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# Crista Galli Morphometry and Morphology: An Anatomical, Radiological, and Machine Learning Application Study

## Crista Galli Morfometría y Morfología: Un Estudio de Aplicación Anatómica, Radiológica y de Aprendizaje Automático

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**SUMMARY:** The study purposed to examine the morphometry and morphology of crista galli in cone beam computed tomography (CBCT) and apply a new analysis, supervised Machine Learning techniques to find the answers to research questions "Can sex be determined with crista galli morphometric measurements?" or "How effective are the crista galli morphometric measurements in determining sex?". Crista galli dimensions including anteroposterior, superoinferior, and laterolateral were measured and carried out on 200 healthy adult subjects (98 females; 102 males) aged between 18-79 years. Also, crista galli was classified with two methods called morphological types and Keros classification. In this study, the Chi-square test, Student's t-test, and Oneway ANOVA were performed. Additionally, Machine Learning techniques were applied. The means of the CGH, CGW, and CGL were found as 14.96 mm; 3.96 mm, and 12.76 mm in males, respectively. The same values were as 13.54 mm; 3.51 mm and 11.59±1.61 mm in females, respectively. The CG morphometric measurements of males were higher than those of females. There was a significant difference between sexes in terms of morphological classification type. Also, when the sex assignment of JRip was analyzed, out of 102 male instances 62 of them were correctly predicted, and for 98 female instances, 70 of them were correctly predicted according to their CG measurements. The JRip found the following classification rule for the given dataset: "if CGH<=14.4 then sex is female, otherwise sex is male". The accuracy of this rule is not high, but it gives an idea about the relationship between CG measurements and sex. Although the issue that CG morphometric measurements can be used in sex determination is still controversial, it was concluded in the analysis that CG morphometric measurements can be used in sex determination. Also, Machine Learning Techniques give an idea about the relationship between CG measurements and sex.

**KEY WORDS: Crista galli morphometry; Keros classification; Morphological classification; Sex determination.**

## INTRODUCTION

There is an upward bony protrusion which is cock's comb in the sagittal direction in the middle and anterior half of the lamina cribrosa of the ethmoid bone (EB), called crista galli (CG). The EB is one of the neurocranium bones. The CG, which is also a remarkable anatomical reference point, is a pyramidal-shaped, smooth, thick structure located in the anterior cranial fossa. The thin and long posterior margin of CG plays a role in the falx cerebri attachment. The thick and short anterior margin articulates with the frontal bone. The CG is a significant marker in the sinonasal region which is the most common anatomical variation. These paranasal sinus variations can be diagnosed with CT practically and rapidly during endoscopic sinus surgery (Danielsen *et al*., 2006; Tetiker *et al*., 2016). When the CG is pneumatized, serious infections can be developed and endoscopic surgery treatment can be needed in this situation. In addition, the narrow bone canals are one of the risk factors in sinus diseases and paranasal sinus variations are the most frequent reason for rhinosinusitis (Tetiker *et al*., 2016).

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The skull, like the pelvis, can be used in prediction of the sex determination and is a reliable method. Additionally, the skull has some advantages in sex prediction. Firstly, it is strongly about environmental conditions and preserved integrity (Gölpınar *et al*., 2022). Sex estimation is necessary for the accurate determination of some factors including race, age, or stature (Spradley *et al*., 2015; Gölpınar *et al*., 2022). Sometimes, the skull can be incomplete or non-intact. The small parts of the skeleton become more important when the bone integrity is not preserved or broken bones are available or destroyed (Okumus¸ *et al*., 2022; Gölpınar *et al*., 2022). Especially, morphometric and morphological measurements are preferred by forensic and archaeological procedures (Okumus¸ *et al*., 2022). In the literature, there are two studies on the relationship between morphological and morphometric features and sex (Gölpınar *et al*, 2022; Okumus¸ *et al*., 2022). Only one study from these studies declared that there was a relation between CG morphometric and morphological features of CG and sex (Gölpınar *et al*., 2022). And there are no studies about age-related changes in CG morphology and morphometry. The structure may be pneumatised or compact bone (Okumus¸ *et al*., 2022). The morphology of CG is different from one subject to another. The Keros classification separates the olfactory fossa depth into 3 structures according to the lateral lamellae of the CG and is a helpful method in CG studies and olfactory region anatomy. Also, the CG morphology classification is based on the CG size and cavitary component presence (Okumus¸ *et al*., 2022; Gölpınar *et al*., 2022).

