Sex assessment efficacy of permanent maxillary first molar cusp dimensions in Indians

ACHLA BHARTI YADAV, PUNNA V. ANGADI¹, SUMIT KUMAR YADAV²

Abstract

Background: The human first maxillary molar provides clues about evolution and is functionally important. It has four main cusps, and each cusp has an independent growth pattern and different evolutionary background. Though less explored, the analysis based on measurement of each cusp appears to be more meaningful biologically than conventional measurements of the whole crown. Aim: This study aimed to demonstrate the extent of sexual dimorphism in permanent maxillary first molar cusp diameters and their potential utility in sex prediction among Indians using logistic regression analysis (LRA). Materials and Methods: The mesiodistal and buccolingual (BL) crown diameters along with cusp dimensions and cusp indices of right maxillary first molar were measured in an Indian sample (149 males, 151 females; age range of 18–30 years). The possible sex dimorphism in these parameters was evaluated, and LRA was performed to ascertain their usefulness in sex prediction. Results: BL crown dimension and the hypocone (distolingual) cusp showed the highest sexual dimorphism. The combination of metacone and hypocone, i.e., distal cusp diameters among cusp parameters showed the highest accuracy (61.3%). While, on combining all the crown and cusp diameters together the overall accuracy was raised (64.3%). Conclusion: This study supports the ontogeny hypothesis suggesting that early-forming mesial cusps demonstrate less sexual variation as compared to subsequently formed distal cusps in the maxillary molar. Though the sex identification accuracy for cusp diameters of the permanent maxillary first molar in Indians is relatively moderate (≈61%), it can be used as an adjunct for sexing of adult Indians in forensic contexts.

Keywords: Cusp dimensions, first maxillary molar, Indians, logistic regression analysis, sex assessment

Introduction

Reconstruction of the biological profile from skeletal remains is essential to understand the demographics of the population and the identification of the individuals in forensic context. Sex assessment of skeletal remains is an indispensable step in the identification of an unknown person and has the advantage of dropping the pool of missing persons by half.[1,2] Anthropometric measurements of the skeleton and the comparison with existing standard data may help to differentiate between male and female remains. Pelvis and cranium are considered to be the most accurate indicators for sex assessment; however, these may not always be feasible in forensic or archeological contexts due to incomplete or fragmentary skeletal remains.[3,4] Teeth are an excellent material in living and nonliving populations for anthropological, genetic, odontologic, and forensic investigations as they are the hardest and chemically the most stable tissue in the body. Additionally, they are selectively preserved and fossilized, thereby providing for the best records for evolutionary change. Their durability in the face of fire and bacterial decomposition makes them invaluable for identification. Tooth morphology, crown size, and cusp size demonstrate distinctive features for males and females.[5,6] However, while determining the sex of an individual one criterion may not be characteristic, and analysis of as many criterions as possible is usually helpful in the majority of cases.[3]

Odontometric studies have played an important role in forensic and legal investigations, but most previous studies of tooth size were based on traditional measures of whole
Each cusp diameter was determined by measuring the diagonal distance from the central pit to the most distant point located along the outer margin of the crown corresponding to the relevant cusp. The same measurements were repeated on 30 randomly selected casts to test for possible intraobserver variation. Since the dimensions on right and left sides of the same dental arch are usually symmetrical, the right side measurements only were taken into consideration for this study. But if a tooth on the right side could not be measured because of absence, abnormality, heavy wear, or other reasons the corresponding tooth on the left side of the arch was measured. The cusp index quantifies cusp size relative to overall crown size. Therefore, cusp index for each cusp was calculated by using following formula:

\[
\text{Cusp index} = \frac{\text{Cusp diameter}}{\sqrt{\text{MD} \times \text{BL}}}
\]

**Materials and Methods**

**Selection criteria**

The present sample comprised of dentitions from 151 males and 149 females from India belonging to the age range of 18–30 years. The sample was limited to young adults to ensure that the teeth were intact in order to obtain optimal odontometric information. Subjects were from different states of India and belonged to a mixture of ethnic groups, religions, and castes so as to evaluate the sex differences in Indians in general. After obtaining verbal informed consent, maxillary alginate impressions were made, and casts were poured using the dental stone. Measurements were made on the casts only if the teeth were fully erupted and had no anomalies of crown morphology, and if the central pit of a tooth crown was clearly distinguishable.

