

DENTAL MEASUREMENTS FOR SEX ESTIMATION - A SYSTEMATIC REVIEW

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ABSTRACT

Background: Methods for sex estimation through dental analysis can be classified into qualitative methods, which examine morphological traits, and quantitative methods, which employ objective techniques for sex classification, including, among others, discriminant functions. This study offers a comprehensive perspective on the efficacy of dental measurements in sex estimation. **Materials and methods:** PubMed, Web of Science, and Scopus databases were systematically searched according to PRISMA guidelines. After applying inclusion and exclusion criteria, 56 relevant articles were included in this review. **Results:** Canines exhibited the most pronounced sexual dimorphism both in adults and children, followed by molars and premolars, highlighting their significance in forensic investigations. **Conclusions:** Although dental methods for sex estimation are generally cost-effective and highly accurate, it is crucial to recognize the various limitations associated with these techniques.

Key words: sex estimation, dental measurements, sex estimation by teeth, dental sex estimation, systematic review, forensic anthropology

INTRODUCTION

The concern for dental health has always been important in the medical field. In our days we are often talking about comparative studies between the dental health systems (1), different aspects of the pathologies (2), clinical developments regarding the chosen treatment methods(3) or articles focused on a particular treatment techniques (4).

But dentition is significant in relation to the uniqueness of the human being. Some various qualitative and quantitative aspects of the teeth create connections with other related fields like forensic sciences.

Sex estimation using teeth has also been used in bioarchaeology and archaeology for the study of ancient populations. Dental sexual dimorphism may help determine the

demographic structure of past communities, allowing for the analysis of dietary habits and the impact of the environment on dental development(5). Looking at dental differences between hominins, especially between Homo sapiens and Neanderthals, has given important clues about how the species evolved and adapted in unique ways (6). It was also highlighted how studying dental features can help us understand the course of human evolution and the genetic and environmental influences that have shaped teeth over time (7). Additionally, the analysis of dental dimorphism provides insights into genetic diversity and the inheritance of dental traits in specific ethnic groups, making a significant contribution to identifying genetic mixing between populations (8,9).

From the forensic anthropological and archaeological investigations point of view, sex discrimination using skeletal remains is an essential first step. Even if various anatomical landmarks are potentially valuable for sex discrimination, the analysis is often complex and difficult, and the results have a high degree of uncertainty, which is often not enough for practical, forensic purposes, especially on partial skeletal remains (10,11).

By examining particular dental traits, like tooth size and form, or distances between various dental or oro-facial landmarks, researchers have shown some significant differences between males and females, which may aid, in variable degrees, for sex estimation (12–14).

Although there are many valuable systematic reviews in the field regarding the usefulness of teeth in sex estimation, most have not focused exclusively on analyzing dental measurements. For example, in 2017, Căpitaneanu *et al.* (12) performed a systematic review that analyzed methods across all skeletal characteristics, with less than half being on teeth (12). It included articles from 1978 to 2015, therefore not including recent methods, some of them based on modern, algorithmic, or machine learning-based approaches. Another scoping review conducted by Beschiu *et al.* (15) included articles that use both dental-based methods and cranial characteristics, highlighting the importance of dental characteristics in sex estimation and examining various techniques and methodologies for assessing dental dimorphism and its variability in human populations. Other authors added other indicators such as mandibular measurements (16), Barr bodies (17), DNA extraction from teeth (18) etc.

Our study aims to offer a comprehensive perspective on the studies performed using dental measurement for sex estimation as a

stand-alone method, thereby facilitating opportunities for further research in this domain and generating valuable data for other specialists in the field, enabling an application to larger sample populations and potentially contribute to developing a standardized formula applicable across broader geographical regions.

MATERIALS AND METHODS

This study was performed by following the PRISMA guidelines (19), and it was registered with the Open Science Framework with number registration: <https://doi.org/10.17605/OSF.IO/8ZYVB>. We used the following inclusion criteria: (1) studies that performed dental measurements for sex estimation (e.g.: crown dimensions, root measurements, whole-tooth analysis, dental indices, or intra-dental distances), (2) the ethnic groups were detailed, (3) published as original articles, (4) studies with or without abstracts, (5) studies on both permanent or deciduous dentition, (6) full-text articles available in the online databases, and (7) sex estimation done only using dental measurements. As exclusion criteria we used: (1) studies without human subjects, (2) review articles, letters, or case presentations, and (3) studies that didn't use teeth measurements as a stand-alone method, and (4) studies that used other methods (including DNA analysis).

Search method: We extracted articles from the following three databases: PubMed, Web of Science, and Scopus, using the following keywords: "sex estimation teeth", "sex determination odontology", "dental sex estimation methods", "dental sex determination methods", "dimorphism," "odontometric analysis," and "sex identification." We used "AND" as a boolean operator. The reference list for each article found was inspected for other potentially relevant studies to be included in this review.

References and abstracts (if available) were imported into the Paperpile software, and the deemed useful articles were downloaded for further analysis.

Data collection and analysis: Two reviewers separately extracted and included data in Excel data sheets for each study. The following information was summarized: name of the author, year of publication, number of subjects including gender, the age range in years, methodology used ("examined on", "examined part", and "method of measurement"), the origin of population, sex estimation of accuracy (%), if was available. We included studies that do not explicitly provide accuracy values but are justified by their significant contributions to the field of dental sex estimation, including the provision of baseline data on sexual dimorphism. We also considered discussion on population-specific variations and the introduction of

novel measurement methodologies.

