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

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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

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tooth crowns, i.e., mesiodistal (MD) and buccolingual (BL) crown diameters.[7-14] However, diagonal crown measurements, such as mesiobuccal (MB)-distolingual (DL) and distobuccal (DB)-mesiolingual (ML) diameters, and root lengths have also been tried by some other investigators.[15-18] Nevertheless, in highly fragmentary remains it is not possible to get all the teeth in intact form, sometimes broken or incomplete tooth crowns are the only available material for investigation purposes. Odontometric characteristics of each molar crown are thought to represent a cumulative effect of individual cusp dimensions,[19] so analysis based on measurement of each cusp promises to be more meaningful biologically than conventional measurements of the whole crown. Therefore, alternative metric analysis of part of the tooth including cusp areas, cusp diameters, etc., should be devised for determining sex. Recent sexual dimorphic investigations on cusp measurements of the permanent maxillary molars displayed greater accuracy as compared to conventional crown length and breadth dimensions.[4,19-23]

The human first maxillary molar provides information regarding evolution and is functionally important.[19] The size of molar as a whole reflects the combined size contributions of the individual cusps and ridges.[20] Crown of the maxillary molar teeth tends to have four cusps, referred to as the paracone (MB), protocone (ML), metacone (DB), and hypocone (DL).[21] Each cusp has an independent growth pattern and different evolutionary background.[22] The protocone is the largest in size, followed by the paracone, metacone, and hypocone. The paracone is the first cusp to appear, whereas the hypocone develops last in terms of both ontogeny and phylogeny. Teeth that develop later ontogenetically tend to be more variable in size, and it has been proposed that they display greater sexual dimorphism due to increasing differences in sex hormone production between males and females.[21] In black South Africans, an accuracy of 58.3–73.6% was achieved in discriminating sex by applying discriminant analysis and using photogrammetric methods on the maxillary molar cusp.[4] In Japanese population, paracone cusp diameter showed greatest percentage of sexual dimorphism (4.5%), in fact more than the BL (4.1%) and MD (3.4%) dimensions of crown, followed by hypocone (3.8%), metacone (2.8%), and protocone (0.8%) in maxillary first molar.[22] Studies on odontometric data related to cusp size in sex identification are largely unexplored in Indian population. The only other existing study has evaluated sex dimorphism in a particular caste (Jat Sikhs) from India.[19] Therefore, this preliminary investigation aimed to explore 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

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 (DB), protocone (ML), and hypocone (DL) 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.[4] 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,[14] 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]

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

Statistical analysis

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 in sex identification. The univariate and multivariate statistical analyses were performed on SPSS 11.0 software package (SPSS Inc., Chicago, IL, USA).

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 BL + 1.245 DB + 12.165 DL − 18 MB − 1.261 Distolingual cuspal index (DLI) + 1.835 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].

Table 1: Descriptive statistics with sexual dimorphism based upon crown dimensions, cusp diameters and cusp indices using Student's *t*-test and percentage dimorphism

Variables	Mean±SD		*t*	*P*	Percentage†
	Male	Female			
Crown dimensions					
MD	10.35±0.56	10.21±0.64	2.125	0.034*	1.37
BL	10.98±0.51	10.68±0.53	5.097	0.000*	2.81
Cusp diameter					
DB	4.69±0.37	4.54±0.35	3.550	0.000*	3.30
DL	5.97±0.45	5.82±0.40	3.123	0.002*	2.58
MB	4.55±0.30	4.49±0.32	1.494	0.136	1.34
ML	4.11±0.31	4.01±0.30	3.038	0.003*	2.50
Cusp indices					
DBI	44.02±3.40	43.57±3.42	1.150	0.251	1.03
DLI	56.05±3.81	55.84±3.77	0.492	0.623	0.38
MBI	42.68±2.80	43.09±2.91	1.229	0.220	−0.95
MLI	38.63±2.93	38.45±2.99	0.545	0.586	0.46

*Statistically significant at $P<0.05$; †Sexual dimorphism percentage=([male mean/female mean]−1)×100. SD: Standard deviation; 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

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.[14,24,25] Various studies demonstrated high degrees of sexual dimorphism among odontometric parameters most commonly by using crown diameter, diagonal crown measurements, root length, etc.[2,3,7,10-18] Since the cusps and ridges collectively reflect overall tooth size in molars and premolars, quantitative assays of cusp size should also reflect sexual dimorphism.[20] Several studies explore the effectiveness of cusp diameters of maxillary molar in sex discrimination among various populations.[4,19-23] 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.[26] 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[4,21,22] including Indians.[19] Garn *et al.* reported greater sexual dimorphism in BL dimensions.[26] 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.[14] The ontogeny of maxillary molar crown development could be reflected by the pattern of relative variation in cusp size. Consequently,

Table 2: Sex classification accuracy using LRA on various combinations of crown and cusp dimensions

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	97/151	64.2	90/149	60.4	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

Table 3: Sex classification accuracy using LRA on various combinations of cusp indices along with combinations with cusp diameters and crown dimensions

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 + MBI + MLI	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...

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	Mean±SD			*t*-test	*P*
	1st observation	2nd observation	Difference		
MD	9.90±0.50	9.89±0.49	0.01±0.11	0.737	0.468
BL	10.49±0.49	10.43±0.52	0.06±0.29	1.093	0.285
DB	4.70±0.36	4.68±0.34	0.02±0.11	0.753	0.459
DL	5.88±0.39	5.83±0.44	0.05±0.11	2.307	0.030*
MB	4.66±0.29	4.62±0.29	0.04±0.08	2.424	0.023*
ML	4.03±0.23	4.00±0.23	0.03±0.09	1.630	0.116

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

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 both ontogenetically and phylogenetically.[22] Cusp indices calculated using cusp and crown dimensions exhibited no sexual 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.[27]

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 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.[22] 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 highest dimorphism.[4] In Japanese population, the paracone showed the least and hypocone showed the highest sexual dimorphism for maxillary second molar, whereas, in maxillary first molar, protocone showed the least dimorphism, followed by the metacone, hypocone, and paracone, i.e., the earliest formed paracone showed the greatest sexual dimorphism.[22] This apparent difference in the pattern of sexual dimorphism is likely due to a combination of environmental and genetic factors[26] emphasizing that dental sexual dimorphism is population specific.[4] To the best of our knowledge, only one study has been done in India regarding cusp size by Agnihotri and Sikri[19] but they have considered a particular caste not a heterogeneous Indian sample as ours, which appears more 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.[19] Further, cusp indices in this study displayed the lesser value of percentage dimorphism similar to other studies.[4,19,22]

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.[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[22] that later developed structures illustrate greater sexual dimorphism than earlier formed structures, so it can presumably be extended to crown components. Macaluso,[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%).[4] 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.[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.[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.[4,21] 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.[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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