexual dimorphism. Odontometry was the technique most frequently implemented for this purpose in 77.6% (n = 111). Meanwhile, 10.5% (n = 15) of the studies were not able to estimate sexual dimorphism. The methods used in these cases were mainly metric, specifically odontometry (n = 8), photogrammetry (n = 3), morphometry (n = 1), and morphometric

geometry (n = 1). At the same time, two used a non-metric method: ultrasound method (n = 1) and agenesis pattern (n = 1) (Table 3).

3.4 Geographical distribution of included studies

We identified studies across the five continents. 40.6% (n = 58) were investigations carried out in the Asian continent. India, with 34 studies, was the country with most publications in this field. While 27.2% of the studies (n = 39) were from America, with the United States as the country with most publications (17 in total), 25.9% (n = 37) were from Europe, whose production around the subject is located mainly in Spain with 11 publications. Although to a lesser extent, 3.5% of the publications (n = 5) were from Africa, and 2.8% (n = 4) were from Oceania.

3.5 Dental tissues studied to estimate the human sexual dimorphism (primary outcome)

Most of the articles included (33.6 %) considered all the teeth for their analysis. However, it is noteworthy that 18.2% of the 143 articles reviewed focused attention only on the molars analysis, and 13.3% only on canines. These are the teeth with the highest reports regarding their ability to estimate human sexual dimorphism. It is also important to highlight that 80% (equivalent to 114 articles) focused their observations and measurements on the dental crown enamel, mainly on the buccolingual (BL) and mesiodistal (MD) diameters. Although in smaller numbers, the other dental components have also been analyzed, with the following percentages, enamel and dentin, 4.9% (n = 7);

enamel, dentin, and dental pulp together, 4.2% (n = 6); the dental pulp was studied only in 3.5% (5 studies); the root length only in 2.1% (n = 3); the whole tooth in 2.1% (n = 3); enamel and root length in 1.4 % (n = 2); enamel- cementum junction in 1.4 % (n = 2) as well; and dentin and dental pulp in 0.7% (n = 1) (Table 3).

3.6 Methods used to estimate sexual dimorphism (secondary outcome)

Biochemical methods were implemented in 4.9% (n = 7) of the 143 articles analyzed. In this method, techniques such as: performed cell and DNA isolation (n = 2); elemental concentration analysis (n = 2); polymerase chain reaction –PCR- (n = 1); trace elements and peptides such as amelogenin in tooth enamel -spectroscopy- (n = 1), and mass spectrometry used for analysis in proteomics (n = 1) have been reported to estimate sex dismorphism (Figure 2).

In contrast, metric methods in which odontometry was the method most frequently implemented to estimate sexual dimorphism, it represents 92.3% of the studies, corresponding to 111 studies. In addition to this one, the following techniques were used to analyze the teeth: photogrammetry in 2.8 % (n = 4); X-rays in 2.8% (n = 4, three of these incorporated deep learning analysis, specifically Convolutional Neural Networks –CNN-); morphometry in 2.1% (n = 3); scanning, microtomography, and tomography in 2.1% (n = 3); geometric morphometric analysis in 2.1% (n = 3, one of this incorporated the used of artificial neural networks -ANN); tomography in 1.4% (n = 2, one of this used data mining); microtomography in 0.7% (n = 1), and microscopy/histology in 0.7% (n = 1) (Figure 3).

Lastly, non-metric methods were the least used to estimate sexual dimorphism in teeth only in 2.8% (n = 4) of the studies. These studies evaluated stages of dental development (n = 1), dental eruption (n = 1), patterns of agenesis (n = 1), and the mechanical and acoustic properties of the teeth by ultrasound (n = 1) (Figure 4).

4. Discussion

This review confirms that teeth constitute a valuable source of biological information, given their high conservation capacity over time and their resistance to physical, chemical, and biological deterioration. This explains why, for several years and from disciplines like forensic odontology or forensic anthropology, teeth have been studied at a histological and morphological level, in particular, to understand the characteristics of their tissues and how these can help in the estimation of biological variables (sex, age and population affiliation of an individual). The relevance of this subject is high for a country rich in history like India by representing 23.8% of the total of articles reviewed. Researchers from this country are leading the research on the subject, which it also shows the ease and high interest in this type of analysis [5].

Odontometry is used to acquire and verify the dimensions of regions of interest, mainly in the tooth crown. The measurements are done taking into consideration the diagonal diameters (MD and VL), cervical, and widths like the intercanine arch. The findings show that measurements with manual calipers directly on the teeth, X-ray images, scans, micro-computed tomography (micro-CT), computerized tomography (CT), and to a greater extent, dental plaster models, have been the widely used techniques in odontometric studies for sex

estimation. This is possibly due to the ease of use, access, transport, application, and low cost of the whole process, and for showing acceptable levels of precision and reproducibility [26]. However, in some cases the sharp tips of these gauges can alter the dental models, generating errors in the measurements. As a result, it is convenient to consider alternatives that increase the precision when obtaining and analyzing the measurements. These alternatives include 2D measurements, bespoke software-based measurements, or geometric morphometry. They are more accurate and suitable to answer questions related to form, which cannot be seen with the naked eye nor with the use of calipers on the casted molds [26, 27, 28].

Another significant alternative that has gained prominence in recent years involves the utilization of artificial intelligence (AI) in combination with metric methods applied to X-ray images and geometric morphometric analysis. The adoption of AI-based approaches has been steadily increasing in various fields, with forensic dentistry standing out as a notable example. In this context, AI plays a pivotal role in establishing sexual dimorphism for human identification through the assessment of radiological examinations [29, 30].

The growing influence of AI in this context can be attributed to the application of advanced techniques, including artificial neural networks (ANN), convolutional neural networks (CNN), deep learning (DL), and data mining [29, 30, 31, 32, 33]. These techniques have demonstrated a remarkable capability to enhance precision in both the acquisition and analysis of measurements while simultaneously reducing the impact of operator subjectivity [30, 33]. This approach has demonstrated accuracy percentages up to 92.31% in estimating sexual dimorphism [29]. Consequently, AI methods consistently outperform earlier odontometric or dental morphometric approaches, which relied on linear or angular

measurements and the analysis of dental crown shapes for sex classification. Moreover, AI techniques have proven invaluable when dealing with a large volume of samples or individuals, as the substantial workload on experts in such cases can potentially introduce human errors [32].

In addition, thanks to the odontometric analysis, it has been found that men's teeth have larger dimensions compared to women's teeth with canines, known as the "key teeth" in human identification, like the most dimorphic teeth, because they are the least affected by periodontal diseases and severe traumas, and the last ones to be extracted, in general [6, 34]. However, there are some rare cases where the findings are the opposite. This is explained by human evolution, which has generated a reduction in sexual dimorphism.

Regarding the examination of temporary and permanent dentitions, the latter shows greater sexual dimorphism. This is consistent with the idea that there is some hormonal influence during tooth development, and because the temporary dentition has a faster development, lasting a shorter period compared to the permanent dentition, and in consequence, it is less exposed to the effects of hormones [35].

According to the literature analyzed in this review, to estimate sexual dimorphism through the teeth, the main dental tissue used was the dental enamel that covers the crowns, followed by the dentin and the dental pulp. For the further analysis of these tissues, biochemical analysis can provide high precision (up to 100%) for estimating sex by allowing the study of genetic variations. DNA isolation enables the analysis of molecular markers from any cellular remnant in the dentin, pulp, or even cementum with the use of PCR [16, 17, 19]. The selection of the aforementioned PCR or non-metric methods depends

on the aim of the study. For example, studying factors in the eruption and development of teeth at different ages, according to sex [13, 21, 22, 23]. As shown in this review, although most dental tissues have been studied to estimate sexual dimorphism, dental cementum has been poorly studied for this purpose, at least in humans. Some studies that have been interested in analyzing this tissue to establish variables like sex, have been paleodemographic and paleoanthropological studies, whose populations of interest are Neolithic women [36], and individuals of the Neanderthal species [37].