In this study, we aimed to determine the length, height, width and morphological types according to two different methods of crista galli in the adult Turkish population and also to analyze whether it changes according to sex and age or not. Also, as a second new analysis, supervised Machine Learning techniques were applied to find the answers to research questions "Can sex be determined with crista galli morphometric measurements?" or "How effective are the crista galli morphometric measurements in determining sex?".

## MATERIAL AND METHOD

**Subject and study design.** This study was approved by our institutional review board, and ethics committee approval also was obtained (2022/126:42). The present study was carried out on 200 healthy adult subjects (98 females; 102 males) aged 18-79 years from 2018 to 2022. All CT scans were obtained using a 64x2-slice multidetector CT (Siemens Somatom Definition AS, Siemens Healthcare). Moreover, inclusion criteria for adult subjects were selected by no history of surgery or trauma affecting the CG structure or frontal, sphenoid, and ethmoid bones.

**Data collection tools**

The landmarks used in this study were as follows. Crista galli dimensions including anteroposterior, superoinferior (height), laterolateral (width) were measured using Computed Tomography in 200 subjects (98 females and 102 males). The Crista galli height (CGH) on coronal view, the crista galli width (CGW), and crista galli length (CGL) on the axial view were used.

Crista galli height (CGH): The highest part between the cribriform plates was determined as the reference point.
Crista galli width (CGW): The greatest transverse of CG as the outer cortical margins of CG were measured as the reference point.

Crista galli length (CGL): The greatest anteroposterior diameter of the CG from the end of the inner cortex of the frontal bone was measured.

In this paper, also two different methods were used for the CG classification. Firstly, the CG was classified as teardrop type, tubular type, and ossified type according to the cavitary component presence (Komut & Golpinar, 2021). Teardrop type: The CG width is greater than one-third of its height, and there is a wide cavitary component. Tubular type: The width of CG is less than one-third of its height and includes a cavitary component from the basis to the apex. Ossified type: The width of CG is less than one-third of its height but, there is no cavitary component.

In the second type of classification, the Keros classification method was used. The method is divided into three types. In type 1, the height is approximately between 1 mm and 3 mm. The lateral lamella is short and an ethmoid bone roof is a similar plane as the cribriform plate. In type 2, the height is approximately 4 mm and 7 mm. The lateral lamella is longer. In type 3, the height is approximately 8mm and 16mm. The ethmoid roof is clearly above the cribriform plate (Keros, 1962).

Additionally, the CG pneumatization presence was evaluated on the coronal view.

Also, subjects grouped as; 18 and 19 years were accepted as group 1; 20–29 years, group 2; 30–39 years, group 3; 40–49 years, group 4; 50–59 years, group 5; 60-69 years, group 6; 70-79 years, group 7. Morphometric measurements were compared according to age groups.

The correlation analysis was performed according to this formula;

R=0.01-0.25: very weak correlation
0.26-0.49: weak correlation
0.50-0.69: moderate correlation
0.70-0.89: strong correlation
0.90-1.0: very strong correlation

**Data.** From the machine learning (ML) perspective, this data needs to be transformed into an intermediate form to enable classifiers to run over it. Hence, we transformed the collected data of 200 patients into a 200 x 4 matrix whose rows represent patients (i.e., data instances) and columns represent attributes, respectively. The attributes are Crista galli height (CGH) on the coronal view, the crista galli width (CGW), and crista galli length (CGL) on the axial view. The last column in the data matrix is the sex of the patient, which is taken as the class label. In the dataset, there are 98 female and 102 male instances. Therefore, it is a binary class classification problem, and the dataset is almost balanced.

