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Original Article

Anatomy Section

Morphological Variations of the Coronoid Process of Dry Adult Human Mandibles: A Cross-sectional Study from the Vadodara Region of Gujarat, India

JAHNAVI NATH[1], HETAL VAISHNANI[2], BHOOPESH N RAJA[3], ADITYA A MUSALE[4]

ABSTRACT

Introduction: The mandible bears two superior projections from its ramus- the coronoid and condylar processes. The coronoid process gives insertion to the temporalis muscle and shows considerable morphological diversity. Knowledge of its shape and morphometry is important for maxillofacial surgeons, radiologists, anthropologists and forensic experts, particularly as the process serves as a donor site for autogenous bone grafts in orbital floor reconstruction, alveolar defect repair and sinus augmentation.

Aim: To study the morphological variations of the coronoid process in dry adult human mandibles of the Vadodara region of Gujarat, India, with morphometric measurements and gender-wise comparison.

Materials and Methods: A cross-sectional study was carried out in the Department of Anatomy, Smt. BK Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth Deemed to be University, Piparia, Vadodara, Gujarat, India, over a period of six months, from October 2025 to March 2026. Thirty dry adult human mandibles (60 sides; 16 male, 14 female by non metric sexing) were examined. Coronoid shape was classified as triangular, hook-shaped or rounded. The base (AB), anterior arm (AC), posterior arm (BC) and height (CD), together with the inter-coronoid distance, were measured bilaterally using Vernier callipers. Data were analysed with the unpaired Student's t-test or Mann-Whitney U test; Chi-square was used for shape-gender association. A p-value <0.05 was considered significant.

Results: The triangular variant was the most common (32/60 sides, 53.33%), followed by hook-shaped (17 sides, 28.33%) and rounded (11 sides, 18.33%). The mean inter-coronoid distance was greater in males (85.93±3.92 mm) than in females (79.26±4.96 mm; p=0.0005). Male mandibles showed higher means for all linear parameters on both sides, reaching statistical significance for the right base (31.80±1.91 vs 29.49±2.36 mm; p=0.003), left base (32.00±2.37 vs 29.09±1.41 mm; p<0.001) and left posterior arm (p=0.037). A significant gender-shape association was observed (χ^2=8.98, p=0.011), with hook-shaped predominant in males (43.8%) and triangular in females (71.4%).

Conclusion: The coronoid process in the Vadodara region exhibits significant morphological diversity and sexual dimorphism, with the triangular shape predominating overall. Gender-related differences in shape and base dimensions may assist maxillofacial surgeons in graft harvesting and forensic experts in sex determination.

Keywords: Anthropometry, Sexual dimorphism, Temporalis muscle, Vernier calliper

INTRODUCTION

The mandible is regarded as the strongest and largest bone of the facial skeleton. It is formed by the union of two halves at the symphysis menti and each half consists of a horizontal body and a vertical ramus [1]. Two processes project superiorly from the upper border of the ramus - the coronoid process anteriorly and the condylar process posteriorly - separated by a concavity known as the mandibular notch or sigmoid notch [2,3].

The term "coronoid" is derived from the Greek word meaning "like a crown" [1]. It is a thin, flattened, triangular projection that arises from the anterior part of the upper border of the ramus and is directed upwards and slightly forwards. The medial surface and margins of the coronoid process provide the principal insertion for the temporalis muscle, while its lateral surface offers insertion to a portion of the anterior fibres of the masseter muscle [3]. Because the temporalis tendon anchors the coronoid process firmly, isolated fractures of the process are uncommon and seldom require intervention unless associated with impingement on the zygomatic arch [2].

Several investigators have demonstrated that the coronoid process shows considerable morphological variation across populations and between sexes. The most widely accepted classification describes three morphological variants- triangular, hook-shaped and rounded (blunt)- in place of the classical "crow's beak" pattern [4,5]. The relative frequency of these variants differs substantially between geographic populations and is thought to reflect the interplay between genetic constitution, masticatory load, dietary habits, hormonal influences and the functional development of the temporalis muscle [6,7]. The morphology of the coronoid process has therefore been proposed as an evolutionary marker of anthropological significance and an adjunct criterion in forensic sex determination [7,8].