Finally, based on the findings of this review, it is essential to acknowledge that while odontometry was the most utilized method for assessing sexual dimorphism, it exhibited a wide range of sex estimation accuracy percentages, spanning from 51% to 95.9%. Nevertheless, odontometry has its own set of limitations, including various biological, methodological, and technical factors. The selection of techniques plays a pivotal role in precision, with certain methods proving more accurate than others. Additionally, factors such as sample sizes, the experience level of evaluators, the specific variables under consideration, the inherent biological variability, and the calibration of measurement equipment all contribute to precision. Notably, population diversity is a significant factor, as teeth can display substantial variations among different geographic and ethnic groups [11]. Hence, it is crucial to understand the unique characteristics of teeth within specific populations to establish precise population-specific values [11, 38, 39].

In the same way, according to the findings of this review, non-metric methods are the least recommended for estimating sexual dimorphism. This recommendation is based on a limited number of studies available for analysis, possibly due to several factors: 1) Lack of objectivity: Non-metric methods often rely on visual observation and subjective

interpretation of anatomical features by evaluators. This subjectivity can lead to biased interpretations and inconsistent results. 2) Limitations in precision: These methods are based on morphological characteristics that may exhibit natural variations within a population or can be challenging to measure accurately. 3) Influence of evaluator experience: Less experienced evaluators may make errors in identifying secondary sexual characteristics or struggle to distinguish subtle differences. This introduces an additional layer of subjectivity and decreases result reliability. 4) Applicability to diverse populations: Non-metric methods are frequently developed using specific populations as reference points, which may limit their applicability to other populations due to biological variability.

In summary, while non-metric methods can be useful in situations where advanced technology is unavailable, it is essential to acknowledge their limitations concerning subjectivity and precision when compared to more modern and objective methods [40, 41]. Therefore, it is recommended to primarily employ metric methods (whether incorporating artificial intelligence or not) and biochemical methods whenever possible to obtain more precise and reliable estimates of sexual dimorphism.

Finally, after conducting this scoping review, it is crucial to consider certain limitations that may have impacted the process of searching and selecting relevant information. A major limitation involves the potential constraints imposed by the use of filters aimed at streamlining the vast amount of data provided by each database. This restriction might have hindered the acquisition of comprehensive results, despite the eventual inclusion of articles meeting the criteria for extracting information pertinent to the review's focus and question. Additionally, the selection of search terms, although encompassing a broad scope—comprising a total of 10 terms related to sexual dimorphism in conjunction with the term

"teeth"—could have constituted another potential limitation. The choice of keywords significantly influences the breadth and depth of the obtained results, and employing additional terms might have enhanced this aspect. Although the total of articles included comprises a significant number of investigations giving a general overview of the accuracy of the most implemented methods and techniques to estimate sexual dimorphism through dental tissues, it is essential to take these limitations into account when interpreting the findings and conclusions derived from the review process.

5. Conclusion

Metric methods, mainly odontometry (intraoral or by means of dental plaster models or digital scanning or software, with an estimation precision that can vary between 51% and 95.9%), biochemical (that can provide a high precision to estimate sexual dimorphism up to 100%), and non-metric methods, although to a lesser extent, and the least efficient (with reported prediction percentages of 58%) have a wide use to establish sexual dimorphism by the analysis of dental enamel in canines and permanent molars. This scoping review enables us to draw the conclusion that employing metric methods, both with and without the utilization of AI, as well as biochemical methods, holds significant potential for establishing crucial biological variables such as sex, population variability, and human identification through the analysis of teeth.

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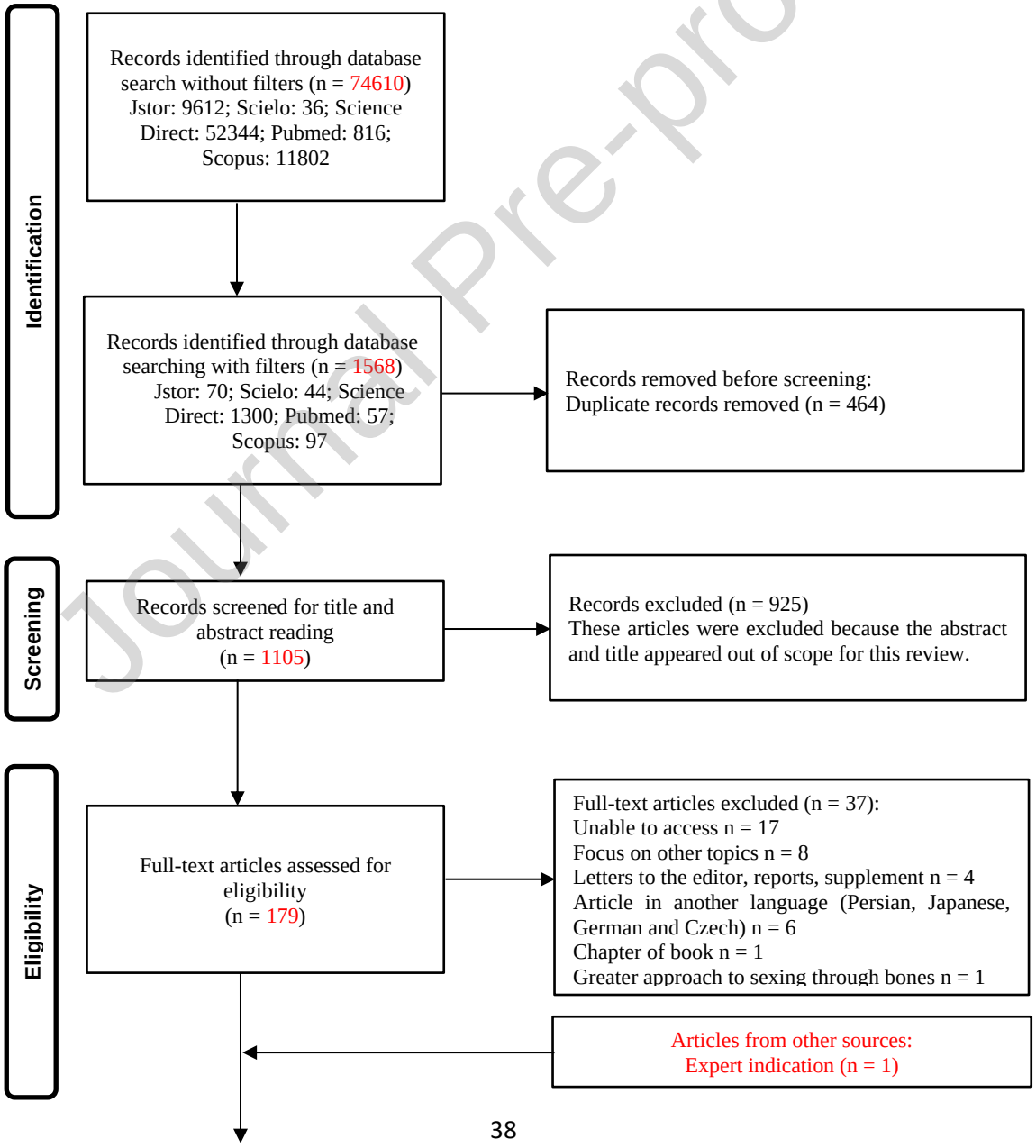
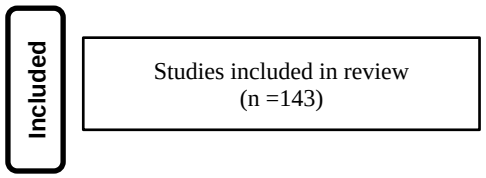
Figure 1. Flowchart according to the PRISMA-ScR guidelines.





The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) flow chart illustrating the study selection procedure for this scoping review.