Risk of bias: For each study, the risk of bias was evaluated separately by two reviewers. The process was conducted using the QUIPS Tool (20) to assess critical methodological quality domains, including study participation, attrition, prognostic factor measurement, outcome measurement, study confounding, and statistical analysis and reporting. Each domain was assigned a score based on the level of bias: 3 points for low risk of bias, 2 points for moderate risk, and 1 point for high risk. The scores across all domains were then aggregated to generate a total score for each study. Articles were subsequently categorized as follows: high quality (15–18 points), moderate quality (10–14 points), and low quality (<10 points). The final scores are presented in Table 1.

Table 1- Studies included in the review in chronological order

No	Name of the study	Number of subjects		Age range (years)	Examined on	Examined part	Origin population	Accuracy (%)	Risk of bias	Quality (points)	
		Females	Males								
1.	Acharya <i>et al.</i> , 2008 (21)	58	65	19-28	dental casts	all teeth (excluding M3)	Nepal	69,8-71,1	moderate	12	
2.	Kapkaila <i>et al.</i> , 2009 (22)	20	20	19-24	intraoral measures and intraoral periapical radiograph	mandibular canines	India		high	9	
3.	Khangura <i>et al.</i> , 2011 (23)	50	50	20-30	intraoral measures	maxillary incisors and canines	India	58-64	moderate	13	
4.	Sonika <i>et al.</i> , 2011	100	100	17-25	intraoral measures	permanent maxillary	India		low	14	

					and dental casts	first molar				
5.	Da Costa <i>et al.</i> , 2012(24)	26	25	18-29	dental casts	maxillary and mandible canines	Brazil		moderate	11
6.	Yuwanati <i>et al.</i> , 2012 (25)	50	50	17-21	dental casts	maxillary canines	India		low	15
7.	Deo Eboh, 2012 (26)	100	100	17-26	intraoral measures	maxillary first molar crown	South-Southern Nigeria		moderate	14
8.	Sharma <i>et al.</i> , 2013 (27)	100	100	12-21	dental casts	first and second maxillary molars	India	63	low	16
9.	Hosmani <i>et al.</i> , 2013 (28)	50		15-21	dental casts	mandibular canines	India		low	15
10.	Shireen <i>et al.</i> , 2014 (29)	300	300	17-25	dental casts	maxillary and mandibula canine	India		low	17
11.	Mujib <i>et al.</i> , 2014 (30)	50	50	17-25	dental casts	maxillary canine and maxillary molar	Karnataka, India	69-73	moderate	14
12.	Paramkusam <i>et al.</i> , 2014 (31)	60	60	20-30	dental casts and intraoral measures	mandibular right and left canines of both arches	India	73.3-76.6	moderate	10
13.	Singla <i>et al.</i> , 2015 (32)	50	50	17-25	dental casts and intraoral measures	maxillary first molar	Himachal, India		high	10
14.	Manchanda <i>et al.</i> , 2015 (33)	100	100	18-57	dental casts	all teeth (excluding M3)	India	47-84	high	9
15.	Narang <i>et al.</i> , 2015 (34)	210	200	20-40	dental casts	mandibular and maxillary molars	India	67,5-88	low	16
16.	Kiran <i>et al.</i> , 2015 (35)	60	60	15-40	intraoral measures and dental casts	left mandibular canines		72,5	moderate	13
17.	Agrawal <i>et al.</i> , 2015 (36)	50	50	17-25	dental casts	mandibular canine and mandibular first molar	Saudi Arabia		moderate	10

18.	Patil <i>et al.</i> , 2015 (37)	200 subjects		15-50	intraoral measures	mandibular and maxillary permanent molar and canine	India		moderate	11
19.	Nadendla <i>et al.</i> , 2016 (38)	60	60	20-30	intraoral measures and intraoral radiograph	mandibular left canines and mandibular inter-canine distance	India	54.2-94.2	moderate	10
20.	Banerjee <i>et al.</i> , 2016 (39)	50	50	19-23	dental casts	all teeth	India		moderate	13
21.	Rajaram <i>et al.</i> , 2016 (40)	100	100	18-25	dental casts and intraoral measures	mandibular canine	India		moderate	14
22.	Gupta <i>et al.</i> , 2016 (41)	53	53	18-25	dental casts	mandibular canines, maxillary incisors, premolar and molar	India	66,8-75,47	moderate	12
23.	Sravva <i>et al.</i> , 2016 (42)	60 subjects			dental casts	maxillary canines	India		moderate	11
24.	Shireen <i>et al.</i> , 2016 (43)	300	300	17-25	dental casts	permanent maxillary M1	Saudi Arabia	85	low	17
25.	Babu <i>et al.</i> , 2016 (44)	66	66	15-25	dental casts	all teeth (excluding M3)	South Kerala	88	high	12
26.	Litha <i>et al.</i> , 2017 (45)	250	250		dental casts	all teeth	India	99,8	low	18
27.	Singh <i>et al.</i> , 2017 (46)	250	250	3-5	dental casts	all teeth (excluding M3)	India		low	18
28.	Grewal <i>et al.</i> , 2017 (47)	100	100	20-30	intraoral measures	all teeth (excluding M3)	India	70-72	moderate	14
29.	Kumawat <i>et al.</i> , 2017 (48)	150	150	17-25	dental casts	mandibular canines	India	78-81,33	moderate	13
30.	Gandhi <i>et al.</i> , 2017 (49)	31	31	15-25	dental casts	mandibular canines	India	79,03	moderate	10