Clinically, the coronoid process has acquired renewed importance in oral and maxillofacial surgery. Autogenous bone grafts have traditionally been harvested from the ilium, ribs or calvaria, each carrying its own donor-site morbidity. In contrast, a coronoid process graft can be raised intra-orally with minimal morbidity, no visible cutaneous scar, reduced operating time and shorter hospital stay [5,9]. Coronoid grafts have been used successfully for alveolar defect repair, orbital floor reconstruction, maxillary and sinus augmentation and repair of non union mandibular fractures [5,10]. In addition, coronoidectomy is a well-established step in access osteotomies for infratemporal fossa surgery and in the management of coronoid hyperplasia causing restricted mouth opening [11,12].

Although morphological and morphometric studies of the coronoid process have been reported from various Indian [7,13,15], other

South-Asian [4,15] and overseas [16] populations, comparable data from the Gujarati population of the Vadodara region are scanty. The present study was therefore designed to observe and classify the shape of the coronoid process in dry adult human mandibles of the Vadodara region, to record morphometric variation in the base, anterior arm, posterior arm, height and inter-coronoid distance, and to compare these parameters between male and female specimens. The findings are intended to add to the existing body of regional anatomical data and to provide a practical reference for maxillofacial surgeons, radiologists, anthropologists and forensic experts working in Western India.

MATERIALS AND METHODS

A cross-sectional study was carried out in the Department of Anatomy, Smt BK Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth Deemed to be University, Piparia, Vadodara, Gujarat, India, over a period of six months, from October 2025 to March 2026, after obtaining approval from the Sumandeep Vidyapeeth Institutional Ethics Committee (SVIEC) (IEC Approval No.: SVIEC/ON/MEDI/SRP/March/26/135). The study was performed in accordance with the principles of the Declaration of Helsinki (2013 revision). As the study used dry bony specimens from the departmental osteology collection, individual informed consent was not applicable.

Inclusion criteria: (i) Dry, fully ossified, adult human mandibles with both coronoid processes intact and free from gross pathology; (ii) specimens allowing clear identification of reference landmarks for the defined morphometric measurements were included.

Exclusion criteria: (i) Mandibles with fractures, erosions, deformities or post-mortem damage involving the ramus or either coronoid process; (ii) edentulous mandibles with gross alveolar resorption precluding reliable non metric sexing; (iii) juvenile mandibles with unerupted third molars or incomplete ossification.

Sample size: Thirty intact dry adult human mandibles (n=30; 60 sides) in which both coronoid processes were preserved, were obtained from the osteology collection. Sampling was purposive. No a priori statistical sample-size calculation was performed; instead, all intact dry adult mandibles in the departmental osteology collection that satisfied the inclusion criteria were enrolled by complete enumeration, yielding a convenience sample of thirty mandibles (sixty sides). This sample size is comparable to those of several earlier osteological and radiographic studies of the coronoid process [5,14,17]. The gender of each mandible was determined by four non metric cranial-osteological criteria, in accordance with established osteological and forensic descriptions [8,18,19]: (i) overall heaviness and robustness of the bone- male mandibles are heavier, larger and more robust with thicker cortical bone, whereas female mandibles are comparatively lighter, smaller and gracile; (ii) shape of the chin- males show a square, broad mental eminence (mentum quadratum), while females present a more rounded or pointed and less prominent chin; (iii) prominence and eversion of the gonial angle- in males the angle is more acute (typically <125°) with marked lateral eversion of the gonion, whereas in females it is wider (typically >125°) and the gonial region is smooth and non everted; and (iv) general ruggedness of the muscular markings- impressions for the masseter and medial pterygoid muscles are coarse and pronounced in males but faint and smooth in females. Application of these criteria yielded 16 male and 14 female specimens.