Figure 2. Main biochemical methods used to estimate sexual dimorphism. These methods concentrate their measurements on proteins and nucleic acids.

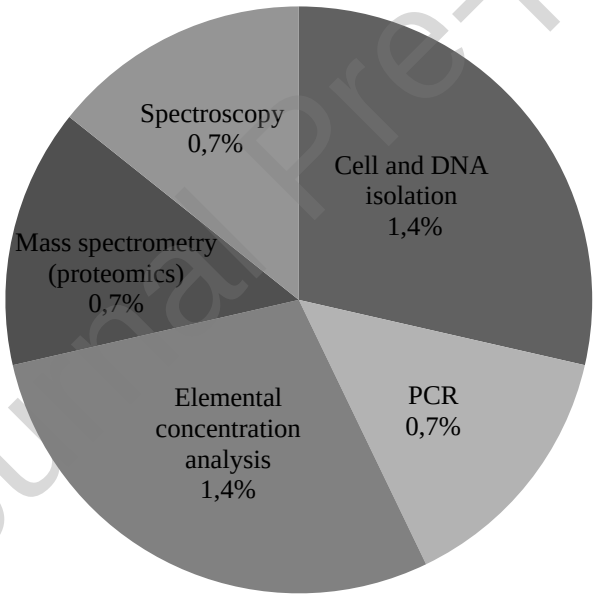


Figure 3. Metric methods used to estimate sexual dimorphism. These methods analyzed dental dimensions (mesio-distal (MD), bucco-lingual (BL), dental indices like the intercanine, diagonal measurements, and lengths) in order to assess differences in tooth sizes and shapes of men and women.

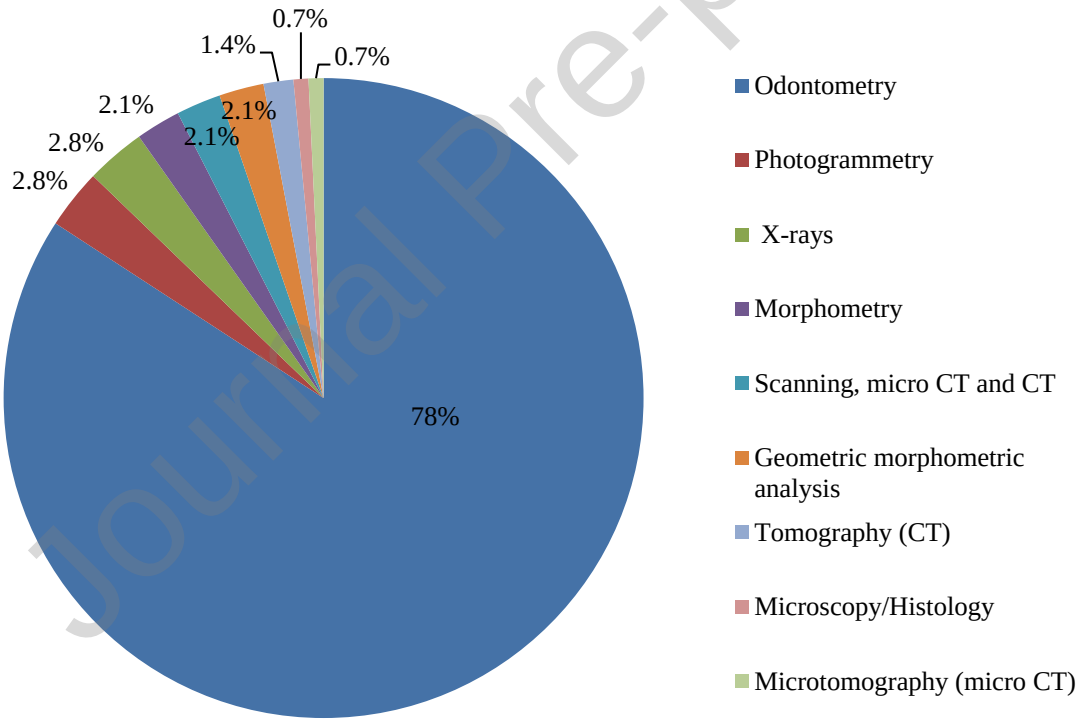


Figure 4. Non-metric methods used to estimate sexual dimorphism. These methods qualitatively evaluate some of the dental characteristics related to dental formation and development that may vary between men and women.

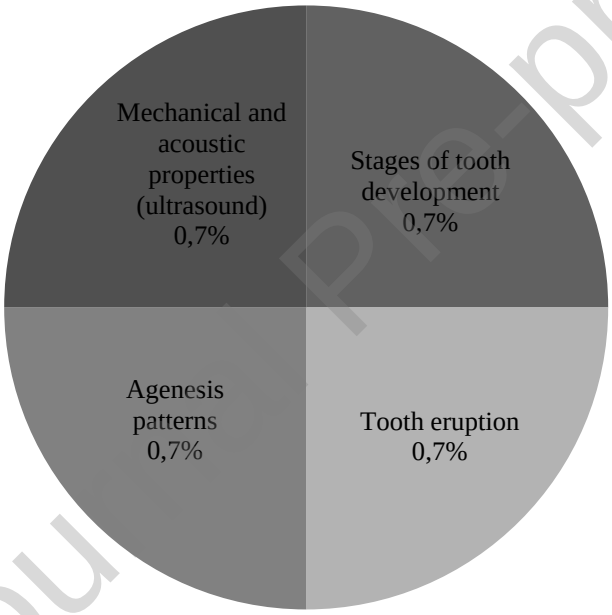


Table 1. PECO strategy used in the evaluation of scientific evidence.

Parameter	Evaluation
Population (P)	Permanent and temporary teeth
Exposure (E)	Dental tissues and methods/techniques used to estimate sexual dimorphism
Comparison (C)	Comparison between biochemical, metric and non-metric methods and dental tissues
Outcome (O)	Method/technique used to estimate sexual dimorphism depending on the dental tissue analyzed

Table 2. Databases consulted, their search formulas, and results.

Databases	Search formulas	Results
Jstor	("teeth" AND "sexual dimorphism") OR ("teeth" and "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment")	5784
	("teeth" AND "sexual difference") OR ("teeth" AND "determining sex") OR ("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric")	3828
Jstor Filter: Abstract	(ab:"("teeth" AND "sexual dimorphism") OR ("teeth" and "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment") ")	56
	(ab:"("teeth" AND "sexual difference") OR ("teeth" AND "determining sex") OR ("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric") ")	13
Scielo	("teeth" AND "sexual dimorphism") OR ("teeth" and "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment") OR ("teeth" AND "sexual difference") OR ("teeth" AND "determining sex") OR ("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric")	36
Scielo Filter: Abstract	(ab:(("teeth" AND "sexual dimorphism") OR ("teeth" and "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment") OR ("teeth" AND "sexual difference") OR ("teeth" AND "determining sex") OR ("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric")))	44
Science Direct	("teeth" AND "sexual dimorphism") OR ("teeth" and "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment")	4194
	("teeth" AND "sexual difference") OR ("teeth" AND "determining sex")	774
	("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric")	47376
Science Direct Filter: Title, abstract, keywords	Title, abstract, keywords: ("teeth" AND "sexual dimorphism") OR ("teeth" and "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment")	143
	Title, abstract, keywords: ("teeth" AND "sexual difference") OR ("teeth" AND "determining sex")	21
	Title, abstract, keywords: ("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric")	1136

PubMed	("teeth" AND "sexual dimorphism") OR ("teeth" and "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment") OR ("teeth" AND "sexual difference") OR ("teeth" AND "determining sex") OR ("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric")	816
PubMed Filter: Title	("teeth"[Title] AND "sexual dimorphism"[Title]) OR ("teeth"[Title] AND "estimating sex"[Title]) OR ("teeth"[Title] AND "sex estimation"[Title]) OR ("teeth"[Title] AND "sex characteristics"[Title]) OR ("teeth"[Title] AND "sex assessment"[Title]) OR ("teeth"[Title] AND "sexual difference"[Title]) OR ("teeth"[Title] AND "determining sex"[Title]) OR ("teeth"[Title] AND "sexing"[Title]) OR ("teeth"[Title] AND "sex patterns"[Title]) OR ("teeth"[Title] AND "odontometric"[Title])	57
Scopus	("teeth" AND "sexual dimorphism") OR ("teeth" and "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment") OR ("teeth" AND "sexual difference") OR ("teeth" AND "determining sex") OR ("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric")	11802
Scopus Filter: Article title	("teeth" AND "sexual dimorphism") OR ("teeth" AND "estimating sex") OR ("teeth" AND "sex estimation") OR ("teeth" AND "sex characteristics") OR ("teeth" AND "sex assessment") OR ("teeth" AND "sexual difference") OR ("teeth" AND "determining sex") OR ("teeth" AND "sexing") OR ("teeth" AND "sex patterns") OR ("teeth" AND "odontometric")	98

Table 3. Summary of the main characteristics of the studies included in the scoping review.