31.	Phulari <i>et al.</i> , 2017 (50)	100	100	15-25	dental casts	maxillary canines and first molar	India	50,5-82	high	11
32.	Tabasum <i>et al.</i> , 2017 (51)	53	57		teeth	maxillary and mandibular molar	India		high	11
33.	Patel <i>et al.</i> , 2017 (52)	200	200	20-40	intraoral measures	mandibular canines	Gandhinagar, India	78,8	moderate	14
34.	Jakhar <i>et al.</i> , 2017 (53)	50	50	18-35	dental casts	arch maxillary	India		moderate	12
35.	Ingaleshwar <i>et al.</i> , 2018 (54)	150 subjects		3-30	dental casts	canines	India		moderate	13
36.	Monalisa <i>et al.</i> , 2018 (55)	30	30		teeth	first premolar	India		high	10
37.	Govindaram <i>et al.</i> , 2018 (56)	500	500		OPG	maxillary and mandibular teeth from canine to first molar	Tamil, India		high	17
38.	Dash <i>et al.</i> , 2018 (57)	100	100	18-25	intraoral measures	all teeth (excluding M3)	India		moderate	12
39.	Shetty <i>et al.</i> , 2019 (58)	50	50	18-60	dental casts	canines	India		moderate	10
40.	Andrade <i>et al.</i> , 2019 (59)	116		13-70	CBCT	upper central incisor and one upper canine	Brazil		moderate	14
41.	Couto <i>et al.</i> , 2019 (60)	100	100	18-30	intraoral measures	central maxillary, lateral and canine incisors	Brazil	70,5	low	15
42.	Liu <i>et al.</i> , 2021 (61)	100	104	18-25	dental casts	incisors, premolars, and the first molars	China		low	15
43.	Soundarya <i>et al.</i> , 2021 (62)	50	50	20-50	dental casts	maxillary and mandibular incisors, canines and molars	India	81	low	15
44.	Oliva <i>et</i>	50	50		GMA and	first left	Italy	80-	low	15

	<i>al.</i> , 2021 (63)				ANN	upper premolar		84		
45.	Alanazi <i>et al.</i> , 2022 (64)	18	12	20- 45	dental casts	canines	Saudi Arabia		high	9
46.	Rakhshan <i>et al.</i> , 2022 (65)	662 subjects		1 2-35	dental casts and radiographs	all teeth (excluding M3)	Iran	69,9- 74	low	11
47.	Bianchi <i>et al.</i> , 2022 (66)	115	115	adult s subje cts	GMA and ANN	the maxillary first and second premolars and maxillary first molar	Italy	82	low	15
48.	Baral <i>et al.</i> , 2022 (67)	104		adult s subje cts	dental casts	maxillary canines	Nepal		hight	8
49.	Bu <i>et al.</i> , 2023 (68)	140	142	21- 59	CBCT	maxillary and mandibular canines and first molars	China	63,9- 82,8	low	16
50.	Dumanci <i>et al.</i> , 2023 (69)	147	155	11- 25	dental casts	upper and lower canines	Croatia	64,4- 82,8	low	16
51.	Wankhede <i>et al.</i> , 2023 (70)	50	50	20- 30	dental casts	maxillary canine, premolar, molar	India	75,6	moderate	10
52.	Valente <i>et al.</i> , 2024 (71)	34	30	3-12	dental casts	first and second deciduous upper molars and the lower deciduous canines	Portugal	36.7- 64.7	moderate	10
53.	Keşkek <i>et al.</i> , 2024 (72)	118	132	16- 63	CBCT	maxillary canine	Turkey		low	17
54.	Ghorban yjavadpo ur <i>et al.</i> , 2024 (73)	59	51	6-12	dental casts	maxillary and mandibular first and second primary molars			moderate	12
55.	Khan <i>et al.</i> , 2024 (74)	50	50	20- 35	dental casts	buccolingual parameters of all the	India	100 % for	hight	8

						teeth (except the third molars) of both jaws		men		
56.	Baban et Mohamad, 2024 (75)	98	98	adult subjects	intraoral scanner and AI	mandibular canine dimensions, mandibular intercanine distance and mandibular canine index		92.5	moderate	13

Abbreviations used: F-females; M-males; CBCT- Cone Beam Computer Tomography; OPG- Orthopantomogram; GMA-Dental Morphometric Geometric; ANN- artificial neural network.

RESULTS

Search synthesis: During the database research, we initially found 8526 studies. After excluding duplicates (5725 articles), we were left with 2801. Next, we applied the inclusion and exclusion criteria, leaving 56 studies for this review.

Most studies were performed in Asia, with 35 cases out of 56 being conducted in India. The size of the study groups varied between 50(28) and 500(43) subjects and the estimated accuracy was between 47(33)-99.8%(45). The most common method used was measuring on dental casts (23,25,27,28,31,33,37-43,45-49,51,55,57,58,62,70,74,76,77).

Five studies were performed in Europe, with subjects from Italy, Croatia, Portugal, and Turkey, aged between 11 and 63 years (63,66,69,71,72).

Most studies used only dental casts (31 articles), followed by intraoral measurements (only), Cone Beam Computed Tomography (CBCT) (3 articles), radiographic imaging (3 articles). Fifteen articles used the combination of these methods.

Sex estimation was mainly performed on permanent dentition (50), most articles evaluating the canines (31 articles), followed by molars (22 articles) and premolars (6 articles). Deciduous dentition was evaluated in 5 articles, most of them evaluating canines and molars.

The studies included in our research were published between 2009 and 2024, thus defining the time frame as consisting of articles published over approximately the last two decades.