Study Procedure

Each mandible was placed on a flat horizontal surface with the occlusal plane parallel to the ground. The shape of both coronoid processes was observed from the lateral aspect and classified, following Hossain SMA et al., and Prajapati VP et al., into three morphological types: (i) triangular, (ii) hook-shaped, and (iii) rounded (blunt) [4,5]. Classification was performed independently by two observers; disagreements were resolved by joint re-examination to minimise observer bias.

Morphometric measurements were carried out on each coronoid process using a digital Vernier calliper calibrated to 0.01 mm. Measurements were taken twice on separate occasions at least 48 hours apart, and the mean of the two readings was recorded to reduce observer error. Four parameters were recorded on each side, defined as follows:

- A point on the lowest part of the mandibular notch was identified and a horizontal line projected through it. At the same height, the points-A (anterior border) and B (posterior border) of the coronoid process were marked. Line AB defined the base of the process.
- Point-C was marked on the tip of the coronoid process. The triangle ABC was thus completed, where AC represented the anterior arm and BC the posterior arm.
- A perpendicular dropped from C to AB met the base at point-D. Line CD represented the height of the coronoid process.
- The inter-coronoid distance was measured directly between the tips of the right and left coronoid processes using a sliding calliper.

All readings were recorded in millimetres and tabulated side-wise and gender-wise. Representative morphological variants, measurement landmarks and inter-coronoid distance are illustrated in [Table/Fig-1-3].

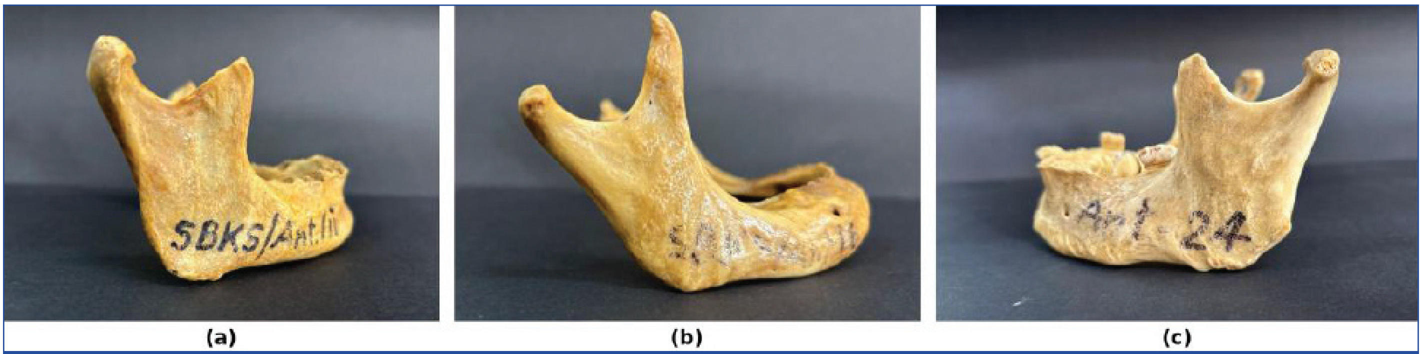
STATISTICAL ANALYSIS

Data were entered into a Microsoft Excel 2019 master chart and analysed using IBM Statistical Package for Social Sciences (SPSS) Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequencies and percentages; continuous variables as mean±Standard Deviation (SD). Normality was assessed using the Shapiro-Wilk test and homogeneity of variance using Levene's test. Male–female differences were compared using the unpaired Student's t-test, Welch's t-test or the Mann-Whitney U test as appropriate. Bilateral symmetry was tested using the paired t-test or the Wilcoxon signed-rank test. The association between gender and coronoid shape was evaluated by Pearson's Chi-square test with Cramér's V as the effect size. A p-value <0.05 was considered statistically significant and <0.01 highly significant. Because both coronoid processes from each mandible were included, the 60 sides do not represent fully independent observations; the chi-square test of the gender-shape association was therefore interpreted with caution, and the dependency is addressed in the study limitations.