**Machine Learning Methods.** We used supervised ML in which labeled training data is needed. In this study, for each patient (i.e., data instance), CGH, CGW, and CGL values form attributes, and the sex of the patient was used as the class label. Supervised ML takes the given CGH, CGW, CGL, and sex values of the patients as the training dataset, and tries to learn a model to predict sex from the given CGH, CGW, and CGL values. To learn the classification model, we used well-known algorithms implemented in Weka (with version 3.8.6) ML toolkit (Witten *et al*., 2005). The brief descriptions of the used classification algorithms are as follows:

- NB: Naïve Bayes (NB) classifier is a simple probabilistic estimator that depends on Bayes' theory with strong independence assumptions (Khan *et al*., 2010). It is easy in terms of both implementation and computation and works well on numeric and textual data when compared to other classifiers (Khan *et al*., 2010).
- SMO: Sequential Minimal Optimization (SMO) is the implementation of Support Vector Machine Learning in Weka (Platt, 1998). SMO uses a linear kernel by default.
- IBk: It is the implementation of the k-nearest neighbor classifier in Weka. It assigns each test instance to one of the predefined sets of classes according to the majority class labels of the k nearest neighbors from the training set (Aha *et al*., 1991).
- RF: Random Forest (RF) is an ensemble classifier of decision trees where each tree is generated by using a random vector that is sampled independently from the given input data (Breiman, 2001).
- J48: It is an implementation of the C4.5 decision tree induction algorithm. A decision tree is composed of nodes and branches such that each node and branch represent an attribute and a value that a node can take (Quinlan, 1993; Mahesh, 2020). Classification of a new instance is done by starting from the root node, following the matching branches until a leaf node, which represents a class label.
- RT: Random Tree (RT) classifier constructs a decision tree that considers k randomly chosen attributes at each node. It does not perform pruning and also has an option to allow the estimation of class probabilities based on a hold-out set (Breiman, 2001; Witten *et al*., 2005).
- JRip: JRip is a propositional classification rule learner that is based on an optimized version of IREP (Cohen, 1995). It learns classification rules for each class from the less prevalent one to the more frequent one in two phases: in the building stage a set of rules for a class is generated, and in the optimization stage the generated rules in the first stage are optimized.

The mathematical definitions of these methods are not given in this paper to save space and reduce the complexity of the study. Nevertheless, the reader is advised to see (Aha *et al*., 1991; Quinlan, 1993; Kohavi, 1995; Platt, 1998; Witten *et al*., 2005; Khan *et al*., 2010; Mahesh, 2020; Alpaydın, 2020) for more details on these classifiers.

**Performance Measurement and Evaluation.** Sex prediction from CG morphometric measurements is a binary class classification problem and our dataset is almost balanced. To measure the performance of a classifier in a binary classification task, actual and predicted labels of test instances are grouped into four main categories that are TP (True Positives), TN (True Negatives), FP (False Positives), and FN (False Negatives) to derive a confusion matrix (Alpaydın, 2020). Using the number of instances in these four categories, several well-known evaluation metrics can be computed. In this study, the performance measure of estimators is performed by using the F1-score (or F-measure) which is formulated as follows (Alpaydın, 2020):

$$F1 - score = \frac{2 \times P \times R}{P + R}$$

where $P = TP/(TP + FP)$ and $R = TP/(TP + FN)$. The F1-score value ranges from 0 to 1 where 1 means the perfect prediction.

Model evaluation is often performed by dividing the dataset into two disjoint subsets namely, training and test sets. In this study, we use *k*-fold cross-validation (Kohavi, 1995) to evaluate our learning models (or estimators). In this way of evaluation, the data at hand is divided into *k* equal-sized subsets each of which is picked as a test set and the remaining $k-1$ subsets taken as a training set; therefore, training and testing processes are done k times (Alpaydın, 2020). Then, the average of these F1 scores is computed. Note that we configured our models to run with 10-fold cross-validation in this study.