Dental casts

Table 2 - Studies that used dental casts in chronological order

No study	Name of the study	Teeth Measured	Parameters Measured	Key Findings	Accuracy (%)
1.	Acharya et al., 2008 (21)	permanent dentition	crown area (BL x MD), crown module ((BL+MD)/2), crown index (100 x BL/MD)	the crown module is most useful for sex determination, with the highest accuracy in teeth 33,34,16,36.	80.6 for males, 81.1 for females

2.	Da Costa <i>et al.</i> , 2012(24)	maxillary and mandibular canines	MD, BL, MB-DL, DB-ML distances	significant differences between upper and lower canines being higher for males than females, and no statistical difference between right and left canines	not specified
3.	Yuwanati <i>et al.</i> , 2012 (25)	maxillary and mandibular canines	MD width	MD width is significantly greater in men, and the average MD width for maxillary canines is 8.02 mm (males) and 7.73 mm (females).	not specified
4.	Sharma <i>et al.</i> , 2013 (27)	maxillary first and second molars	BL, MD, MB-DL, crown widths and cusp diameters (hypocone, protocone, paracone, metacone)	upper molars show sexual dimorphism, with men's dimensions larger; protocone and hypocone are more specific for sex discrimination.	63
5.	Hosmani <i>et al.</i> , 2013 (28)	mandibular canines	MD, inter-canine arch width, mandibular Canine Index (MCI)	there were no statistically significant differences in MD or inter-canine arch width, but there were some slight trends in males having larger measurements.	standard MCI: 40 for males, 50 for females; Rao's MCI: 33.33 for males, 60 for females
6.	Shireen <i>et al.</i> , 2014 (29)	maxillary and mandibular canines	MD and BL	MD and BL dimensions were useful for sex determination, with more significant sexual dimorphism in BL (3.57%), significantly greater in males than females, compared to MD (1.92%).	not specified
7.	Mujib <i>et al.</i> , 2014 (30)	maxillary canines and molars	MBDL and DBML of crowns and cervical areas	MBDL measurements are more reliable for sex determination, with right molar cervical MBDL showing the most differences with accuracy rate being higher in females	71
8.	Manchanda <i>et al.</i> , 2015 (33)	maxillary and mandibular teeth	MBDL and DBML diameters	maxillary central incisors show the most dimorphic characteristics with dimensions bigger in males than females, and maxillary premolars are the least useful for sex discrimination.	MBDL: 55%-75% in males and 47-84% in females; DBML: 55%-80% in males and 65-80% in females
9.	Narang <i>et al.</i> , 2015 (34)	maxillary and mandibular first molars	MD and BL	MD dimension in mandibular first molar and BL/MD in maxillary first molar are useful for gender determination.	67.5-88
10.	Agrawal <i>et al.</i> , 2015 (36)	mandibular canines and first molar	MD and BL	MD dimensions of mandibular canines and first molars show significant sexual dimorphism, with more dimorphism in the left canine.	not specified
11.	Banerjee <i>et al.</i> , 2016 (39)	maxillary central incisor, canine,	MD, BL width, crown length	the maxillary permanent canine is the most dimorphic with bigger dimensions in males than females subjects, and the	not specified

		premolar and molar		cervical angle is inadequate for gender determination.	
12.	Gupta <i>et al.</i> , 2016 (41)	mandibular canines	mandibular canine index, Pont's index	mandibular canine index showed high accuracy for sex estimation: right mandibular canine index at 75.47%, left mandibular canine index at 66.98%.	66.98-75.47
13.	Stravya <i>et al.</i> , 2016 (42)	maxillary canines	MD using Garn and Lewis's formula for sexual dimorphism	maxillary canines exhibit significant dimorphism and larger MD width in the tribal population with bigger dimensions in males than females.	not specified
14.	Shireen <i>et al.</i> , 2016 (43)	maxillary first molars	MD and BL	BL dimensions are more dimorphic than MD, with significant dimorphism (3.57% for BL vs. 1.92% for MD), with bigger dimensions in males than females.	not specified
15.	Litha <i>et al.</i> , 2017 (45)	all upper teeth (except third molars)	MD and BL	significant size differences; males have larger teeth and achieved accuracy in gender classification comparable to pelvic or cranium methods.	99.8
16.	Singh <i>et al.</i> , 2017 (46)	maxillary and mandibular teeth	MD and BL crown dimensions	males had larger MD and BL dimensions for most teeth, except for maxillary central incisors, mandibular central incisors, and mandibular lateral incisors, where females had bigger dimensions.	not specified
17.	Kumawat <i>et al.</i> , 2017 (48)	mandibular canines	MD	mandibular canine index is effective for sex determination, with the mean distances larger in males than females.	73 (left canine)-75 (right canine)
18.	Gandhi <i>et al.</i> , 2017 (49)	mandibular canines	mandibular canine index	left mandibular canine exhibits higher sexual dimorphism (7.62%) than right (6.85%), with mean width higher in males than in females.	73.33% in males and 80% in females
19.	Phulari <i>et al.</i> , 2017 (50)	first maxillary molar and canine	MD, BL and intercanine distance	BL dimension of maxillary first molar most useful for sex determination (82% accuracy); Reverse dimorphism observed for maxillary canine (-26.8%); MD width of canine and CI was greater in females; the mean molar tooth dimensions are greater in 20. males as compared to females	82 for maxillary first molar
21.	Jakhar <i>et al.</i> , 2017 (53)	maxillary canines, first premolars,	width between maxillary canines, width between first maxillary premolars, depth of the palate, anteroposterior width of the palate	width between maxillary canines, width between first maxillary premolars, and palate depth are good indicators for sex determination; the anteroposterior width of the palate is less useful; mean values of maxillary inter-canine width, maxillary first inter-premolar width, palatal width were larger in males than females, in contrast with the mean values of anteroposterior width that are larger in females than males	not specified
22.	Ingaleswar <i>et al.</i> , 2018 (54)	maxillary and mandibular canines	maximum BL, MD diameter, clinical crown height (CCH)	significant differences in permanent canines for clinical crown height and MD diameter; there was no significant difference in CHH for mandibular	not specified

