Original Article

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Dentistry Section

Morphologic and Morphometric Analysis of Crista Galli for Gender Determination using Cone Beam Computed Tomography: A Cross-sectional Study

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ABSTRACT

Introduction: Gender determination is a key process in forensic investigations. The Crista Galli (CG) is a significant anatomical structure of the skull and a crucial endoscopic landmark in pituitary surgeries and the frontal sinus approach. A few studies have reported a certain degree of sexual dimorphism in the morphology of the CG. Considering the scarcity of studies in which the CG and adjacent structures were analysed using Cone Beam Computed Tomography (CBCT), especially in the Indian population, a need was felt to conduct this study.

Aim: To analyse the morphologic and morphometric characteristics of the CG and its application for gender determination using CBCT.

Materials and Methods: The present cross-sectional study was conducted in the Department of Oral Medicine and Radiology at Dr. D. Y. Patil College and Hospital, Pimpri, Pune, Maharashtra, India, over a period of six months from April 2024 to October 2024. A total of 228 CBCT scans, 114 for each gender, were retrospectively analysed by two independent observers using Image Comparison Analysis Tool (i-CAT) software version 1.9.3.14. The height, width, length, and shape of the CG, as well as the presence of pneumatisation, were assessed. Kero's classification was used for morphological categorisation. Descriptive and inferential statistics, unpaired t-tests, and Chi-square tests were performed for statistical analysis. The Cronbach alpha test was used to measure inter-examiner reliability.

Results: Out of the 228 participant scans, the mean±SD of the length of the CG in males was 11.17±2.14 mm, whilst in females it was 11.45±2.19 mm. The mean±SD of the width of the CG in males was 4.72±1.66 mm, whereas in females it was found to be 5.08±1.35 mm. The mean±SD of the height of the CG in males was 13.08±2.88 mm and in females it was 13.32±2.52 mm. A statistically significant difference (p-value=0.049) in the width of the CG was observed between the two genders. A significant association was found between Kero's classification and gender, but not between pneumatisation and gender. The Cronbach alpha score of 0.911 was indicative of good inter-examiner reliability.

Conclusion: This study suggests that the CG could serve as a potential indicator for gender determination. Additionally, since the CG shows morphological variation, its meticulous examination before any interventional procedure in the anatomical region is essential.

Keywords: Computed tomography scan, Ethmoid bone, Forensic, Identification

INTRODUCTION

Forensic science deals with an essential aspect of identification in order to gain valuable data for the purpose of creating the biological profile of unknown individuals or providing evidence for criminal investigations. Gender determination is one of the important parameters for this process. There are two types of procedures for sex determination: morphometric and morphologic. Morphometric analysis involves statistical evaluation and comparison of measurements to generate a probabilistic estimation of sex, whereas morphological analysis is more subjective, relying on the visual inspection of dimorphic traits [1-3].

The pelvic bone and skull are relatively strong and indestructible parts of the human skeleton, thus proving to be of great value in gender determination in the field of forensics. Forensic dentists and anthropologists may sometimes face challenges in cases where bone integrity is compromised, such as in instances of mass disasters. In such scenarios, small skeletal structures become significant for gender identification [2,4].

The CG is an important anatomical entity situated above the ethmoidal bone's Cribriform Plate (CP). It is located in the anterior part of the anterior cranial fossa as a ridge with a smooth triangular appearance. It serves as an attachment point for the falx cerebri, which partially separates the cerebral hemispheres. Additionally, the CG is considered an important surgical landmark and may exhibit pneumatisation in a few individuals despite being a compact bony structure. Morphological variations in the CG may influence the approaches and techniques used in neurosurgical and craniofacial procedures, thus necessitating accurate image interpretation to guide treatment plans [3-5].