**Statistical Analysis.** Categorical variables were expressed as numbers and percentages, whereas continuous variables were summarized as mean and standard deviation and median and minimum-maximum where appropriate. The chi-square test was used to compare categorical variables between the groups. For the comparison of continuous variables between two groups, the Student's t-test was used. For the comparison of more than two groups, Oneway ANOVA was used. Regarding the homogeneity of variances, Tukey, Games & Howell tests were used for multiple comparisons of groups. All analyses were performed using IBM SPSS Statistics Version 20.0 statistical software package. The statistical level of significance for all tests was considered to be 0.05.

Also, as a second new analysis, supervised Machine Learning techniques were applied to find the answers to research questions "Can sex be determined with crista galli morphometric measurements?" or "How effective are the crista galli morphometric measurements in determining sex?".

## RESULTS

The CT scans of 200 healthy adult subjects (98 females; 102 males) aged 18-79 years were obtained using a 64x2-slice multidetector CT (Siemens Somatom Definition AS, Siemens Healthcare). The CGH, CGW, and CGL morphometric dimensions were measured and are shown in Table I. According to this table, the means of the CGH, CGW, and CGL were found as 14.96mm; 3.96mm, and 12.76mm in males, respectively. The same values were as 13.54mm; 3.51mm and 11.59±1.61mm in females, respectively. The CGH, CGW, and CGL values were less in females than in males (Table I).

The analysis of the CG variables according to age groups is given in Table II. According to these results, CGH has the least value in Group 1, while the highest value was obtained in 30-39 years. In the evaluation of the CGW value, the least value was obtained in Group 2, and the highest value was obtained in Group 3 and Group 5. Also, CGL took the least and highest values in Groups 1 and 3 like the CGH value (Table II).

The Post Hoc comparison of the CG dimensions according to the age group was until from Gruoup 1 (18-19 years) to Group 7 (70-79 years). CG morphometric

Table I. The crista galli morphometric measurements according to sex.

| Sex | | Males (n=102) | Females (n=98) | p |
|---|---|---|---|---|
| | | Means±Standard deviations | Means±Standard deviations | |
| Variables | CGH | 14.96±1.90 | 13.54±1.83 | <0.001 |
| | CGW | 3.96±0.76 | 3.51±0.71 | <0.001 |
| | CGL | 12.76±1.69 | 11.59±1.61 | <0.001 |

CGH: Crista galli height; CGW: Crista galli width; CGL: Crista galli length

Table II. The analysis of the CG variables' means, minimum and maximum values according to age groups.

| Variables | Group 1 18-19 years (n=31) | Group 2 20-29 years (n=42) | Group 3 30-39 years (n=46) | Group 4 40-49 years (n=31) | Group 5 50-59 years (n=18) | Group 6 60-69 years (n=23) | Group 7 70-79 years (n=9) |
|---|---|---|---|---|---|---|---|
| CGH | 13.28±1.62 | 14.11±1.53 | 15.20±1.93 | 14.04±2.52 | 14.32±2.12 | 14.26±2.04 | 14.21±1.33 |
| | 12.68-13.88 | 13.63-15.59 | 14.62-15.77 | 13.11-14.96 | 13.27-15.38 | 13.38-15.14 | 13.19-15.23 |
| | 10.00-15.10 | 10.10-16.80 | 10.20-18.90 | 10.10-18.90 | 10.10-17.50 | 10.40-18.60 | 11.70-16.40 |
| | | | | p=0.004 | | | |
| CGW | 3.60±0.75 | 3.58±0.63 | 3.96±0.70 | 3.70±0.90 | 3.96±0.88 | 3.70±0.77 | 3.73±0.87 |
| | 3.32-3.88 | 3.38-3.78 | 3.75-4.16 | 3.37-4.03 | 3.52-4.39 | 3.36-4.03 | 3.06-4.40 |
| | 2.40-5.80 | 2.20-5.10 | 2.50-5.90 | 2.10-6.10 | 2.30-5.70 | 2.10-5.30 | 2.00-4.90 |
| | | | | p=0.227 | | | |
| CGL | 11.49±1.46 | 12.16±1.32 | 12.74±1.77 | 12.16±2.22 | 12.36±1.87 | 11.90±1.82 | 12.40-1.64 |
| | 10.95-12.03 | 11.75-12.56 | 12.22-13.27 | 11.35-12.98 | 11.43-13.29 | 11.12-12.69 | 11.14-13.66 |
| | 8.10-13.70 | 8.80-14.70 | 8.10-16.40 | 8.50-16.50 | 8.10-16.40 | 7.90-15.80 | 9.10-15.50 |
| | | | | P=0.102 | | | |