				canines in deciduous dentition; the dimensions of the right teeth were higher in males than females, except CCH from the upper and lower teeth	
23.	Shetty <i>et al.</i> , 2019 (58)	maxillary and mandibular canines	BL dimensions and inter-canine width	BL dimensions were significantly larger in males, with a statistically significant difference in mandibular inter-canine arch width.	not specified
24.	Liu <i>et al.</i> , 2021 (61)	maxillary teeth	MD, BL, intercanine distance, 25. crown area, 26. crown module, crown index, maxillary canine index	crown area and MD exhibit higher sexual dimorphism compared to other parameters, with greater dimensions in males than females.	69.2- 72
27.	Soundarya <i>et al.</i> , 2021 (62)	incisors, canines, and first molars	cervical-incisal length, MD, and labiolingual widths	cervical-incisal dimension of the mandibular first molar and MD of maxillary canine were most reliable for sex identification, with greater dimensions in males than females.	72.5% for cervical-incisal dimension of first mandibular molar
28.	Alanazi <i>et al.</i> , 2022 (64)	canines	MD, labiolingual, crown index, intercanine width	MD and crown index were higher for women, while labiolingual and intercanine widths were higher for men in Arabian subjects.	not specified
29.	Baral <i>et al.</i> , 2022 (67)	maxillary canines	MD width	minimal sexual dimorphism was observed in MD measurements for right and left maxillary canines, with slightly higher values in males than females.	not specified
30.	Dumanci <i>et al.</i> , 2023 (69)	maxillary and mandibular canines	MD and BL, distal accessory ridge	MD and BL dimensions of maxillary and mandibular canines showed significant sexual dimorphism, with greater dimensions in males than females; the distal accessory ridge had the highest accuracy	73.5% (distal accessory ridge - based formula)
31.	Wankhede <i>et al.</i> , 2023 (70)	canines, premolars, molars	MD and BL	men had greater average values for all combinations of tooth widths.	68-75.6
32.	Valente <i>et al.</i> , 2024 (71)	first and second deciduous molars, mandibular canines	MD, BL lengths of first and second upper molars and lower canines; presence of Carabelli's cusp	statistically significant differences in BL, with the mean measurements higher in males than females, Carabelli's cusp distinguished sexes for tooth 65.	64.1
33.	Ghorbany javadpour <i>et al.</i> , 2024 (73)	first and second deciduous molars	MD and BL	MD and BL dimensions of primary molars, especially mandibular molars, are useful for sex identification, with the first mandibular primary molar being the most reliable.	not specified
34.	Khan <i>et al.</i> , 2024 (74)	all teeth, excluding third molars	BL	16 out of 28 odontometric parameters were significantly larger in males.	not specified

Abbreviations used: MD-mesiodistal, BL-buccolingual, MBDL-mesiobuccal and distolingual, and DBML-distobuccal and mesiolingual.

Intraoral measurements**Table 3 - Studies that used intraoral measurements in chronological order**

No study	Name of the study	Teeth Measured	Parameters Measured	Key Findings	Accuracy (%)
1.	Khangura <i>et al.</i> , 2011 (23)	maxillary incisors and canines	MD	maxillary canines exhibit significant sexual dimorphism and are useful for sex estimation, with mean dimensions and SD larger in males than females.	64 for females, 58 for males
2.	Deo Eboh, 2012 (26)	maxillary first molars	MD and BL	statistically significant differences in all dimensions (higher in males than females) except for left maxillary MD width.	59.75 for MD, 56.25 for BL
3.	Patil <i>et al.</i> , 2015 (37)	maxillary and mandibular molars, canines	MD, crown width, intercanine distance	maxillary molars and intercanine distance show significant gender dimorphism, with higher dimensions in males than females.	not specified
4.	Grewal <i>et al.</i> , 2017 (47)	maxillary anterior teeth	arch length, intercanine width, intermolar width, combined width	all four maxillary odontometric parameters showed higher mean values in men.	71
5.	Patel RA <i>et al.</i> , 2017 (52)	mandibular canines	MD width of right and left canines, intercanine distance	mandibular canines exhibit sexual dimorphism with larger dimensions in men.	not specified
6.	Dash <i>et al.</i> , 2018 (57)	maxillary and mandibular teeth (excluding third molars)	MD and BL	male teeth dimensions larger than females, reverse dimorphism observed in several teeth.	not specified
7.	Couto <i>et al.</i> , 2019 (60)	maxillary right dentition	MD and incisor-cervical	significant sexual dimorphism in lateral incisor and canine measurements.	70.5

Abbreviations used: MD-mesiodistal and BL-buccolingual

Intraoral measurements and intraoral radiographs**Table 5 - Studies that used intraoral measurements and intraoral radiographs in chronological order**

No study	Name of the study	Teeth Measured	Parameters Measured	Key Findings	Accuracy (%)
1.	Sonika <i>et al.</i> , 2011 (77)	maxillary first molar	MD and BL	intraoral measurements had higher dimorphism than cast measurements; the right maxillary first molar was the most dimorphic (5.34% BL)	not specified
2.	Paramkusam <i>et al.</i> , 2014 (31).	maxillary and mandibular canines	MD width, intercanine distance, mandibular canine index	mandibular canine index more reliable than MD width for gender determination; it is recommended for forensic gender determination due to its accuracy, while the MD width	73.33–76.66

				can be used when only a single tooth or jaw fragment is available, although with lower reliability.	
3.	Singla <i>et al.</i> , 2015 (32)	maxillary first molar	MD and BL	population-specific calibration for gender determination; significant sexual dimorphism in mesiodistal dimensions in the Himachali, Indian population	95
4.	Kiran <i>et al.</i> , 2015 (35)	mandibular canines (left side)	MD width, discriminating canine index	discriminating canine index is a reliable alternative to mandibular Canine Index, higher accuracy for women	discriminating canine index: 68.3 (men), 76.7 (women)
5.	Rajaratnam BN <i>et al.</i> , 2016 (40)	mandibular canines and inter-canine distance	mesiodistal width, mandibular canine index	mandibular canines can be used to determine gender as an adjunctive method	73