A few studies have reported a certain degree of sexual dimorphism in the morphology of the CG but have suggested further research to confirm such relationships [5-8]. Most of these studies were conducted using CT scans. It is now well-established that CBCT is a promising alternative to CT for imaging skull anatomy due to its accuracy, precision, and reduced cost [3,5-8]. Considering the limited research [9] available, and with this being the second study focusing on a different population, there is a recognised need to analyse the CG and its adjacent structures using CBCT, especially in the Indian population. This study aims to investigate the morphologic and morphometric characteristics of the CG and explore its potential application in gender determination. This will offer a unique contribution to the research, thereby highlighting potential geographical distinctions in CG structure and further advancing the understanding of sexual dimorphism in skull anatomy.

MATERIALS AND METHODS

The present cross-sectional study was conducted in the Department of Oral Medicine and Radiology at Dr. D. Y. Patil Dental College and

Hospital, Pimpri, Pune, Maharashtra, India, over a period of six months from April 2024 to October 2024. During this time, the study was planned and executed, along with data analysis and interpretation. Permission was obtained from the Scientific Advisory Committee and the Institutional Ethical Committee (Ref. No. EC/582/144/2023). The CBCT scans of patients were obtained from the department's database, following the procedures in accordance with the ethical standards of the Helsinki Declaration of 1975 (revised in 2024). For the purpose of this study, data spanning the past ten years was taken into consideration.

Sample size calculation: The sample size was determined using the following formula:

"Sample size n={DEFF×Np(1-p)}/{(d²/Z²(1-α/2)×(N-1))+p×(1-p)}"

Where DEFF (Design Effect)=1, N (Population Size)=560, p (Proportion)=0.5, d (Margin of Error)=0.05, Z-score for 95% confidence=1.96.

$n=1\times560\times0.5\times0.5/\{1.96^2\times0.05^2\times(560-1)+0.5\times0.5\}$

$n=0.25\times560/\{0.000651\times559+0.25\}$

$n=140/0.614809$

$n\approx227.93$

The estimated sample size for this study was calculated to be 228 (95% confidence interval).

Inclusion criteria: CBCT scan volumes of patients aged above 18 years that covered the entire extent of the CG region were included in the study.

Exclusion criteria: CBCT scans of patients with a history of tumour or surgery in the region, or those displaying partially reconstructed images and artifacts compromising the diagnostic quality of the scans, were excluded from the study.

Study Procedure

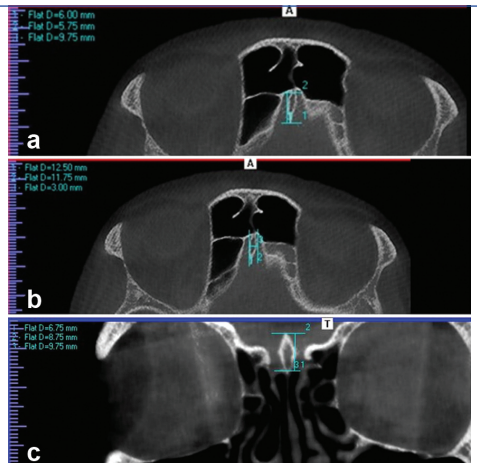
The 228 retrieved scans of patients aged between 18 and 70 years were equally divided into two groups, with 114 scans in each:

Group 1: 114 scans of males;

Group 2: 114 scans of females.

All 228 scans were selected from the last 7-8 years, with a full Field of View (FOV). They were taken with i-CAT 17-19 Platinum, Imaging Sciences International, USA; Equipment ID-G-XR-88686, following the configuration of Voltage: 120 kVp, Current: 37.07 mAs, exposure time: 26.9 seconds, FOV: 16×13 cm, Voxel size: 0.25×0.25×0.25 millimetres, and slice thickness: 1 mm.

The i-CAT software version 1.9.3.14 was used to view and assess the images. All standard protocols were followed during this process. The digital measuring tool of the i-CAT software was utilised to determine the dimensions of the CG [Table/Fig-1].