measurements were compared between the age groups. According to these results, CGH showed a significant difference between only Groups 1-3 and there was a significant difference in CGL value between Groups 1 and 3 . In the comparison, no significant differences were detected in terms of CG morphometric measurements except for Groups 1-3.

The teardrop, tubular and ossified types of morphological classification were determined according to the CG dimensions and the cavitary component presence. The furthest number was obtained in the tubular type both males and females The least number was determined as the ossified type in females and males. There was a significant difference between sexes in terms of morphological classification type (p=0.023) (Table III).

In Table IV, Keros classification types are given and Type 1 was 11(10.8 %), Type 2, 64 (62.7 %), and Type 3, 27 (26.5 %) were in males, respectively. The same values were found as 12 (12.2 %), 67 (68.4 %), and 19 (19.4 %) females, respectively (Table IV). Also, there was no significant difference between sexes in terms of the Keros classification (p=0.491) (Table IV).

According to Table V, pneumatization was found as 34 (33.3 %) and 13 (13.3 %) in males and females. There was no pneumatization as 68 (66.7 %) in males; 85 (86.7 %) in females. Also, there was a significant difference between sexes (p=0.001).

According to the correlation analysis, the CGH value showed a moderate and positive correlation with CGW and showed a strong positive correlation with the CGL value. The CGW value showed a moderate and positive correlation with both CGH and CGL values. The CG pneumatization presence showed a weak and negative correlation with CGH, CGL, and CGW and a positive weak correlation with new classification values (Table VI).

Table III. Morphological classification according to the sexes

| Sex | | Males (n=102) n (%) | Females (n=98) n (%) |
|---|---|---|---|
| Morphological classification | Teardrop type | 40 (39.2) | 22 (22.4) |
| | Tubular type | 53 ( 52) | 60 ( 61) |
| | Ossified type | 9 ( 8.8) | 16 ( 12.5) |
| P value | 0.023 | | |

Table IV. Keros classification according to the sexes.

| Sex | | Males (n=102) | Females (n=98) |
|---|---|---|---|
| | | n (%) | n (%) |
| Keros classification | Type 1 | 11(10.8) | 12 (12.2) |
| | Type 2 | 64 (62.7) | 67 (68.4) |
| | Type 3 | 27 ( 26.5) | 19 (19.4) |
| P value | 0.491 | | |

Table V. The presence of the pneumatization according to the sexes.

| Sex | | Males (n=102) n (%) | Females (n=98) n (%) |
|---|---|---|---|
| Pneumatization presence | Presence | 34 (33.3 %) | 13 (13.3 %) |
| | No presence | 68 (66.7 %) | 85 (86.7 %) |
| P value | 0.001 | | |

Table VI. The correlation of the CG morphometry and morphology variables

| Variables | CGH | CGW | CGL | CG pneumatization |
|---|---|---|---|---|
| CGH | - | 0.640<br><0.001 | 0.798<br><0.001 | -0.340<br><0.001 |
| CGW | 0.640<br><0.001 | - | 0.667<br><0.001 | -0.313<br><0.001 |
| CGL | 0.798<br><0.001 | 0.667<br><0.001 | - | -0.370<br><0.001 |

In Table VII, the relationship between the pneumatization and morphologic classification was given and there was a significant difference (p <0.001).