**Odontometry**

MD and BL crown diameters and cusp diameters, i.e., paracone (MB), metacone (ML), and hypocone (DB) of permanent maxillary first molar were measured on the casts using a digital calliper with calibration of 0.01 mm (Mitutoyo, Japan). The MD dimension was defined as the greatest distance between the contact points on the proximal surfaces of the tooth crown. The BL dimension was defined as the greatest distance between the labial surface and the lingual surface of the tooth crown, measured with the calliper beaks held at right angles to the MD dimension. Each cusp diameter was determined by measuring the diagonal distance from the central pit to the most distant point located along the outer margin of the crown corresponding to the relevant cusp. The same measurements were repeated on 30 randomly selected casts to test for possible intraobserver variation. Since the dimensions on right and left sides of the same dental arch are usually symmetrical, the right side measurements only were taken into consideration for this study. But if a tooth on the right side could not be measured because of absence, abnormality, heavy wear, or other reasons the corresponding tooth on the left side of the arch was measured. The cusp index quantifies cusp size relative to overall crown size. Therefore, cusp index for each cusp was calculated by using following formula: [22]

Descriptive statistics, independent samples t-test, and calculation of percentage were done to evaluate the possible sex variation in crown, cusp diameters, and cusp indices of right permanent maxillary first molar while the intraobserver differences were tested using the paired t-test. LRA was performed on various measurements in different combinations to ascertain the usefulness of these parameters.
Results

Table 1 depicts the mean values of crown dimensions, cusp diameters, and cusp indices with their respective standard deviations for both males and females. We obtained statistically significant sexual dimorphism \( (P < 0.05) \) for all the measurements of crown and cusp except paracone (MB) cusp diameter with mean values for males exceeding those of females. Hypocone (DL) showed largest mean sexual dimorphism followed by metacone, paracone, and protocone. The percentage sexual dimorphism of cusp diameters was greatest in the metacone (DB) followed by hypocone (DL), and protocone (ML). In fact, metacone diameter was more dimorphic than MD and BL crown dimensions. It is evident that the cusp indices calculated using cusp and crown dimensions exhibited no significant sexual dimorphism between males and females \( (P > 0.05) \). Similarly, percentages of sexual dimorphism were also lesser as compared to crown and cusp diameters.

Tables 2 and 3 revealed the sex classification accuracy of LRA using various combinations of studied parameters. Overall accuracy was highest for combined crown dimensions (62.7%), however, among cusp parameters combination of metacone and hypocone (distal) cusp diameters (61.3%) showed the highest accuracy. However, on combining all the crown and cusp diameters together, the overall accuracy was raised to 64.3% with 66.9% accuracy in males and 61.7% accuracy in females. On using backward likelihood ratio overall accuracy was raised to 65.7% with 66.9% accuracy in males and 64.4% accuracy in females \( (y = 1.713 \text{ BL} + 1.245 \text{ DB} + 12.165 \text{ DL} − 18 \text{ MB} − 1.261 \text{ Distolingual cuspal index (DLI)} + 1.835 \text{ Mesiobuccal cuspal index (MBI)} − 22.819) \). Combinations of cusp indices with other parameters and among themselves revealed lesser accuracy (50.3–64%).

The paired \( t \)-test evaluating the potential intraobserver variation showed insignificant statistical differences for all the measurements except hypocone (DL) and paracone (MB) cusp diameter [Table 4].