Abbreviations used: MD-mesiodistal and BL-buccolingual

Intraoral measurements and intraoral radiographs

Table 5 - Studies that used intraoral measurements and intraoral radiographs

No study	Name of the study	Teeth Measured	Parameters Measured	Key Findings	Accuracy (%)
1.	Kapila <i>et al.</i> , 2011 (22)	mandibular canines	maximum MD width	the left mandibular canine had a greater sexual dimorphism (9.7%) compared to the right one (7.4%); the MD parameters were larger in males than females	not specified

Abbreviations used: MD-mesiodistal

Radiological investigations

Table 6 - Studies that used radiological investigations

No study	Name of the study	Teeth Measured	Parameters Measured	Key Findings	Accuracy (%)
1.	Govindaram <i>et al.</i> , 2018 (56)	maxillary and mandibular canine to first molar	root length	significant differences at teeth 13, 14, 15, 16, 23, 26, 33, 36, 43, and 46 (mesial) and significant statistical differences between men and women in root length	not specified
2.	Andrade <i>et al.</i> , 2019 (59)	maxillary incisors and canines		after Pearson's correlation, validation showed high accuracy of age estimation in individuals older than 35 years, but when it comes to sex estimation formulas, they are low when the age is unknown	upper canine: 28 (without knowing the age); the upper central incisor and

					canine: 94 (with age info)
3.	Bu <i>et al.</i> , 2023 (68)	left maxillary and mandibula r canines	volume, mesiodistal diameter	compared two formulas using left maxillary canines and left mandibular canines, and showed that the accuracy was higher than teeth volume and that the formula that used the left mandibular canines	up to 78.57%
4.	Keşkek <i>et al.</i> , 2024 (72)	maxillary canines	transverse and radial dimensions	established cut-off values for the transverse and radial dimensions of the maxillary canines can moderately accurately estimate sex when only teeth are available or in cases of uncertainty; volumetric measurements were found higher in males than females	not specified

Dental casts and radiographs

Table 7 - Studies that used dental casts and radiographs

No study	Name of the study	Teeth Measured	Parameters Measured	Key Findings	Accuracy (%)
1.	Rakhshan <i>et al.</i> , 2022 (65)	maxillary and mandibula r permanent teeth	MD, BL and Bolton indices	mandibular teeth were more dimorphic than the maxillary ones, and the most suitable ones proved to be the BL ones of the mandibular and maxillary canines, BL of the right and left mandibular canines and the right and left mandibular first premolars, as well as the MD of the right and left mandibular canines with anterior, posterior, and overall Bolton indices calculated to be 78.05, 105.42, and 91.87, respectively; higher dimensions for all the parameters in males than females	not specified

Abbreviations used: MD-mesiodistal and BL-buccolingual

Intraoral measurements and radiographs

Table 8 - Studies that used intraoral measurements and radiographs

No study	Name of the study	Teeth Measure d	Parameters Measured	Key Findings	Accurac y (%)
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1.	Nadenla <i>et al.</i> , 2016 (38)	mandibular left canines	MD, inter-canine distance	a notable statistically significant difference in the MD width and inter-canine distance was observed between males and females; the assessments demonstrated nearly equal effectiveness in determining gender, achieving an accuracy ranging from 55% to 75% for both males and females. Utilizing all the variables significantly enhanced the accuracy of gender determination, raising it to 94%.	55–75; 94
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Abbreviations used: MD-mesiodistal.

Tooth measurements

Table 9 - Studies that used tooth measurements

No study	Name of the study	Teeth Measured	Parameters Measured	Key Findings	Accuracy (%)
1.	Tabasum <i>et al.</i> , 2017 (51)	maxillary and mandibular molars	diagonal and linear dimensions of the crown and cemento-enamel junction; mesiodistal cervical diameter	molars are larger in men than in women. mesiodistal cervical diameter is the most reliable for sex determination, with ISD higher in mandibular molars.	66.9–70
2.	Monalisa <i>et al.</i> , 2018 (55)	mandibular and maxillary premolars	EA, CDA, ETA	EA and EAT are smaller in males, while CDA is smaller in females. First premolars are effective for sex estimation	not specified

Abbreviations used: MDCV-Mesiodistal Cervical Diameter, EA-enamel area, CDA-Coronal Dentin Area, ETA-Average Enamel Thickness

Novel approaches

Table 10 - Studies that used novel approaches for sex estimation

No study	Name of the study	Teeth Measured	Parameters Measured	Key Findings	Accuracy (%)
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1.	Oliva <i>et al.</i> , 2017 (63)	permanent premolars		combination of GMA and ANN for sex determination, showed that this combination demonstrated greater accuracy than other morphometric measurements	73 for men 90 for women
2.	Bianchi <i>et al.</i> , 2018 (66)	shape of crown of the maxillary posterior teeth		combination of GMA and ANN for sex determination, showed that this combination demonstrated greater accuracy than other morphometric measurements	68 for men 94 for women
3.	Baban et Mohammed, 2024 (75)	mandibular arch and canine		mean mandibular canine width had the highest sexual dimorphism with the area under the curve; the Gaussian Naive Bayes classifier demonstrated the highest testing accuracy among all machine learning models	92.5

Abbreviations used: GMA-geometric morphometric analysis, ANN-artificial neural

DISCUSSION

Odontometry, which can be used in forensic anthropology for sex estimation, relies on dental dimorphism. Modern methods use dental metrics computed using advanced algorithms, based on imaging like radiographs and CBCT. Machine learning helps create predictive models to identify dysmorphic dental characteristics. Additionally, robust statistical analyses underpin the reliability and accuracy of these methodologies (78–81).