RESULTS

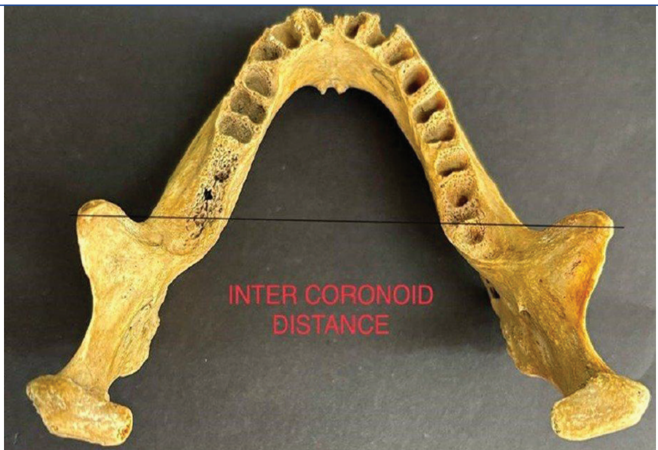
Among the 60 coronoid processes examined (30 mandibles, bilateral), the triangular shape was the predominant variant, observed in 32 sides (53.33%), followed by the hook-shaped variant in 17 sides (28.33%) and the rounded variant in 11 sides (18.33%). The distribution was broadly similar on the right and left sides, with triangular processes in 17 and 15 sides, hook-shaped in eight and nine sides, and rounded in five and six sides, respectively [Table/Fig-4].

When the shape distribution was stratified by gender (pooling both sides), a significant association was observed between gender and coronoid shape. Hook-shaped processes were more frequent in male mandibles (14 of 32 sides, 43.75%) than in female mandibles (3 of 28 sides, 10.71%), whereas triangular processes were proportionately more frequent in females (20 of 28 sides, 71.43%) than in males (12 of 32 sides, 37.50%). The Pearson's Chi-square test confirmed this association as statistically significant (χ^2=8.98, df=2, p=0.011; Cramér's V=0.39, reflecting a medium-to-large effect) [Table/Fig-5].



[Table/Fig-1]: Representative dry mandibles showing the three morphological types of the coronoid process- (a) triangular, (b) hook-shaped; and (c) rounded.

[Table/Fig-2]: Measurement of the coronoid process on a dry mandible showing the base (AB), anterior arm (AC), posterior arm (BC) and height (CD). Point A (anterior border) and point B (posterior border) define the base; point C is the tip; point D is the foot of the perpendicular dropped from C to the base AB.



[Table/Fig-3]: Superior view of the mandible showing the inter-coronoid distance measured between the tips of the right and left coronoid processes.

Shape of process	Right-side	Left-side	n (%)
Triangular	17	15	32 (53.33)
Hook-shaped	8	9	17 (28.33)
Rounded	5	6	11 (18.33)
Total	30	30	60 (100.00)

[Table/Fig-4]: Incidence of different morphological variants of the coronoid process in 30 mandibles (60 sides).

Shapes	Male sides n (%)	Female sides n (%)
Triangular	12 (37.50)	20 (71.43)
Hook-shaped	14 (43.75)	3 (10.71)
Rounded	6 (18.75)	5 (17.86)
Total	32 (100.00)	28 (100.00)

[Table/Fig-5]: Gender-wise distribution of coronoid process shapes (χ^2=8.98, df=2, p=0.011; Cramér's V=0.39).

The mean inter-coronoid distance was greater in males than in females, at 85.93±3.92 mm (range 78.80 - 92.10 mm) and 79.26±4.96 mm (range 70.01 - 84.60 mm), respectively. The difference was highly significant on the Mann-Whitney U test (U=196.0, p=0.0005; effect-size r=0.64), which confirms inter-coronoid distance as a sexually dimorphic dimension in this population [Table/Fig-6].

Gender	n	Mean±SD (mm)	Range (mm)	p-value
Male	16	85.93±3.92	78.80 – 92.10	0.0005***
Female	14	79.26±4.96	70.01 – 84.60	

[Table/Fig-6]: Mean inter-coronoid distance - gender-wise comparison (Mann-Whitney U test). *** p < 0.001.