Discussion

In forensic anthropological analysis, sex estimation is one of the most valuable steps in building the biological profile of skeletal remains. Among skeletal parameters, the pelvis and skull bones are considered to be the preferred indicators of sex with a high degree of reliability. It is frequently observed that during forensic and archeological investigations, these predictors are destroyed or fragmented or not available at all. As dentition is highly resistant to postmortem insults, may be the only materials available for sex determination in markedly decayed or skeletonized bodies. Various studies demonstrated high degrees of sexual dimorphism among odontometric parameters most commonly by using crown diameter, diagonal crown measurements, root length, etc. Since the cusps and ridges collectively reflect overall tooth size in molars and premolars, quantitative assays of cusp size should also reflect sexual dimorphism. Several studies explore the effectiveness of cusp diameters of maxillary molar in sex discrimination among various populations. The existence of sexual dimorphism in the size of the permanent teeth is contributed by inheritance and environmental factors. Therefore, magnitude and patterning of sexual dimorphism vary from population to population. This study provides the odontometric data based on cusp diameters of permanent maxillary first molar, which has been sparsely studied in Indian population.

Univariate analysis

The BL crown dimension of maxillary first molar showed the greatest sexual dimorphism among all the studied parameters. Similar results were obtained by many researchers working on cusp size sexual dimorphism in various populations including Indians. Garn et al. reported greater sexual dimorphism in BL dimensions. Recently, Prabhu and Acharya found mandibular first molar to be most dimorphic followed by canines and BL dimension of the maxillary first and second molars. The ontogeny of maxillary molar crown development could be reflected by the pattern of relative variation in cusp size. Consequently,
| Variables                  | Males          | Females          | Total          |
|---------------------------|----------------|------------------|----------------|
|                           | Number | Percentage | Number | Percentage | Number | Percentage |
| MD and BL (crown)         | 94/151  | 62.3       | 94/149  | 63.1       | 188/300 | 62.7       |
| MB and DB (buccal cusps)  | 88/151  | 58.9       | 90/149  | 60.4       | 179/300 | 59.7       |
| ML and DL (lingual cusps) | 91/151  | 60.3       | 84/149  | 56.4       | 175/300 | 58.3       |
| MB and ML (mesial cusps)  | 96/151  | 63.6       | 81/149  | 54.4       | 177/300 | 59         |
| DB and DL (distal cusps)  | 94/151  | 62.3       | 90/149  | 60.4       | 184/300 | 61.3       |
| All cusp diameters        | 91/151  | 60.9       | 90/149  | 60.4       | 182/300 | 60.7       |
| MD + MB + DB              | 88/151  | 58.3       | 85/149  | 57         | 173/300 | 57.7       |
| MD + ML + DL              | 91/151  | 60.3       | 87/149  | 58.4       | 178/300 | 59.3       |
| MD + MB + ML              | 92/151  | 60.9       | 78/149  | 52.3       | 170/300 | 56.7       |
| MD + DB + DL              | 91/151  | 60.3       | 90/149  | 60.4       | 181/300 | 60.3       |
| BL + MB + DB              | 99/151  | 65.6       | 90/149  | 60.4       | 189/300 | 63         |
| BL + ML + DL              | 92/151  | 60.9       | 95/149  | 63.8       | 187/300 | 62.3       |
| BL + MB + ML              | 96/151  | 63.6       | 93/149  | 62.4       | 189/300 | 63         |
| BL + DB + DL              | 99/151  | 65.6       | 89/149  | 59.7       | 188/300 | 62.7       |
| MD + BL + MB + DB         | 97/151  | 64.2       | 89/149  | 59.7       | 186/300 | 62         |
| MD + BL + ML + DL         | 96/151  | 63.6       | 91/149  | 61.1       | 187/300 | 62.3       |
| MD + BL + MB + ML         | 95/151  | 62.9       | 92/149  | 61.7       | 187/300 | 62.3       |
| MD + BL + DB + DL + MB + ML| 101/151 | 66.9      | 92/149  | 61.7       | 193/300 | 64.3       |