This review highlights the role and limits of dental metrics in sex estimation; however, methodological discrepancies, population-specific biases, dependence on conventional measurement approaches, and the fact that not all the studies displayed the accuracy rate limit their broader applicability. Several factors, such as data collection, method variability, population differences, sample size, age range,

or statistical methods, may limit the usefulness or accuracy of sex estimation using dental measurements. Most studies were performed on young adults (aged 18-30-years-old). The main reason may be the need to obtain relevant data on complete, healthy dentures without cavities, carious pathology, or fractures and also to minimize potential that could have distorted the measurements (82). The studies were conducted on subjects with complete dentures to not mislead the results.

Depending on the rigor of the employed methodologies, the analyzed parameters, the number of subjects, or other variables, the accuracy of these methods varies from 33,3% (83) to 99,8% (45).

The emphasis on specific regional demographics, such as participants from South India or North India, limits a broader applicability of the results and underscores the

need for calibration and standardization tailored to specific groups (23,26).

As observed in several studies included in this review, canines exhibit the most pronounced sexual dimorphism among dental structures, as evidenced by MD and BL measurements, which makes them particularly valuable for forensic identification(22–24,29,36,38–

40,45,54,58,60,62,64,65,67,69,72).

Additionally, the Mandibular Canine Index is used for sex estimation, although its accuracy may vary considerably(28,35,41,48,52). As an alternative, the Discriminant Canine Index for mandibular canines could represent a more suitable option(53,61). Molars also exhibit sexual dimorphism, although it is less pronounced compared to that of canines(26,27,30,32,34,37,43,50,51,77).

Premolars show moderate sexual dimorphism, with size differences between sexes generally being less significant than those observed in canines and molars(21,47,55,65,70). Although studies conducted exclusively on the under-18 age group have been limited, they have demonstrated, as in the case of adults, that canines can be utilized for sex estimation(46,54). Innovative approaches can be highly useful; however, they require further calibration on larger population samples to be implemented on a broader scale(63,66,75).

Some authors who obtained contradictory results regarding the importance of crown measurements in sexual dimorphism. Acharya *et al.*(21) and Yuwanati *et al.*(25) underscore the importance of crown dimensions in sexual dimorphism. Acharya's investigation into the crown module index among young Nepalese adults demonstrated remarkable accuracy, exceeding 80%, particularly when utilizing premolars and molars. Contrastingly, Yuwanati's work on Central Indian populations identified significant mesiodistal width differences in maxillary and mandibular

canines, highlighting regional variation in dental dimensions.

Sharma *et al.*(27) and Valente *et al.*(71) expanded the scope to molars and deciduous teeth and provided further context. Sharma's examination of maxillary molars yielded a limited accuracy of 63% in sex determination, indicating a constrained utility of odontometric measures. Valente's research on Portuguese children emphasized significant sexual dimorphism in buccolingual dimensions of deciduous molars, though accuracy varied across dental features.

Studies on population-specific differences, such as those by Khan *et al.*(74) (North Indians) and Shetty *et al.*(58) (Navi Mumbai residents) revealed moderate accuracy in sex determination using buccolingual and inter-canine dimensions. They found statistical significance in inter-canine widths but considered buccolingual dimensions more reliable. Other authors further emphasized the role of geographic and population-specific factors. Agrawal *et al.*(36), Shireen *et al.*(29), and Babu *et al.*(44) further emphasized the role of geographic and population-specific factors. Agrawal highlighted mesiodistal and buccolingual variability in mandibular canines and molars among Indian populations. In a similar direction, Shireen *et al.*(43) and Babu *et al.*(44) found that the buccolingual measurements of molars were more reliable indicators of sexual dimorphism than mesiodistal measurements. The studies utilized various statistical methods to improve predictive accuracy. For instance, Mujib *et al.*(30) utilized discriminant analysis, achieving a 71% accuracy rate by measuring mesiobuccal-distolingual diameters, whereas Gupta *et al.*(41) applied regression models. Even with improvements in methodologies, differences in measurement methods and population characteristics often impede direct comparisons.

Litha *et al.*(45) achieved an impressive 99.8% accuracy in sex estimation by utilizing buccolingual dimensions, which prompts further investigation into the replicability of these findings across diverse populations. In contrast, Gandhi *et al.*(49) and Kumawat *et al.*(48) reported a more moderate average accuracy of approximately 80% when analyzing mandibular canine indices, underscoring their practical utility in sex determination. These findings align with broader trends emphasizing its prominence, although dimorphism levels varied by population.

A common constraint in various studies, such as those conducted by Baral *et al.*(67) and Jakhar *et al.*(53), is the dependence on small, regionally uniform samples limits their generalizability. Hosmani *et al.*(28) and Soundarya *et al.*(62) demonstrated reduced accuracy rates, highlighting the necessity for standardized measurement protocols and improved statistical methods.

Khangura *et al.*(23) and Eboh(26) find the significance of specific crown dimensions in sex determination but demonstrate contrasting results regarding accuracy and methodology. Khangura analyzed the mesiodistal distances of upper permanent incisors and canines in a North Indian cohort, identifying maxillary canines as reliable markers of sexual dimorphism. However, the reported accuracy rates of 64% for females and 58% for males indicate moderate efficacy. Eboh's work on maxillary first molars in a Nigerian population found statistically significant sexual dimorphism in most dimensions. However, accuracy rates were lower, with 59.75% for mesiodistal width and 56.25% for buccolingual width. These findings emphasize the variability in dental dimensions across populations and question the universal applicability of these measures. Grewal *et al.*(47) and Patel *et al.*(52) expanded the

analysis to include multifactorial parameters and larger samples. Grewal examined four maxillary odontometric parameters—arch length, inter-canine width, inter-premolar width, and the combined width of six anterior teeth—in 200 Indian subjects. Their study achieved a higher accuracy rate of 71%, suggesting that combining multiple measurements improves reliability. On the other hand, Patel's study focused the mandibular canine index in 400 individuals, highlighting its cost-effectiveness for more extensive studies. Couto *et al.*(60) used digital calipers on upper right dentition in a Brazilian population and found significant sexual dimorphism in lateral incisors and canines, achieving 70.5% accuracy for sex determination. While Patel's and Couto's studies featured key dental parameters, differing statistical methods hindered direct comparisons. Their results emphasize the need for broader validation. Common limitations across studies include reliance on small, homogeneous samples, as seen in Khangura *et al.*(23) and Grewal *et al.*(47) (Indian populations), Eboh(26) and Couto(60) (Nigerian and Brazilian subjects). These variations underscore the impact of geographic and genetic factors on dental dimorphism. Baral *et al.*(67) and Jakhar *et al.*(53) emphasized the necessity for larger, more diverse datasets.