Gender-wise comparison of the four morphometric parameters of the coronoid process showed that mean values were consistently greater in male than in female mandibles on both sides. On the right-side, the mean base length was 31.80±1.91 mm in males and 29.49±2.36 mm in females (p=0.003), while differences in the anterior arm, posterior arm and height did not reach statistical significance (p=0.269, 0.104 and 0.140, respectively) despite higher mean values in males [Table/Fig-7]. On the left-side, the male-female difference was statistically significant for the base (32.00±2.37 vs 29.09±1.41 mm; p<0.001) and the posterior arm (15.18±2.59 vs 13.40±1.68 mm; p=0.037), with non significant trends favouring males for the anterior arm (p=0.128) and height (p=0.252) [Table/Fig-8].

Measurement	Male (n=16) Mean±SD (mm)	Female (n=14) Mean±SD (mm)	p-value
Base (AB)	31.80±1.91	29.49±2.36	0.003 **
Anterior arm (AC)	13.93±2.32	13.17±1.30	0.269
Posterior arm (BC)	15.25±2.67	13.87±1.63	0.104
Height (CD)	12.14±2.78	11.00±1.45	0.140

[Table/Fig-7]: Morphometric parameters of the right coronoid process (mean±SD, in mm). **significant

Measurement	Male (n=16) Mean±SD (mm)	Female (n=14) Mean±SD (mm)	p-value
Base (AB)	32.00±2.37	29.09±1.41	<0.001***
Anterior arm (AC)	14.24±2.95	12.90±1.57	0.128 ns
Posterior arm (BC)	15.18±2.59	13.40±1.68	0.037*
Height (CD)	12.48±2.68	11.34±1.42	0.252 ns

[Table/Fig-8]: Morphometric parameters of the left coronoid process (mean±SD, in mm). ***p<0.001; *p<0.05; ns=not significant.

When the right and left coronoid processes were compared within the same set of specimens, no parameter showed a statistically significant side-to-side difference. The base length averaged 30.72±2.40 mm on the right and 30.64±2.44 mm on the left (p=0.897), the anterior arm 13.58±1.92 mm versus 13.62±2.47 mm (p=0.916), the posterior arm 14.60±2.32 mm versus 14.35±2.36 mm (p=0.372), and the height 11.61±2.29 mm versus 11.95±2.22 mm (p=0.657). These findings confirm bilateral symmetry of coronoid morphometry in the present sample.

DISCUSSION

The present observational cross-sectional study examined 30 dry adult human mandibles (60 sides) from the Vadodara region of

Gujarat and documented the morphological diversity of the coronoid process alongside its morphometric parameters, with side-wise and sex-wise comparison. The triangular shape emerged as the commonest variant (53.33%), followed by hook-shaped (28.33%) and rounded (18.33%). Male mandibles demonstrated higher mean values than female mandibles for all linear parameters and the inter-coronoid distance, and a statistically significant association between gender and coronoid shape was detected. These findings substantiate both the morphological heterogeneity and the sexual dimorphism of the coronoid process reported in earlier literature.

A direct comparison of the coronoid shape distribution in the present study with that of previously published series is summarised in [Table/Fig-9] [4,5,13,14,20,21]. The predominance of the triangular variant observed here is broadly congruent with Isaac B and Holla SJ, who in an Indian dry-bone study reported triangular 49%, hook-shaped 27.4% and rounded 22.6% [15]. Kiran C et al., in an Eastern-Indian (Bihar) series, likewise found the triangular form commonest, with triangular 57.6%, rounded 28.3% and hook-shaped 14.1% [13]. Prajapati VP et al., in a Gujarati population of 120 dry mandibles, observed triangular 54.17%, hook-shaped 21.25% and rounded 24.58% [5]- a distribution virtually identical to our triangular frequency. Quadri A and Ahmed HST, in 200 South Indian subjects, reported an even higher triangular predominance of 67% [20], and comparable findings have been documented in other recent Indian osteological and radiographic series [21-23].