LRA: Logistic regression analysis; MD: Mesiodistal; BL: Buccolingual; DB: Distobuccal; ML: Mesiolingual; DL: Distolingual; MB: Mesiobuccal

| Variables                  | Males          | Females          | Total          |
|---------------------------|----------------|------------------|----------------|
|                           | Number | Percentage | Number | Percentage | Number | Percentage |
| Combinations of cusp indices |      |            |        |            |        |            |
| MBI + DBI                 | 89/151 | 58.9       | 78/149 | 52.3       | 167/300 | 55.7       |
| MLI + DLI                 | 85/151 | 56.3       | 73/149 | 49         | 158/300 | 52.7       |
| MBI + MLI                 | 80/151 | 53         | 71/149 | 47.7       | 151/300 | 50.3       |
| DBI + DLI                 | 86/151 | 57         | 76/149 | 51         | 162/300 | 54         |
| DBI + DLI + MBI + MLI     | 87/151 | 57.6       | 80/149 | 53.7       | 167/300 | 55.7       |
| Cusp diameters with their indices |     |            |        |            |        |            |
| MB + DB + MBI + DBI       | 88/151 | 58.3       | 90/149 | 60.4       | 178/300 | 59.3       |
| ML + DL + MLI + DLI       | 93/151 | 61.6       | 81/149 | 54.4       | 174/300 | 58         |
| MB + ML + MLI + MBI       | 85/151 | 56.3       | 85/149 | 57         | 170/300 | 56.7       |
| DB + DL + DBI + DLI       | 94/151 | 62.3       | 85/149 | 57         | 179/300 | 59.7       |
| MB + DB + ML + DL + MBI + DBI + MLI + DLI | 88/151 | 58.3 | 92/149 | 61.7 | 180/300 | 60 |
| Crown parameters with cusp indices |     |            |        |            |        |            |
| MD + MBI + DBI            | 89/151 | 58.9       | 83/149 | 55.7       | 172/300 | 57.3       |
| MD + MLI + DLI            | 86/151 | 57         | 78/149 | 52.3       | 164/300 | 54.7       |
| MD + MBI + MLI            | 89/151 | 58.9       | 82/149 | 55         | 171/300 | 57         |
| MD + DBI + DLI            | 89/151 | 58.9       | 78/149 | 52.3       | 167/300 | 55.7       |
| BL + MBI + DBI            | 98/151 | 64.9       | 90/149 | 60.4       | 188/300 | 62.7       |
| BL + MLI + DLI            | 96/151 | 63.6       | 92/149 | 61.7       | 188/300 | 62.7       |

Contd...
this study emphasized on the role of cusp diameter as sex predictor. All the cusp showed sexual dimorphism comparable to, even greater than crown dimensions, except paracone cusp diameter (MB). It has been suggested that teeth which form early in ontogeny should be least variable in sexual dimorphism as they form before significant changes take place in the hormones of males and females. This could be the reason that paracone cusp does not show any dimorphism as this is the first cusp to appear later in developmental pattern, and it is also the point of intersection of ridges and occlusal grooves. We measured the diagonal distance from the central pit to the most distant point located along the outer margin of the crown corresponding to the relevant cusp, and these measurements were considered as cusp diameters as done previously.[4] The hypocone showed the largest size followed by metacone, paracone, and protocone. This pattern of size variation did not match any other previous studies which could be attributed to the difference in ethnicity or in measuring techniques or the landmarks they have used. The hypocone cusp diameter defined by our way was showing larger than actual cusp size and protocone showed smaller than actual size. Further investigations are needed in this context to clarify the relation between cusp size, cusp diameter, and cusp area.