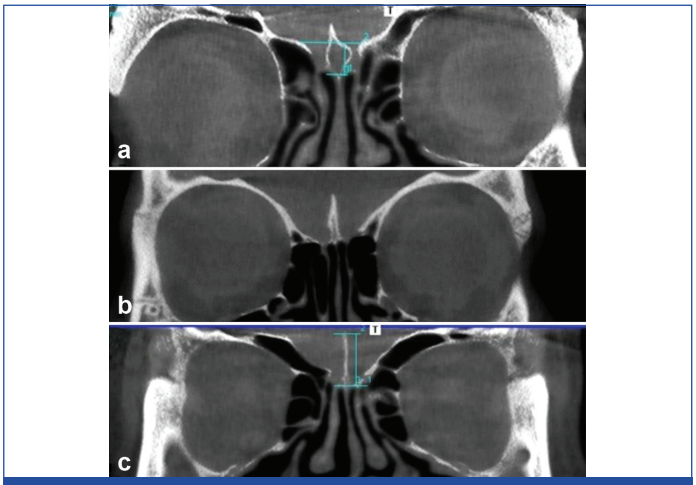
[Table/Fig-1]: a) Measurement of dimensions of Crista Galli (CG), Axial view of CG showing maximum length; b) Axial view of CG showing maximum width; c) Coronal view of CG showing greatest height.

a) **Length:** The maximum anteroposterior diameter of the CG was measured from the end of the inner cortex of the frontal bone on the axial view.

b) **Width:** The greatest transverse measurement of the CG was referenced to the outer cortical borders on the axial view.

c) **Height:** The highest point between the CP and the CG was estimated on the coronal view.

d) **Morphology:** The measurements of the CG and the presence of pneumatisation were noted. Komut and Golpinar's classification [6] was used to categorise the studied CGs according to their shape [Table/Fig 2]:



[Table/Fig-2]: Morphological types of Crista Galli (CG): a) Type I: Teardrop; b) Type II: Tubular; c) Type III: Ossified.

- Type I (Teardrop): A wide cavitary part evident, with a width greater than one-third of the CG's height.
- Type II (Tubular): A cavitary part observed, with a width less than one-third of the CG's height.
- Type III (Ossified): Absence of a cavitary part, with the width of the CG being less than one-third of its height.

e) **Kero's classification [7]:** According to this classification, based on the height of the lateral lamella of the CP, the depth of the olfactory fossa is divided into three categories:

- Type 1: 1-3 mm. Short lateral lamella, with the ethmoid roof approximately at the same plane as the CP.
- Type 2: 4-7 mm. Longer lateral lamella.
- Type 3: 8-16 mm. The ethmoid roof is above the CP.

f) **Pneumatisation of the CG:** The presence of pneumatisation was evaluated on the coronal view [Table/Fig-3].

[Table/Fig-3]: Coronal view showing pneumatisation of Crista Galli (CG).

STATISTICAL ANALYSIS

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) software (IBM Corp) (v. 21.0). Descriptive and inferential statistics were carried out for the different parameters assessed in the study. The comparison of length, width, and height of the CG between males and females was conducted using independent samples/unpaired t-tests to assess significant

differences between the two groups for continuous variables. The Chi-square test of association was used to evaluate significant differences among categorical variables and gender. A p-value of less than 0.05 was considered statistically significant in the study.

RESULTS

Out of the 228 scans, 114 were from male subjects and 114 from female subjects. The age range of the individuals included in the study was 18 to 70 years. This indicated that the gender distribution was equal, and a varied age presentation was observed within the groups [Table/Fig-4].

Age (in years)	Minimum	Maximum	Mean±Std. Deviation
Male	17.00	79.00	43.04±15.86
Female	18.00	69.00	39.53±14.90

[Table/Fig-4]: Descriptive statistics of age (in years) in males and females.

The mean±SD of the CG dimensions was analysed, revealing a statistically significant difference between males and females in CG width (p-value=0.049). However, no significant differences were observed in CG length and height. Therefore, it can be inferred that among the measured parameters, the width of the CG may serve as a significant indicator for gender differentiation [Table/Fig-5].