Author (year)	Place of study	Triangular (%)	Hook-shaped (%)	Rounded (%)
Isaac B and Holla SJ [14] (2001)	Maharashtra	49.00	27.40	22.60
Quadri A and Ahmed HST (2016) [20]	South India	67.00	30.00	03.00
Prajapati VP et al., [5] (2011)	Gujarat, India	54.17	21.25	24.58
Hossain SMA et al., [4] (2011)	Bangladesh	29.65	45.00	25.35
Kiran C et al., (2021) [13]	Bihar, India	57.60	14.10	28.30
Sinha U et al., (2025) [21]	Jharkhand, India	47.50	17.50	35.00
Present study (2026)	Vadodara, Gujarat, India	53.33	28.33	18.33

[Table/Fig-9]: Comparison of the incidence of morphological variants of the coronoid process in the present study with previously published studies (percentages) [4,5,13,14,20,21].

By contrast, Hossain SMA et al., in a Bangladeshi population, reported a reversed pattern, with the hook-shaped variant in 45%, the rounded in 25.35% and the triangular in only 29.65% [4]. Such inter-population variability likely reflects the combined influence of genetic background, dietary consistency, masticatory load and the developmental pull of the temporalis muscle - factors emphasised in the morphometric analysis of Manoj M et al., and in gender-based studies of the coronoid process by Basso IB et al., [24,25].

A notable finding is the statistically significant association between gender and coronoid shape (χ^2=8.98, p=0.011; Cramér's V=0.39). Hook-shaped processes were more common in male mandibles (43.75%), whereas triangular processes strongly predominated in female mandibles (71.43%). Gender-related differences in coronoid shape have been reported by several workers, although their direction is not uniform: Quadri A and Ahmed HST found the triangular type more frequent in males and the hook-shaped and rounded types more common in females [20], while Kharoshah MAA et al., highlighted the role of sex-linked mandibular growth patterns [18]. The comparatively higher frequency of hook-shaped processes in the current study male sample may reflect the modest sample size and regional variation; nonetheless, the strong predilection for the triangular variant in our female sample may offer ancillary value as a shape-based indicator in sex determination when traditional metric indices are equivocal.

About the morphometric dimensions, the mean inter-coronoid distance was significantly greater in males (85.93±3.92 mm) than in females (79.26±4.96 mm); a comparable sexual dimorphism of coronoid and mandibular-ramus dimensions has been documented in other Indian and South Asian dry-bone and radiographic series [14,17]. The highly significant sex difference in inter-coronoid distance (p=0.0005, effect-size r=0.64) reinforces the potential of this single linear measurement as an accessory criterion for forensic sex determination, where it may complement more established mandibular indices such as the bigonial breadth and the gonial angle [18,19]. The significant male predominance in base length on both sides (right p=0.003; left p<0.001) is concordant with the greater coronoid dimensions reported in males by Kausar H and Tripathi A [26] and by Arthanari A et al., [6]. Differences in the anterior arm, posterior arm and height followed the same direction but did not consistently reach significance, likely reflecting the modest sample size and within-group variability. Bilateral symmetry of all four parameters (paired tests p>0.05) is in keeping with earlier reports of a high degree of side-to-side symmetry of the coronoid process [5,21] and confirms that either side may be used interchangeably for graft-harvesting planning.

From a clinical perspective, awareness of coronoid morphological variants is directly relevant to oral and maxillofacial surgery. The triangular coronoid, broader at its base, offers the largest harvestable cortico-cancellous volume and is best suited as an autogenous graft in orbital floor reconstruction, alveolar ridge augmentation, maxillary sinus augmentation and repair of non union mandibular fractures [5,10]. Hook-shaped and elongated coronoids predispose to impingement on the zygomatic arch, to coronoid hyperplasia and to restriction of mouth opening; their early radiological recognition is therefore important [11,12,24]. Coronoidectomy demands precise appreciation of the height and inclination of the process to avoid inadvertent injury to the maxillary artery and the pterygoid venous plexus [11].