Author, year	Sample (n) / Participants	Population	Tooth / Teeth	Tooth region analyzed	Method/ technique for sex estimation	Sexual dimorphism present (yes/no)	Accuracy percentage/Result
Bailit et al., 1964 [40]	50: ♀25 ♂25	American children	Permanent canines, and molars (2th and 3th, if the latter was present). First molars in young children	Whole tooth	Non-metric method: Development stages	Yes	58%
Garn et al., 1966 [42]	117 Indeterminate: 117	American adolescents (from southwestern, Ohio)	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	The sexual dimorphism amounted to 5.6% for the buccolingual diameter as compared to 4.2% for the mesiodistal diameters.

Lewis et al., 1967 [43]	43: Indeterminate: 43	Canadian	Permanent teeth	Crown: enamel	Metric method: odontometry	No	N/A
Biggerstaff, 1976 [44]	199 dental models: ♀99 ♂100	American	Permanent mandibular molars	Crown: enamel	Metric method: photogrammetric methods	No	N/A
Sciulli et al., 1977 [45]	109: ♀57 ♂52	Ohio Valley Native American groups	Permanent canines	Crown: enamel	Metric method: odontometry	Yes	79.4%
Black, 1978 [46]	133: ♀64 ♂69	American boys and girls	Right temporary teeth: incisors, canines, molars	Crown: enamel	Metric method: odontometry	Yes	75%
Levesque et al., 1981 [41]	4640 panoramic radiographs: ♀2362 ♂2278	French Canadian children and young adults.	Permanent third molars	Whole tooth	Non-metric method: method of Demirjian et al. X-rays	Yes	The slight advance of girls over boys at the crown-completion stage was similar to previous observations on other mandibular teeth, particularly the second molar. The root development course of the third molar was faster in males than in females.
Coppa et al., 1982 [47]	108: ♀37 ♂71	Adult population of Alfedena (Italy)	Permanent upper teeth	Crown: enamel	Metric method: odontometry	Yes	The coefficient of variance in males was larger than in females: 5.70% versus 5.35%
Kieser, 1985 [48]	28: Indeterminate: 28	Skeletal population in South Africa	Permanent canines and molars	Crown: enamel, dentin, and pulp chamber	Metric method: odontometry	Yes	Canines and molars showed significant patterns of variability between sexes.

Kieser et al., 1985 [49]	202 dental arches: ♀102 ♂100	Living Language Indians of the Chaco area of Paraguay	Permanent teeth	Crown: enamel	Metric method: odontometry	Yes	84.5%
Burchett et al., 1988 [50]	16 photographs Indeterminate: 16	American Randomly selected from a large patient population	Permanent anterior teeth	Crown	Metric method: photometric method	No	N/A
Bishara et al., 1989 [51]	171: ♀80 ♂91	Individuals from Iowa City, Iowa, Alexandria, Egypt, and Chihuahua, Mexico	Permanent incisors, canines, premolars and first molars	Crown: enamel	Metric method: odontometry	Yes	The findings in this investigation indicated the presence of sexual dimorphism in the three populations, in particular between the canines and between the first molars.
Duffy et al., 1991 [52]	50: ♀20 ♂20 Indeterminate: 10	Canadian	Permanent third molars	Dental pulp	Biochemical method: isolation of cells from the dental pulp	Yes	At chamber temperatures up to 75°C sex diagnosis in human pulps from extracted teeth was still possible.
Bermúdez de Castro et al., 1993 [53]	134: Indeterminate: 134	Sample from SH deposit (Sierra de Atapuerca, Spain) and Kaprina dental sample	Permanent lower lateral incisors, canines, premolars, and first molars	Crown: enamel	Metric method: odontometry	Yes	Between 89.4 and 95.4%
Stroud et al., 1994 [54]	98 x-rays: ♀39 ♂59	Caucasian American	Permanent right posterior mandibular dentition: premolars and molars (except third molars)	Crown: enamel and dentin	Metric method: odontometry with x-rays	Yes	Dentin is significantly thicker in males than females.

Beyer-Olsen et al., 1995 [55]	145 skulls: Indeterminate: 145	Medieval skeletons excavated in Norway	Permanent teeth	Crown: enamel	Metric method: odontometry	Yes	85 % (left maxillary first molar represented by its facio-lingual dimension)
Hattab et al., 1996 [56]	198: ♀112 ♂86	Jordan	Permanent incisors, canines, premolars and first molars	Crown: enamel	Metric method: odontometry	Yes	Males had significantly larger teeth than females, ranging from $p < 0.05$. The overall percentage dimorphism was 3.6% on average.
Harris et al., 1998 [57]	115: Indeterminate: 115	American caucasoids	Permanent upper incisors	Crown: enamel and dentin	Metric method: odontometry	No	N/A
Kondo et al., 1998 [58]	272 dental models: ♀134 ♂138	Dental models taken from Chinese residents of Kaohsiung (Taiwan)	Second temporary molar and first molar	Crown: enamel	Metric method: odontometry	Yes	With the exception of trigonid mesiodistal diameters, the mean values of males were larger than females.
Satake, 1999 [59]	73: ♀42 ♂31	Japanese children from an elementary school in Tokyo	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	There are statistically significant differences between sexes.
Pettenati-Soubayroux et al., 2002 [60]	146: Indeterminate: 146	Osteoarchaeological sample of 200 burials dating from the outbreak of the plague in Marseilles (1720-1722) from the Ossuary of Observance	Permanent maxillary and mandibular incisors and canines	Crown: enamel	Metric method: odontometry	Yes	58%
Işcan et al., 2003 [61]	100 dental models: ♀50 ♂50	Turkish students	Permanent left side maxillary and mandibular teeth (except	Crown: enamel	Metric method: odontometry	Yes	Between 73 and 77%

			third molars)				
Kaur et al., 2003 [62]	400 ♀200 ♂200	Jat Sihks, Indian agricultural community	Lower permanent incisors	Crown: enamel	Metric method: odontometry	No	N/A
Lewis et al., 2004 [63]	84: ♀32 ♂52	English	Temporary molars	Dental pulp	Biochemical method: PCR	Yes	100%
Kondo et al., 2004 [64]	138: ♀68 ♂70	Australians aborigines	Temporary and permanent molars	Crown: enamel	Metric method: odontometry	Yes	All crown diameters were larger in males than in females on average, so the percentage dimorphism values in crown dimensions were always positive.
Kuswandari et al., 2004 [65]	297: ♀137 ♂160	Kindergarten children in Yogyakarta, Indonesia	Temporary teeth	Crown: enamel	Metric method: odontometry	Yes	The coefficient of variance in males was larger than in females (5.70% versus 5.35%). Sexual dimorphisms were found in the lateral incisor and first molar in the maxilla, and the canine, first and second molars in the mandible.
Feeney, 2005 [24]	18: Indeterminate: 18	Individuals of European Indian descent	Permanent and temporal incisors, canines and premolars	Crown: enamel and dentin	Non-metric method: ultrasound methods	No	N/A