We also quantified the magnitude of sexual dimorphism using the percentage dimorphism formula proposed by Garn et al.[26] which revealed that among cusp diameters the metacone showed the highest percentage of sexual dimorphism followed by hypocone. This could be due to the later development of the distal cusp and thus displayed greater dimorphism as compared to mesial cusps.[23] In fact, metacone was more dimorphic than MD and BL crown dimensions. Similarly in Japanese and black South Africans, hypocone diameter was the second most dimorphic cusp dimension of a maxillary first molar.[4,22] All the cusps showed the greater value of dimorphism than MD crown diameter except paracone that showed the least dimorphism. This may be because the paracone is the first cusp to develop and consequently shows the least variation. There are some notable differences in the present and previous studies. For example in the present study, metacone displayed the highest percentage of sexual dimorphism, whereas in black South Africans it is least dimorphic with protocone showing the least dimorphism. This is in consensus with Acharya and Mainali who illustrated in their study that dental indices have no added utility in forensic sex assessment.[19] but they have considered a particular caste not a heterogeneous Indian sample as ours, which appears more

| Table 3: Contd... |
|-------------------|----------------|----------------|----------------|
| Variables         | Males          | Females        | Total          |
|                   | Number         | Percentage     | Number         | Percentage     | Number         | Percentage     |
| BL + MBI + MLI    | 95/151         | 62.9           | 93/149         | 62.4           | 188/300        | 62.7           |
| BL + DBI + DLI    | 96/151         | 63.6           | 90/149         | 60.4           | 186/300        | 62             |
| MD + BL + MBI + DBI | 98/151       | 64.9           | 90/149         | 60.4           | 188/300        | 62.7           |
| MD + BL + MLI + DLI | 96/151      | 63.6           | 93/149         | 62.4           | 189/300        | 63             |
| MD + BL + MBI + MLI | 95/151      | 62.9           | 93/149         | 62.4           | 188/300        | 62.7           |
| MD + BL + DBI + DLI | 97/151      | 64.2           | 90/149         | 60.4           | 187/300        | 62.3           |
| MD + BL + MBI + DBI + MLI + DLI | 100/151 | 66.2           | 92/149         | 61.7           | 192/300        | 64             |

LRA: Logistic regression analysis; MD: Mesiodistal; BL: Buccolingual; DB: Distobuccal; ML: Mesiolingual; DL: Distolingual; MB: Mesiobuccal; DBI: Dental biofilm index; DLI: Distolingual cuspal index; MBI: Mesiobuccal cuspal index; MLI: Mesiolingual cuspal index

| Table 4: Paired t-test for evaluating the intra-observer differences in crown and cusp measurements |
|-----------------------------------------------|----------------|----------------|----------------|----------------|
| Variable                                      | 1st observation | 2nd observation | Difference     | t-test         |
| MD                                            | 9.90±0.50       | 9.89±0.49       | 0.01±0.11      | 0.737          |
| BL                                            | 10.49±0.49      | 10.43±0.52      | 0.06±0.29      | 1.093          |
| DB                                            | 4.70±0.36       | 4.68±0.34       | 0.02±0.11      | 0.753          |
| DL                                            | 5.88±0.39       | 5.83±0.44       | 0.05±0.11      | 2.307          |
| MB                                            | 4.66±0.29       | 4.62±0.29       | 0.04±0.08      | 2.424          |
| ML                                            | 4.03±0.23       | 4.00±0.23       | 0.03±0.09      | 1.630          |

*Statistically significant at P<0.05. MD: Mesiodistal; BL: Buccolingual; DB: Distobuccal; ML: Mesiolingual; DL: Distolingual; MB: Mesiobuccal; SD: Standard deviation