The strengths of the present study include duplicate measurements by two observers to minimise bias and the combined use of morphological classification and linear morphometry on the same specimens. To our knowledge, this is among the first osteological studies of the coronoid process in central Gujarat, contributing regional normative data for clinical and anthropological practice in Western India. These observations are consistent with recent studies that have likewise reported a predominance of the triangular variant and a high degree of bilateral symmetry of the coronoid process in dry-bone and radiological samples [21,27,28].

Limitation(s)

The present study has certain limitations that should be acknowledged. First, the sample was drawn from a single departmental osteological collection and comprised only 30 mandibles; the relatively modest sample size, while adequate for the primary comparisons, reduced the power to detect smaller effect sizes on the anterior arm and height and may have contributed to non significant p-values for some parameters where the direction of difference was nevertheless consistent with sexual dimorphism. Second, sex was determined by non metric morphological criteria alone, as information on age, ancestry and cause of death was not available for the archival specimens. Third, CT-based three-dimensional reconstruction was not performed, precluding volumetric and orientation analyses. Fourth, correlation of morphometric findings with temporalis muscle mass or masticatory function was not possible. An additional statistical limitation is that both coronoid processes from each mandible were treated as independent observations; the Chi-square test of the gender-shape association (χ^2=8.98, p=0.011) did not account for the resulting within-individual (bilateral) correlation, and a paired approach such as McNemar's test, or an analysis using the mandible rather than the side as the unit of observation, would have been more appropriate. This gender–shape association should therefore be regarded as preliminary.

Future prospective multi-institutional studies combining dry-bone osteometry with cone-beam CT imaging from the same geographic region are therefore warranted.

CONCLUSION(S)

The present cross-sectional osteometric study of 30 dry adult human mandibles from the Vadodara region demonstrates that the coronoid process exhibits marked morphological diversity, with the triangular variant predominating in 53.33% of sides, followed by the hook-shaped (28.33%) and rounded (18.33%) variants. A statistically significant association exists between gender and coronoid shape, with hook-shaped processes predominating in males and triangular processes in females. Male mandibles show significantly greater inter-coronoid distance and base length than female mandibles on both sides, confirming clear sexual dimorphism of the mandibular ramus in this population. Bilateral symmetry of all four linear parameters was evident. These regional normative data may aid maxillofacial surgeons in autogenous coronoid graft harvesting, assist radiologists in interpretation of mandibular imaging, and provide forensic experts and anthropologists with additional shape- and dimension-based criteria for sex determination from fragmentary mandibular remains.

In the Vadodara population, the coronoid process is predominantly triangular and shows clear sexual dimorphism in both shape and size, making it a useful ancillary aid for autogenous graft harvesting and for forensic sex estimation from fragmentary mandibular remains.

Authors' contribution: JN: Conception and design of the study, data acquisition, morphometric measurements, drafting of the manuscript; HV: Supervision of study design, critical revision of the manuscript for important intellectual content, final approval of the version to be published. Both authors agree to be accountable for all aspects of the work.

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AI use declaration: ChatGPT and Artificial Intelligence tools were used to reframe and adjust the language and grammar for this manuscript.

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PARTICULARS OF CONTRIBUTORS:
1. Postgraduate Resident, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth Deemed to be University, Piparia, Vadodara, Gujarat, India.
2. Professor and Head, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth Deemed to be University, Piparia, Vadodara, Gujarat, India.
3. 3rd Year Postgraduate Resident, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth Deemed to be University, Piparia, Vadodara, Gujarat, India.
4. 3rd Year Postgraduate Resident, Department of Anatomy, Smt. B.K. Shah Medical Institute and Research Centre, Sumandeep Vidyapeeth Deemed to be University, Piparia, Vadodara, Gujarat, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Dr. Jahnavi Nath,
House No. 37-B, Prime Vatika Society, Opposite Sumandeep Vidyapeeth, Piparia, Waghodiya, Vadodara-391760, Gujarat, India.
E-mail: drjahnavinath@gmail.com

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