Yamaguto et al., 2005 [66]	60 dental models: ♀35 ♂25	Brazilian	Permanent second molars	Crown: enamel	Metric method: odontometry	Yes	There is sexual dimorphism at all distances MD of the teeth of male individuals; larger than the teeth of female individuals.
Uysal et al., 2005 [67]	150: ♀78 ♂72	Turkish	Permanent incisors, canines, premolars and first molar	Crown: enamel	Metric method: odontometry	Yes	Significant sex differences were shown for the overall ratio.
Schwartz et al., 2005 [68]	169: ♀122 ♂47	South Africa, England, UK and Ayrshire, Scotland, UK. The majority of each sample was of European origin	Permanent mandibular canines and third molars	Crown: enamel and dentin	Metric method: scan, odontometry	Yes	In canines, females possess a significantly higher index of relative enamel thickness.
Kondo et al., 2005 [69]	117: ♀52 ♂65	Students from Tokyo, Japan	Permanent upper molars (except third molars)	Crown: enamel	Metric method: odontometry	Yes	The mean values of molar crown dimensions in males exceeded those in females for all variables.
Ates et al., 2006 [70]	100: ♀50 ♂50	Students from Istanbul	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	81% (total sample), 76% (upper front), and 81% (lower front teeth)
Altherr et al., 2007 [71]	120: ♀60 ♂60	Black and white subjects from the University of North Carolina School of Dentistry clinic	Permanent canines and premolars	Crown: enamel	Metric method: odontometry	Yes	The predictive accuracy was significantly overestimated in the white female group (p .001, least square means).

Vodanović et al., 2007 [72]	86 skulls: Indeterminate: 86	Skulls excavated from the medieval cemetery (10th-11th century) at the Bijelo Brdo archaeological site near Osijek.	Permanent teeth	Crown: enamel	Metric method: odontometry	Yes	55.8% (on the basis of craniofacial features alone) to 86.0% (combining craniofacial and odontometric features).
Saunders et al., 2007 [73]	45: ♀22 ♂23	Individuals collected from the historic St. Thomas Anglican Church Cemetery in Belleville, ON, Canada	Permanent mandibular canines and premolars	Crown: enamel, dentin, and dental pulp	Metric method: odontometry	Yes	t-test results shows that significant differences between males and females occur for both the canine and the premolar.
Ling et al., 2007 [74]	459: ♀164 ♂295	Chinese	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	All teeth are statistically significantly different (t-test, p .05) between male and female in their buccolingual dimensions.
Acharya et al., 2007 [75]	123 dental models/ 53 (after exclusions): ♀58+22 ♂65+31	Nepalese	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	67.9% (maxillary posterior teeth) and 92.5% (teeth from both jaws)
Acharya et al., 2008 [76]	123: ♀58 ♂65	Nepalese young adults	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	Between 69.8 to 81.1%
Guatelli-Steinberg et al., 2008 [77]	At least 50 teeth per population (seven populations)	Samples from Canada (Igloolik), Taiwan, the Philippines and Iceland, Sweden, Australia and the United States (Ohio)	Permanent teeth	Crown: enamel	Metric method: odontometry	No	N/A
Rodriguez Flórez et al., 2008 [78]	98: ♀48 ♂50	Subadults from the City of Córdoba, Argentina.	Temporary teeth	Crown: enamel	Metric method: odontometry	Yes	The BL UM1 dimension: 90.9% (male) and

							93.7% (female)
Uysal et al., 2009 [79]	228: ♀128 ♂100	Patients from the Department of Orthodontics at Selcuk University. School of Dentistry, Konya, Türkiye.	Permanent mandibular incisors, canines and premolars	Crown: enamel	Metric method: odontometry	Yes	The correlation coefficients ranged from 0.956 to 0.989, with higher values in the girls. The r2 values were 91% (boys) and 98% (girls).
Prabhu et al., 2009 [80]	105: ♀53 ♂52	Indian students	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	75.2% (mandibular teeth), 74.3% (teeth of both jaws taken together) or 62.9% (only maxillary teeth)
Acharya et al., 2009 [81]	123: ♀58 ♂65	Nepalese	Permanent canines	Crown: enamel	Metric method: odontometry	Yes	MD measurement of canines gave recognisably greater sex classification accuracy (69.1%) than discriminant analysis of the MCI.
Torres Chianale et al., 2010 [82]	34: ♀17 ♂17	Chilean preschool children	Temporary molars	Crown: enamel	Metric method: odontometry	No	N/A
Galdames et al., 2010 [22]	40: ♀20 ♂20	Chilean adult patients	Permanent premolars and third molars	Dental pulp	Metric method: microscopy	Yes	100%
Adler et al., 2010 [83]	151: ♀74 ♂77	Sample Australian, European ancestry from Sydney, Australia.	Temporary canines and molars	Crown: enamel	Metric method: odontometry	Yes	Between 70.2% and 74.8%

Suazo Galdames et al., 2010 [84]	150: ♀83 ♂67	Chilean	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	The largest dimensions were found in men, differences significant in buccolingual diameters with $p<0.05$.
Pereira et al., 2010 [85]	80 dental models: ♀55 ♂25	Portuguese students	Permanent upper incisors and canines	Crown: enamel	Metric method: odontometry	Yes	Significant differences ($p < 0.05$) were found in all variables except for the ‘‘Incisor Index”.
Anuthama et al., 2011 [86]	100: ♀59 ♂41	Indian	Permanent upper incisors and canines	Crown: enamel	Metric method: odontometry	Yes	90%
Macaluso, 2011 [8]	235: ♀105 ♂130	Black south africans	Permanent upper molars	Crown: enamel	Metric method: digital photogrammetry	Yes	Between 59.6 and 74.5%
Jain et al., 2011 [87]	150 dental models: ♀75 ♂75	Indian	Permanent incisors, canines, premolars and first molars	Crown: enamel	Metric method: odontometry	Yes	There was a statistically significant difference in mesiodistal tooth width between males and females where the males showed.
Acharya et al., 2011 [88]	105: ♀52 ♂53	Indian students	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	LRA enabled optimal sex prediction (100%) when all teeth in both the jaws were included. 76.2% (only maxillary) or 84.8% (mandibular)

Sonika et al., 2011 [89]	200: ♀100 ♂100	Indian	Permanent maxillary first molars	Crown: enamel	Metric method: odontometry	Yes	Among the group of study models, the upper left first molar was found to exhibit the greatest sexual dimorphism (5.54%) in terms of buccolingual dimension. The present study established the existence of statistically significant sexual dimorphism in the upper first molars.
Hassett, 2011 [90]	25: Indeterminate: 25	Known sex sample from St. Bride's Church, London and a partially known sex sample from Old Church, Chelsea, London	Permanent canines	Crown: enamel	Metric method: odontometry	Yes	93.8% (St. Bride's) and 95% (Old Church)
Acharya et al., 2011 [91]	205: ♀102 ♂103	Young adults of Indian origin	Permanent mandibular canines	Crown: enamel	Metric method: odontometry	Yes	62 to 66%
de Armas González et al., 2012 [92]	362: ♀174 ♂188	Students from basic secondary schools in the city of Matanzas, Chile	Permanent incisors and canines	Crown: enamel	Metric method: odontometry	Yes	Men had a larger diameter mesiodistal than females.
Thapar et al., 2012 [93]	200: ♀104 ♂96	Adult Indian	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	Between 61.5 and 76%
Zorba et al., 2012 [94]	107: ♀54 ♂53	Individuals of the human skeletal collection:	Maxillary and mandibular	Crown: enamel	Metric method: odontometry	Yes	93% (total sample), 77.4% (upper jaw),