Parameters	Gender	N	Minimum-Maximum	Mean±Std. Deviation	Mean difference	t-value	p-value
Length (mm)	Male	114	6.00-17.75	11.17±2.14	-0.27698	-0.963	0.337
	Female	114	6.40-18.50	11.45±2.19			
Width (mm)	Male	114	1.00-9.00	4.72±1.66	-0.35344	-1.762	0.049*
	Female	114	2.50-10.00	5.08±1.35			
Height (mm)	Male	114	7.50-20.50	13.08±2.88	0.35877	-0.685	0.494
	Female	114	7.50-21.90	13.32±2.52			

[Table/Fig-5]: Descriptive statistics and comparison of length, width and height of Crista Galli (CG) between males and females.
*p-value <0.05 statistically significant, <0.01 highly significant; Descriptive statistics and Unpaired t-test

A significant association was noted (p-value=0.05) between Kero's classification and gender, whereas no significant differences were noted between pneumatisation and gender (p-value=0.560) [Table/Fig-6].

Parameters		Gender		Total n (%)	Chi-square p-value
		Male n (%)	Female n (%)		
Pneumatisation	Absent	105 (46.05%)	108 (47.36%)	213 (93.42%)	0.560
	Present	9 (3.94%)	6 (2.63%)	15 (6.57%)	
	Total	114 (50%)	114 (50%)	228 (100%)	
Kero's classification type (Percentage)	Type 1	30 (13.15%)	18 (7.89%)	48 (21.05%)	0.05*
	Type 2	75 (32.89%)	79 (34.64%)	154 (67.54%)	
	Type 3	9 (3.94%)	17 (7.45%)	26 (11.40%)	
	Total	114 (50%)	114 (50%)	228 (100%)	

[Table/Fig-6]: Association of Pneumatisation and Kero's classification type between males and females.
*p-value <0.05 statistically significant, Chi-square test

Most prevalent shape of CG in our study as per Komut and Golpinar Classification (in coronal and axial section) was teardrop shape (67%) followed by tubular (29%) and ossified (4%). Some variations were also seen in the shape of CG that was slightly different than the established morphological types. However, no significant association was noted between gender and the above parameters [Table/Fig-7]. Inter-examiner reliability was evaluated, demonstrating a Cronbach's Alpha score of 0.911, which is interpreted as having good consistency between the two investigators.

DISCUSSION

Gender determination is crucial for forensic investigations, particularly when identifying the skeletal remains of individuals. In the present study, conducted using CBCT scans, a midline anatomical structure called the CG, located in the anterior cranial fossa of the skull, was examined for its potential role in gender identification.

The morphometric analysis of the CG revealed that among the parameters measured, the width of the CG showed a statistically significant difference between males and females. Specifically, females demonstrated a greater mean width compared to males, indicating sexual dimorphism. However, no significant differences were observed in the height and length of the CG between genders. This suggests that the width of the CG could be considered a reliable parameter for gender differentiation. Conversely, the length of the CG was found to be increased in males compared to females in the study conducted by Govindraju P et al. Similarly, Vuralli D et al., found that males had significantly larger CG dimensions than females, which is inconsistent with the findings of the current study [9,10]. Additionally, no significant differences in CG dimensions were found between genders in a study conducted by Özeren KC and Aytuğar E [11].