In Table VIII, Keros classification and pneumatization status is shown and there was a significant difference (p <0.013).

According to Table IX, in the group with pneumatization CGH, CGL, and CGW values were statistically higher than in the group with no pneumatization.

**ML Results.** When we applied the classification algorithms to the dataset, we obtained the results given in Table I where TPR and F1 columns give the true positive classification rate and F1-score, respectively, for the male and female classes. The weighted average column presents the weighted average of TPR and F1-score values of male and female classes. As an example, the NB classifier correctly classifies 63.7 % of male and 59.2 % of female test instances, and sex prediction of 61.5 % of all test instances is done correctly. For each column in the table, the best result is written in bold (Table X).

According to the results of the experimental study, NB, SMO, and IBk classifiers tend to label the majority of the test samples as male, whereas J48 and JRip label the majority of the samples as female. On the other hand, RF and RT assign more balanced class labels with respect to the other methods. When all classifiers are compared, it is found that JRip has the best sex prediction ability with respect to other methods with the overall classification F1-score as 0.659. When we analyzed the sex assignment of JRip, out of 102 male instances 62 of them were correctly predicted, and for 98 female instances, 70 of them were correctly predicted according to their CG measurements. The JRip found the following classification rule for the given dataset: “if CGH <= 14.4 then sex is female, otherwise sex is male”. The accuracy of this rule is not high, but it gives an idea about the relationship between CG measurements and sex.

Table VII. Morphological classification and pneumatization status

| Pneumatization status | Teardrop (n=62) n (%) | Tubuler (n=113) n (%) | Ossified (n=25) n (%) |
|---|---|---|---|
| Pneumatizated Group (n=47) | 29 (61.7 %) | 16 (34 %) | 2 (4.3 %) |
| Nonpneumatized Group (n=153) | 33 (21.6 %) | 97 (63.4 %) | 23 (15.0 %) |
| P value | | <0.001 | |

Table VIII. Keros classification and pneumatization status.

| Pneumatization status | Type 1 (n=23) n (%) | Type 2 (n=131) n (%) | Type 3 (n=46) n (%) |
|---|---|---|---|
| Pneumatizated Group (n=47) | 3 (6.4 %) | 26 (55.3 %) | 18 (38.3 %) |
| Nonpneumatized Group (n=153) | 20 (13.1 %) | 105 (68.6 %) | 28 (18.3 %) |
| P value | | <0.013 | |

Table IX. The means and minimum-maximum values of the CG morphometric measurements according to pneumatization status

| Pneumatization status | CG height Means±Standard (Minimum-Maximum) | CG width Means±Standard (Minimum-Maximum) | CG length Means±Standard (Minimum-Maximum) |
|---|---|---|---|
| Pneumatizated Group (n=47) | 15.48±2.12 (10.20-18.90) | 4.17±0.81 (2.10-6.10) | 13.36±1.72 (9.50-16.50) |
| Nonpneumatized Group (n=153) | 13.89±1.80 (10.00-18.90) | 3.61±0.70 (2.00-5.80) | 11.83±1.60 (7.90-16.20) |
| P value | <0.001 | <0.001 | <0.001 |

Table X. Prediction scores of ML methods.