		"Athens Collection", Athens, Greece	permanent molars				and 88.4% (lower jaw)
Loyd et al., 2012 [95]	55: ♀33 ♂22		Permanent third molars	Dental pulp	Biochemical method: in vitro superfusion method	Yes	100%
Radlanski et al., 2012 [96]	50 intraoral photographs: ♀50 ♂50	German (Berlin)	Permanent incisors and canines	Crown: enamel	Metric method: morphometric study	No	N/A
Sabóia et al., 2013 [97]	100 dental models: ♀50 ♂50	Brazilian	Permanent incisors, canines, premolars and first molars	Crown: enamel	Metric method: odontometry	Yes	The greatest sexual dimorphism was observed in the left mandibular canine ($p<0.001$) with effect size over 0.8 (0.94)
Angadi et al., 2013 [98]	669 dental models: ♀323 ♂346	Indian	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	68.1% (maxillary teeth), 73.9% (mandibular) and 71% (teeth of both jaws combined)
Freire Fernandes et al., 2013 [99]	100 dental models: ♀50 ♂50	Brazilian	Permanent teeth	Crown: enamel	Metric method: odontometry	Yes	Most of mesiodistal measures present particular characteristics in relation to gender, with higher values for males.
Shankar et al., 2013 [100]	183: ♀93 ♂90	Indian	Permanent upper canines, first and second molars	Crown: enamel	Metric method: odontometry	Yes	Between 87.2 and 88%
Zapico et al., 2013 [17]	14: ♀9 ♂5	Spanish	Permanent incisors and molars	Dentin and dental pulp	Biochemical method: DNA isolation, PCR	Yes	100%

Viciano et al., 2013 [101]	269: ♀119 ♂150	Individuals from the osteological collection of Granada (Spain).	Temporary and permanent teeth	Crown: enamel	Metric method: odontometry	Yes	Between 78.1 and 93.1% (deciduous dentition) and between 79.4 and 92.6% (permanent teeth)
Zorba et al., 2014 [102]	102: ♀44 ♂58	Individuals from the Athens Collection, Greece	Permanent incisors, canines and premolars	Root length	Metric method: odontometry	Yes	Between 58.6% and 90.0%
Mitsea et al., 2014 [103]	172 dental models: ♀108 ♂64	Greek (Athens)	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	72%
Abou El-Yazeed et al., 2014 [104]	573 dental models: Indeterminate: 573	Egyptian	Maxillary and mandibular temporary canine, first and second molars, Permanent canines, first and second premolars, and first molars	Crown: enamel	Metric method: odontometry	Yes	Sexual dimorphism was obvious in upper deciduous canine area as well as at the upper and lower permanent left first molar areas where's boys are longer than girls.
Sharma et al., 2014 [105]	44: ♀22 ♂22	Indian	Permanent teeth	Crown: enamel	Metric method: odontometry	Yes	A significant correlation was found between the MD and BL widths of the premolar teeth.
Peckmann et al., 2015 [106]	103: ♀50 ♂53	African American individuals from the Robert J. Terry Anatomical Skeletal Collection, Canada	Permanent mandibular and maxillary molars	Crown: enamel	Metric method: odontometry	Yes	Between 63.9% and 77.6%

Narang et al., 2015 [107]	410: ♀210 ♂200	North Indian	Permanent first molars	Crown: enamel	Metric method: odontometry	Yes	Between 67.5 and 88%
Agrawal et al., 2015 [12]	100: ♀50 ♂50	Saudi Arabia	Permanent mandibular canines and first molars	Crown: enamel	Metric method: odontometry	Yes	Comparison of the mean values of the measured parameters between men and women showed highly significant differences of $P < 0.005$.
Singla et al., 2015 [108]	100: ♀50 ♂50	Individuals from Sirmour District, India	Permanent upper first molars	Crown: enamel	Metric method: odontometry	Yes	95%
Manchanda et al., 2015 [109]	200 dental models: ♀100 ♂100	Indian	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	Between 51% and 80%
Viciano et al., 2015 [13]	149: ♀39 ♂81	Individuals from three protohistoric Samnite population: Opi, Alfedena and Bazzano (central-southern Italy)	Permanent teeth	Crown: enamel	Metric method: odontometry	Yes	Between 83.7% and 95.9%
Peckmann et al., 2016 [110]	303 dental models: ♀177 ♂126	Chilean	Permanent maxillary incisors and canines	Crown: enamel	Metric method: odontometry	Yes	Between 54.4% and 63.3%
Flohr et al., 2016 [111]	146: ♀81 ♂65	Early Neolithic (Linear Pottery Culture) and an early medieval skeletal assemblage from Germany	Permanent canines	Crown: enamel-cementum junction	Metric method: odontometry	Yes	94.0% (in the early medieval) and of 79.2% (in the Early Neolithic assemblage)

Lagos et al., 2016 [112]	150: ♀85 ♂65	Chilean	Permanent mandibular canines	Crown: enamel	Metric method: odontometry	Yes	75.29% (MCI) and 84.71% (MD width of the canine)
Filipovic et al., 2016 [38]	201: ♀100 ♂101	Serbian	Permanent incisors, canines, premolars and first molars	Crown: enamel	Metric method: odontometry	Yes	Vestibulolingual dimensions showed greater statistically significant difference between the sexes.
Banerjee et al., 2016 [35]	100: ♀50 ♂50	Indian	Permanent upper central incisor, canine, premolar and molar	Crown: enamel	Metric method: odontometry	Yes	The present study indicates a significant sexual dimorphism defined in the molar, canine and incisor in the expression of the three parameters MDW, BLW, CL (p value).
Martins Filho et al., 2016 [113]	200: ♀100 ♂100	Caucasoid Brazilian adults	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	79.87% (KNN discriminant function), 78.0% (logistic regression) and 71.2% (linear discriminant function).
Hottel et al., 2016 [114]	40: ♀20 ♂20	American	Permanent maxillary incisors and canines	Crown	Metric method: photometric method	No	N/A
Silva et al., 2016 [10]	120 plaster molds: ♀70 ♂50	Portuguese	Permanent mandibular canine	Crown: enamel	Metric method: odontometry	Yes	64,2%
Paknahad et al., 2016 [115]	124: ♀60 ♂64	Iranian	Temporary teeth: mandibular and	Crown: enamel, dentin and	Metric method: odontometry	Yes	68%

			maxillary second molar	dental pulp			
Aggarwal et al., 2016 [116]	60: ♀30 ♂30	Indian students	Permanent mandibular canines	Crown: enamel	Metric method: odontometry	Yes	The difference in males and females is statistically significant.
Pandey et al., 2016 [117]	100: ♀50 ♂50	Indian	Permanent maxillary and mandibular canines	Crown: enamel	Metric method: odontometry	Yes	Males show larger mean dimensions of teeth than females.
Capitaneanu et al., 2016 [118]	200 digital panoramic radiographs: ♀100 ♂100	Belgium	Permanent teeth	Crown: enamel	Metric method: odontometry	No	N/A
Mehta et al., 2017 [119]	50: ♀25 ♂25	Indian	Permanent upper molars	Crown: enamel	Metric method: odontometry	Yes	Average BLW and MDW were higher in men than in women.
Shaweesh, 2017 [120]	204 dental models: ♀124 ♂80	Jordanian teenagers	Permanent teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	The coefficients of variation in those teeth are slightly greater in males than in females.
Jakhar et al., 2017 [121]	100: ♀50 ♂50	North Indian: from the dental wing department of Government Hospital, Haryana, India	Permanent incisors, canines, and premolars	Crown: enamel	Metric method: odontometry	Yes	The maxillary inter-canine width, maxillary first inter-premolar width, and palatal depth can aid in sex determination.
Tabasum et al., 2017 [122]	130: ♀57 ♂73	Indian	Permanent upper and lower molars	Crown: enamel	Metric method: odontometry	Yes	69,4%