In this study, central pit was considered as a landmark for assessing the size of individual cusps, as it divides the cuspal areas according to their developmental pattern, and it is also the point of intersection of ridges and occlusal grooves. We measured the diagonal distance from the central pit to the most distant point located along the outer margin of the crown corresponding to the relevant cusp, and these measurements were considered as cusp diameters as done previously.[4] The hypocone showed the largest size followed by metacone, paracone, and protocone. This pattern of size
representative. Similar to our findings, Agnihotri and Sikri in their study on Jat Sikhs displayed hypocone to be the most dimorphic followed by metacone and least dimorphism was demonstrated by paracone.\cite{18} Further, cusp indices in this study displayed the lesser value of percentage dimorphism similar to other studies.\cite{14, 19, 22}

**Logistic regression analysis**

Acharya *et al.* demonstrated that LRA superior to discriminant function analysis (DA) for odontometric sex prediction irrespective of complete or incomplete set of dentition as they found accuracy of 76–100% by LRA and 52–71% using DA.\cite{28} Considering it as a robust technique over any other analysis, we analyzed data using LRA to determine the efficacy for sex identification using various combinations [Tables 2 and 3]. Cusp diameter measurements of maxillary first molar provide low to moderate sex discrimination for different combinations with overall classification accuracies ranging between 50.3% and 64.3%. Lower accuracy was shown by combinations of cusp indices with other parameters and among themselves. Among cusp parameters combination of metacone and hypocone (distal) cusp diameters (61.3%) showed the highest accuracy. Our results support the ontogenetic hypothesis\cite{22} that later developed structures illustrate greater sexual dimorphism than earlier formed structures, so it can presumably be extended to crown components. Macaluso,\cite{4} used discriminant function analysis for black South Africans and provided overall classification accuracy from 58.3% to 73.6% and among cusp size, mesial and lingual cusps showed accuracy of 71.9% followed by distal cusps (68.9%).\cite{14} Various combinations of the crown with cusp diameter and crown with cusp indices showed moderate accuracy in sex identification. However, on combining all the crown and cusp diameters together, the overall accuracy was raised to 64.3% with males being identified accurately 66.9% and females 61.7%. This difference in accuracy between male and female could be due to the existence of an overlap between tooth dimensions as has been discussed extensively.\cite{14} Prabhu and Acharya demonstrated as sex classification accuracy of 75% among Indians using MD and BL measurements of all the teeth by applying stepwise discriminant function analysis.\cite{14} Whereas, a study conducted in our department on the large sample using MD and BL measurements of all the teeth showed 72% accuracy by applying LRA (unpublished data). In this study, use of backward likelihood ratio offered an overall accuracy of 65.7% with males showing the accuracy of 66.9% and females 64.4%. This is commendable from measurement of a single tooth as opposed to above-stated examples which used the MD and BL measurements of all teeth. The advantages of our study include the use of robust multivariate analysis, i.e., LRA not used previously for cusp dimensions, and measurements were taken directly on the cast as compared to previous studies.\cite{14, 23} where measurements were done on photographs.

**Observer variability**

The significant intraobserver variability in hypocone and paracone cusp diameter measured may be attributed to the smaller size of cusp as compared to crown and difficulty in measuring these dimensions. Studies have revealed a tendency for observer variation, indicating the possibility of systematic errors in certain tooth dimension.\cite{14} While even though, there is statistical significance ($P < 0.05$), the mean difference for hypocone and paracone was 0.05 and 0.04, respectively, which may not have practical significance.

**Conclusion**

The results of our study supported ontogeny hypothesis suggested that early-forming mesial cusps demonstrate less variation as compared to subsequently formed distal cusps in the maxillary molar. The sex identification accuracy for cusp diameters of the permanent maxillary first molar in Indians is relatively moderate (≈61%), but the simplicity and the fact that this accuracy is obtained with a single tooth is commendable. Furthermore, the derived regression formulae developed in this study have particular value in situations where the recovered skeletal material is highly fragmentary and when conventional dimensions of all teeth cannot be accurately recorded. Still, these can be used as adjunct to more reliable sex predictors rather than as the only criteria for sex assessment.

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**Conflicts of interest**

There are no conflicts of interest.

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