When compared to existing literature, the findings of this study are in alignment with those of Okumuş Ö, who also reported a significant difference in CG width between genders, supporting the idea that CG dimensions may aid in sex determination [7]. On the other hand, studies conducted by Komut E and Golpinar M, and

Komut and Golpinar classification	Gender		Total n (%)	Chi-square p-value
	Male n (%)	Female n (%)		
Type I (Teardrop)	76 (33.33%)	77(33.77%)	153 (67.10%)	0.201
Type II (Tubular)	29 (12.71%)	36 (15.78%)	65 (28.50%)	
Type III (Ossified)	9 (3.94%)	1 (0.43%)	10 (4.38%)	
Total	114 (50%)	114 (50%)	228 (100%)	

[Table/Fig-7]: Association of Komut and Golpinar Classification between males and females.
*p-value <0.05 statistically significant

Govindraju P et al., presented contrasting results, stating that both the height and width of the CG exhibited a statistically significant relationship with gender, thereby extending the scope of measurable parameters for gender identification beyond just the width [6,9]. This inconsistency may be due to differences in sample size, population demographics, or measurement techniques used in various studies [7,9,12]. Furthermore, the study by Mladina R et al., also found the height of pneumatised CG to be significantly higher in females, which again supported the notion of sexual dimorphism in CG morphology, although the current study did not find height to be a differentiating factor [12]. Additionally, no association was found between pneumatisation and gender in the present study, which was contrary to the findings of Çalış kan A et al., who reported a 5% prevalence of pneumatisation and a gender-related correlation with CG pneumatisation [13].

In the study conducted by Manea C and Mladina R, pneumatisation of the CG was observed in 59 out of 196 patients with chronic sinusitis, accounting for 30.1% of the cases [14]. Their results indicated that the craniocaudal diameter length was slightly shorter in females compared to males, and a significant difference was found in the latero-lateral diameter of the CG between the genders.

However, the anteroposterior diameter length showed no statistically significant differences between the genders. Additionally, Acar G et al., found CG pneumatisation in 29.8% of 402 patients, while Hajiioannou J et al., reported pneumatisation in 14.1% of the scans from 99 patients [15,16].

In terms of morphological classification based on the criteria established by Komut E and Golpinar M, the current study found no statistically significant association between CG morphology and gender [6]. However, it was noted that not all scans adhered strictly to the predefined morphological types outlined in their classification system. Several instances revealed variations in the observed morphology, suggesting potential deviations or alternative forms that did not entirely align with the established criteria. As these unclassified variations might represent population specific features or previously undocumented morphotypes, it is necessary for broader research to be conducted to enhance the reliability of such classification systems, which can then be utilised for clinical and forensic applications.

The Keros classification system was also applied in this study, and a significant association was found between its type II variant and gender, supporting its utility in gender determination. This finding was consistent with the results reported by Okumuş Ö and Paber JELB et al., who also observed a gender-related correlation with Keros classification types [7,17]. Conversely, while Komut E and Golpinar M did not find any significant relationship between Keros types and gender, Acar G et al., found that the type II variant was present in the majority of subjects (63.6%) [15]. The association of Keros classification and gender may be influenced by factors such as sample characteristics or regional anatomical differences.

According to the present and previous studies, the CG showed morphological variation, warranting meticulous examination before any interventional procedure in the anatomical region [18-20]. Some studies have discussed the morphometric features of this structure and its pneumatisation, but very few have evaluated it for its sexual dimorphism [2,4-6,11]. Thus, this study suggested that the CG could serve as a potential indicator for gender determination.

Limitation(s)

A key limitation of this study lies in its focus on a single population group, which may restrict the generalisability of the findings to broader or more diverse populations. Further studies with larger sample sizes and different population bases are recommended for the assessment of the CG and for validating it as a reliable and consistent indicator for gender determination.

CONCLUSION(S)

In conclusion, the present study highlights the potential of the CG, particularly its width, as a reliable morphometric parameter for gender determination using CBCT imaging. While height and length did not show significant gender differences, the observed sexual dimorphism in width supports its forensic relevance. The study also found a significant association between the Keros type II classification and gender, reinforcing its possible role in gender identification. However, no correlation was noted between CG pneumatisation or morphological types and gender, suggesting limited utility of these parameters in sex determination. These findings emphasised the importance of a thorough anatomical evaluation of the CG. Further research involving diverse populations is essential to strengthen these observations and establish standardised criteria for clinical and forensic applications.

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