Gouveia et al., 2017 [123]	60: ♀20 ♂20 Indeterminate: 20	Portuguese	Permanent lower second premolars, upper central incisors, and lower first molars	Crown: enamel	Metric method: odontometry	Yes	Above 80%
Davoudmanesh et al., 2017 [124]	220 dental models: ♀110 ♂110	Iranian students	Permanent maxillary and mandibular canines	Crown: enamel	Metric method: odontometry	Yes	70.1%
Gouveia et al., 2017 [125]	60: ♀20 ♂20 Indeterminate: 20	Italian	Permanent lower second premolars, upper central incisors, and lower first molars	Crown: enamel and root	Metric method: odontometry	Yes	88.9% (male) and 83.3% (female)
Mishra et al., 2017 [23]	301 radiographs: Indeterminate: 301	Indian	Permanent mandibular third molars and second premolars	Crown	Non-metric method: Agenesis pattern	No	N/A
Gandhi et al., 2017 [127]	62: ♀31 ♂31	Indian	Permanent mandibular canines	Crown: enamel	Metric method: odontometry	Yes	79,03%
Kazzazi et al., 2017 [14]	52: ♀20 ♂32	Iranian	Permanent teeth	Root	Metric method: scan, CT scan	Yes	Between 80.6 and 100%
Thabitha, 2017 [1]	180 dental models: ♀90 ♂90	Indian	Permanent incisors, canines, premolars and molars	Crown: enamel	Metric method: odontometry	Yes	The MDW of both maxillary and mandibular permanent canines showed a statistically significant

							difference between males and females ($P < 0.05$).
Singh et al., 2017 [9]	500 dental models: ♀250 ♂250	Indian	Temporary teeth	Crown: enamel	Metric method: odontometry	Yes	The presence of sexual dimorphism in the primary dentition of the children was adequately supported by the findings of this study.
Ingaleshwar et al., 2018 [128]	150 (100 adults and 50 children) ♀50 (adults)/25 (girls) ♂50 (adults)/25 (girls)	Bagalkot district of Karnataka, India.	Temporary and permanent canines	Crown: enamel	Metric method: odontometry	Yes	CCH and MMD showed significant differences except maxillary canines which did not show significant differences in MBL ($p < 0.05$).
García-Campos et al., 2018 [129]	56: ♀27 ♂29	Sample of anthropological collections from Madrid (Spain), South Africa and clinics from Sudan	Permanent upper and lower canines	Crown: enamel, dentin and dental pulp	Metric method: Scanning, microtomographic images, three-dimensional measurement	Yes	92,3%
Shivani et al., 2018 [130]	100 dental models: ♀50 ♂50	Nagpur	Permanent maxillary first premolar and first molar	Crown: enamel	Metric method: odontometry	Yes	87% (males) and 83% (females)
Govindaram et al., 2018 [11]	1000 orthopantomograms: ♀500 ♂500	Tamil ethnic	Permanent maxillary and mandibular teeth from the canine to the	Root length	Metric method: odontometry, with digital software	Yes	The percentages of sexual dimorphism for maxillary teeth ranged from 9.2% to 14.15%, and for

			first molar				mandibular teeth ranged from 10.8% to 11.6%.
Taduran, 2018 [131]	200: ♀100 ♂100	Philippine	Permanent maxillary and mandibular canines	Crown: enamel	Metric method: odontometry	Yes	56.41% (maxillary) and 74.36% (mandibular)
Burgueño Torres et al., 2018 [132]	1250: ♀623 ♂627	Children of Madrid, Spain	Temporary teeth: incisors, first premolar, canine, first and second molars	Crown: enamel	Metric method: odontometry	No	N/A
López-Lázaro et al., 2018 [133]	68: ♀32 ♂36	Identified subadults from the osteological collection of Granada, Spain	First temporary molars	Crown: enamel	Metric method: geometric morphometry	Yes	93.23% (males) and 83.17% (females) (shape variables of first maxillary deciduous molar), and 100% (males) and 87.50% (females) (with shape and size variables).
Monalisa et al., 2018 [28]	60: ♀30 ♂30	Indian	Permanent maxillary and mandibular first premolars	Crown: enamel and dentin	Metric method: photomicrographs	Yes	CDA was found to be significantly greater in males than in females in both mandibular first premolar ($p = 0.0005$) and maxillary first premolars ($p \leq 0.0001$)
Yong et al., 2018 [20]	140: ♀70 ♂70	Indigenous Australians and Australians of European descent	Permanent upper and lower premolars	Crown: enamel	Metric method: 3D geometric morphometry	Yes	80 and 92.8% (upper premolars) and 60 and 75.7%

							(lower premolars)
López-Lázaro et al., 2018 [34]	139: ♀65 ♂74	Individuals from Spanish osteological collections	Permanent maxillary posterior teeth	Crown: enamel	Metric method: geometric morphometrics	No	N/A
Aris et al., 2018 [7]	149: ♀57 ♂56 Indeterminate: 36	English	Permanent upper first molars	Crown: enamel	Metric method: odontometry	Yes	94.6% (adults) and 90.9% (immatures)
Andrade et al., 2019 [6]	232 and 116 cone beam CT scans: Indeterminate: 232 + 116	Brazilian	Permanent upper central incisors and canines	Dental pulp	Metric method: scanning, CBCT	Yes	Between 83 to 94%
Godinho et al., 2019 [134]	34: Indeterminate: 34	Follow-up patients in dental offices of the University of Coimbra, Portugal	Permanent molars	Crown: enamel	Metric method: odontometry	Yes	Post-heating sexing overestimated the number of males and underestimated the number of females.
Shetty et al., 2019 [39]	100: ♀50 ♂50	Indian	Permanent maxillary and mandibular canines	Crown: enamel	Metric method: odontometry	Yes	The average BL diameters exceeded in men with statistically significant sexual dimorphism in maxillary and mandibular canines.
Yepes et al., 2019 [135]	109: ♀46 ♂63	Contemporary mestizo population of the city of Manizales, Colombia	Permanent canines	Crown: enamel	Metric method: odontometry	Yes	Between 71.42% and 78.26%
Parker et al., 2019 [16]	40 enamel samples: Indeterminate: 40	American	Permanent second and third molars	Crown: enamel	Biochemical method: mass spectrometry / proteomics	Yes	Proteomic sex estimation concludes that an individual is likely a female instead of a

							male (Pr(F)=0.96)
Azevedo et al., 2019 [127]	120 dental models: ♀70 ♂50	Portuguese	Permanent mandibular canines	Crown: enamel	Metric method: odontometry	Yes	85.8%
Sorenti et al., 2019 [27]	36: ♀16 ♂20	Forensic collection of the Department of Anatomy of the School of Legal and Forensic Medicine of the Complutense University of Madrid	Permanent mandibular molars	Crown: enamel and dentin	Metric method: 2D measurements / microtomographic scans	Yes	74.36%
Kaeswaren et al., 2019 [136]	140: ♀70 ♂70	Volunteers from three major ethnic groups (Malay, Chinese and Indian) and are Malaysian citizens residing in Selangor.	Permanent canines	Crown: enamel	Metric method: odontometry	Yes	69%
Manhaes-Caldas et al., 2019 [137]	78 images: Indeterminate: 78	Brazilian	Permanent upper central incisors, upper and lower canines, and lower lateral incisors	Crown: enamel, dentin, and pulp chamber	Metric method: CBCT	Yes	83.7%
Sehrawat et al., 2019 [138]	511: ♀108 ♂146 Indeterminate: 257	Indian	Permanent mandibular first and second molars	Crown: enamel	Metric method: odontometry	Yes	75,9%
Mahoney et al., 2020 [139]	94: ♀48 ♂46	English	Permanent third molars	Enamel	Metric method: histological analysis, odontometry	Yes	89.5%