Sonika *et al.*(77) compared the dimensions of maxillary first molars in 200 Indian subjects using intraoral and cast methods, finding larger sizes on the left side with dimorphism of 5.34% intraorally and 5.54% on casts. However, small differences and methodological biases affect broader applicability. Similarly, Singla *et al.*(32) studied Himachali maxillary first molars, achieving 95% reliability in mesiodistal measurements, but their findings are limited by a sample size of 100 subjects.

Kiran *et al.*(35) and Rajarathnam *et al.*(40) examined mandibular canine indices, with Kiran reporting 68.3% accuracy for men and 76.7% for women using the Discriminating Canine Index (DCI). Rajarathnam achieved 73% accuracy with intraoral and cast measurements. However, their reliance on a single parameter limits their application. Kapila *et al.*(22) combined intraoral measurements, casts, and radiographs, finding greater dimorphism in the left canine (9.7%) than the right (7.4%). Nevertheless, their small sample size of 40 subjects reduces statistical power.

Radiographic methodologies provide high precision in dental assessments, albeit with certain challenges. Research conducted by Govindaram *et al.*(56) on orthopantomograms from 1,000 Tamil subjects revealed significant sexual dimorphism in root lengths across specific teeth. However, it is crucial to acknowledge that these measurements may be influenced by various environmental and pathological variables, potentially affecting their reproducibility across different populations. Andrade *et al.*(59) demonstrated a high degree of accuracy (94%) for age estimation using cone-beam computed tomography (CBCT). However, the reliability of sex estimation in the absence of age data varied significantly, ranging from 28% to 94%. This underscores the critical interdependence between age and sex in predictive modeling frameworks.

Bu *et al.* showed that mesiodistal dimensions of left mandibular canines yield a sex determination accuracy of 78.57%, which is better than tooth volume measurements. This finding aligns with Keşkek *et al.*(72)'s research on maxillary canine dimensions using CBCT. Both studies highlight the potential of advanced imaging techniques while also noting issues related to cost and accessibility.

Rakhshan *et al.*(65) combined cast and

radiographic methods to analyze 331 Iranian subjects. They found greater dimorphism in mandibular teeth, particularly in the buccolingual dimensions of canines and first premolars. While comprehensive, the study's reliance on Bolton indices complicates its practical application.

Tabasum *et al.*(51) identified mesiodistal cervical diameter as a reliable variable for sex determination in molars, achieving 66.9–70% accuracy rates. Monalisa *et al.*(55) focused on enamel and dentin dimensions, noting moderate dimorphism. These findings reinforce the limitations of single-tooth metrics in achieving high accuracy.

Innovative methods like 3D digital scanning and artificial neural networks show promise. Liu *et al.*(61) achieved 69.2–72% accuracy using 3D scanning, while Oliva *et al.*(63) and Bianchi *et al.*(66) combined geometric morphometric analysis with artificial neural networks, achieving 90–94% accuracy for women and 73–68% for men. Despite their potential, these methods require validation in diverse populations and involve specialized technology.

Similar to our review, other studies were conducted, but unlike the other odonto-stomatological reviews, ours focused exclusively on studies targeting teeth without involving adjacent structures such as the cranial bones, sinuses, or palatal ridges, and used only dental measurements. Furthermore, our review is up-to-date, including articles published after 2020, thereby providing a comprehensive perspective on sex estimation using only teeth.

Despite significant progress in sex estimation using dental characteristics, to achieve universally reliable results remains a challenge. Litha *et al.*(45) set a high standard with their study on buccolingual teeth dimensions (excluding third molars), achieving nearly perfect accuracy. In contrast,

studies by Hosmani *et al.*(28) which focused on mesiodistal dimensions of mandibular canines and intercanine arch width, and Andrade *et al.*(59) which examined maxillary incisors and canines, reveal limitations associated with certain methodologies. Future research should capitalize on significant advancements in imaging technologies such as 3D scanning and integrate artificial intelligence for sex estimation based on dental characteristics.

Among the limitations is that differences in measurement techniques and equipment specifications can affect the reliability of the findings. Dental casts may not accurately represent intraoral conditions, and the angles used in radiographic images could lead to distortion, complicating the development of universal standards. Furthermore, variations in diet, nutrition, and oral practices have not been thoroughly examined and could play a role in the differences observed. Variations in sample characteristics, such as age, may affect the

comparability of results among populations (40,77,84). For that, numerous studies acknowledge that results may not apply to all populations because genetic factors can influence odontometric measurements. To improve accuracy and effectiveness, further studies should target key factors such as population-specific calibration and sample size while including more dental parameters.

CONCLUSIONS

Canines show significant sexual dimorphism, useful for forensic identification and sex estimation, with the Discriminant Canine Index being the most accurate. Investigators should be cautious when using dental measurements for sex estimation due to limitations from variable techniques, inaccuracies in casts, and influences from diet and genetics. These factors can result in inaccurate conclusions without proper population-specific calibration.

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