Sehrawat et al., 2020 [140]	200: ♀46 ♂54 Indeterminate: 100	Indian	Permanent mandibular molars	Whole tooth	Biochemical method: Elemental concentration analysis-Biomonitoring of trace elements	Yes	59% (44.4% male and 76.1% female)
Qamar et al., 2020 [21]	60: ♀30 ♂30	Pakistani and Saudi Arabian	Permanent upper premolars	Crown: enamel	Metric method: odontometry	No	N/A
Viciano et al., 2020 [141]	132: ♀62 ♂70	Individuals from the collection of identified human skeletons from the Certosa Cemetery (Bologna, Italy) of the University of Bologna	Temporary and permanent teeth	Crown: enamel	Metric method: odontometry	Yes	90.9%
Daniele et al., 2020 [142]	210 study models + 50 models to evaluate the predictive equation ♀107 + 25 ♂103 + 25	Spanish	Permanent incisors, canines, premolars and first molars	Crown: enamel	Metric method: odontometry	Yes	76.2%
Ribeiro et al., 2020 [26]	179: ♀91 ♂88	Australian	Temporary, mixed, and permanent dentitions: central incisors, lower lateral incisors, canines, second premolars, first and second molars	Crown: enamel	Metric method: odontometry	Yes	Lower canines showed the highest values of sexual dimorphism in both MZ and DZSS twins: 9.1% and 6.0% respectively.
Zúñiga et al., 2021 [143]	80 digital models: Indeterminate: 80	Chilean	Permanent canines, premolars and molars	Crown: enamel	Metric method: scan, odontometry	Yes	Between 70.9 and 88.9%

Milošević et al., 2021 [31]	76293 x-ray images: ♀44321 ♂31972	Individuals from the collection of the Department of Dental Anthropology Faculty of Dental Medicine University of Zagreb, Croatia	Permanent teeth	Crown: enamel	Metric method: deep learning specifically CNN	Yes	The specialized models achieve an overall accuracy of 72.40%, and the general model reaches an overall accuracy of 72.68%
Kanchan et al., 2021 [144]	307 dental models: ♀148 ♂159	Indian	Dental arch of the canines, premolars and molars of both jaws	Crown: enamel	Metric method: odontometry	Yes	Between 72.7% and 86.5%
Sharif et al., 2021 [145]	1410: ♀890 ♂520	Egyptian	Permanent maxillary teeth (except third molars)	Crown: enamel	Metric method: odontometry	Yes	58.8 %
Viciano et al., 2021 [146]	70: ♀29 ♂41	Contemporary Spanish population. Individuals from the San José cemetery in Granada (Spain). Osteological Collection of Granada	Permanent maxillary teeth	Crown: enamel	Metric method: odontometry	Yes	Up to 92.3% (combination of cranial and maxillary dental measurements)
Soundarya et al., 2021 [147]	100 dental models: ♀50 ♂50	Indian	Permanent upper and lower incisors, canines and first molars	Crown: enamel	Metric method: odontometry	Yes	81%
Oliva et al., 2021 [32]	100 dental models: ♀50 ♂50	Caucasian italian adults	Permanent upper left first premolar	Crown: enamel	Metric method: Based on a GMA and ANN	Yes	The accuracy was 0.84 and 0.80 for the training and test samples, respectively
Gowland et al., 2021 [15]	43: ♀8	Individuals from four archaeological sites in England:	Temporary and permanent teeth	Crown: enamel	Biochemical Method: Sex Chromosome -Linked	Yes	This method is essentially qualitative. The successful

	♂20 Indeterminate: 15	Piddington Coach Lane, Victoria Gate and Fewston.			Isoforms of Amelogenin Peptide		application of this method to estimate sex in non-adults, particularly perinatals, has the potential to revolutionize the way bioarchaeologists study infancy and childhood.
Esmaeilyfard et al., 2021 [29]	485 CBCT imaging: ♀240 ♂245	Iranian	Permanent teeth	Crown: enamel	Metric method: odontometry using data mining on CBCT	Yes	92.31%
Ademir Franco et al., 2022 [33]	4003 panoramic x-rays: ♀ 2194 ♂ 1809	Brazilian	Temporary and permanent teeth	Crown: enamel	Metric method: machine learning setup (CNN)	Yes	Women and men ≥ 15 years old were 87% and 84%, respectively. Women and men < 15 years old, the correct classifications were 80% and 83%, respectively.
Paknahad et al., 2022 [148]	200 cone beam computed tomography imaging: ♀100 ♂100	Iranian	Permanent maxillary and mandibular first molars	Crown: enamel, dentin and pulp chamber	Metric method: odontometry	Yes	84% (mandibular) and 77% (maxillary)
Lukacs et al., 2022 [149]	142: ♀81 ♂61	Modern Indonesian Malay Children	Temporary teeth	Crown: enamel	Metric method: odontometry	Yes	Sex dimorphism in Malay crown dimensions is low (1.1%) among Asians
Barraza Salcedo et al., 2022 [150]	162 skeletons: ♀62 ♂100	Modern Colombian Human Skeletal Collection of Legal	Permanent maxillary and mandib	Crown: enamel	Metric method: odontometry	Yes	82.1% (upper canines) and 77.8% (lower canines)

		Medicine in Bogotá DC, Colombia	ular canines				
Priyanka et al., 2022 [19]	170: ♀88 ♂82	Indian	Healthy permanent teeth	Crown: enamel	Biochemical method: LIBS	Yes	Female teeth samples seem to have higher trace elemental composition when compared to the males.
Vila-Blanco et al., 2022 [30]	1746 x-rays: ♀872 ♂874	Spanish	Permanent teeth	Crown: enamel-cementum junction	Metric method: deep learning specifically CNN	Yes	91.82%
Lukacs, 2022 [151]	Teeth from 37 studies: Indeterminate: 37	African (Nigerian and San), European (Polish), South Asian (India—Haryana), and Chinese (Taiwan) individuals	Temporary teeth	Crown: enamel	Metric method: odontometry	Yes	The most sexually dimorphic teeth in the deciduous dental arcade vary by dimension (MD, BL) and by jaw and include incisor, canine and molar tooth classes.

Abbreviations: n: total number of sample, ♀: women, ♂: men, N/A: Not applicable, MD: Mesio-distal, BL UM1: Bucco-lingual Upper Molar 1, MCI: Mandibular canine index, LRA: Logistic regression analysis, BL: bucco-lingual, MDW: Mesiodistal width, BLW: Buccolingual width, CL: clinical crown length, KNN: K-Nearest Neighbor, CCH: Clinical crown height, MMD: Maximum mesiodistal diameter, MBL: Maximum buccolingual width, CDA: coronal dentin area, Pr(F): probability, MZ: monozygotic, DZSS: dizygotic same-sex, ANN: Artificial neural network, CBCT: Cone Beam Computed Tomography, CT scan: Computed tomography scan, DNA: Deoxyribonucleic acid, GMA: Geometric morphometric analysis, LIBS: Laser induced breakdown spectroscopy, OPG: Orthopantomograms, PCR: Polymerase chain reaction, CNN: Convolutional Neural Networks.

Conflict of interest statement

The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Tatiana M. Herrera Escudero (TMHE): Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Resources, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing. **David Arboleda Toro (DAT):** Conceptualization, Data Curation, Supervision, Validation, Writing – Original Draft Preparation, Writing – Review & Editing. **Mónica T. Parada-Sanchez (MTPS):** Conceptualization, Data Curation, Formal Analysis,

Methodology, Project Administration, Resources, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing.

Highlights

- Canines and permanent molars are the most dimorphic teeth.
- Odontometry, a metric method, is the most employed to assess sexual dimorphism.
- 51% to 95.9% of sex estimation accuracy can be achieved when using odontometry.
- Biochemical methods are the most recommended for highly accurate sex estimation.
- Combining artificial intelligence and metric methods offers precise sex estimation.