| | Prediction Score (True Positive Rate and F1-score) | | | | | |
|---|---|---|---|---|---|---|
| | Male | | Female | | Weighted Average | |
| Method | TPR | F1 | TPR | F1 | TPR | F1 |
| NB | 0.637 | 0.628 | 0.592 | 0.601 | 0.615 | 0.615 |
| SMO | **0.686** | 0.622 | 0.459 | 0.514 | 0.575 | 0.569 |
| IBk | 0.559 | 0.543 | 0.480 | 0.495 | 0.520 | 0.519 |
| RF | 0.608 | 0.611 | 0.602 | 0.599 | 0.605 | 0.605 |
| J48 | 0.373 | 0.487 | 0.837 | 0.672 | 0.600 | 0.578 |
| RT | 0.588 | 0.577 | 0.531 | 0.542 | 0.560 | 0.560 |
| JRip | 0.608 | **0.646** | **0.714** | **0.673** | **0.660** | **0.659** |

## DISCUSSION

The crista galli is a bony protuberance projecting upward from the midline of the cribriform plate. Embryologically, the crista galli originates from the ethmoid bone and it is formed from the perpendicular plate by mesethmoidal cartilage during the second fetal month. This cartilage is derived from presphenoid cartilage. The crista galli begins to ossification between 1 and 2 months of age. Also, ossification shows a speedy increase and continues until 24 months of age (Som *et al*., 2009; Hajiioannao *et al*., 2010; Akiyama & Kondo, 2020). Additionally, the crista galli is an endoscopic surgical landmark in frontal sinus approach and pituitary surgery. The excessive pneumatization may be related to ENT-related headaches or neurological symptoms about frontal lobe implications. The presence of pneumatization and congenital malformations such as meningocele, and the crista galli ectoderm's developmental embryological defect leads to clinical symptoms (Cobzeanu *et al*., 2014; Hajiioannao *et al*., 2010). Also, CG is the most important in some approaches such as extradural and endoscopic transcribriform. Due to the clinical significance, the CG morphometry, pneumatization, and morphologic properties should be well known (Uçar *et al*., 2021).

The prevalence of CG pneumatization showed a difference (Hajiioannou *et al*., 2010; Cobzeanu *et al*., 2014; Manea & Mladina, 2016; Akiyama & Kondo, 2020; Okumus¸ *et al*., 2022). In some subjects, the Crista galli is a compact bone and it also may be pneumatized. CG pneumatization and its adjacent structures are critical in surgery and the knowledge of the CG regional anatomy and its variations will help radiologists and otorhinolaryngologists (Tetiker *et al*., 2016). CG serves as a landmark in endoscopic surgery and CG pneumatization may contain a cell arising from the anterior ethmoid. It does not give any clinical symptoms and can only emerge on preoperative radiographs. Additionally, axial and coronal planes may be in the CG definition (pneumatization or not). In a corresponding study performed with 205 CT scans (97 females, and 108 males) of the Romanian population by Cobzeanu *et al*. (2014). CG pneumatization was found as 22.92 % (42 cases) in association with Type 2. This prevalence was reported as 61.95 % in Type 2 (Cobzeanu *et al*., 2014). Also, when crista galli may be pneumatized, CG may communicate with the frontonasal duct which connects the frontal sinus to the middle meatus. This leads to sinusitis and mucocele formation in crista galli. Additionally, the knowledge of these variations may be important in the decision of treatment choice such as clinical or surgical decisions. In a study performed in the United Kingdom with 99 CT scans, crista galli Type 1 was found in 28 patients. 23 were nonpneumatized and 5 patients were pneumatized. Also, Crista galli Type 2 was found in 63 patients of whom 60 patients were non pneumatized and 3 patients were pneumatized. Eight patients were in crista galli Type 3, 2 patients were non pneumatized and 6 patients were pneumatized. The presence of the pneumatized in Crista galli Type 3 was 75 %. The reason for this may be related to crista galli subtype which descends markedly to the nasal cavity (Hajiionannou *et al*., 2010). There are two accepted theories. The first is pneumatization from the ethmoid sinus and the second is the Crista galli pneumatization from the frontal sinus (Miadien *et al*., Som *et al*., 2009). There is a connection between pneumatized crista galli and attached paranasal structures via an opening similar to the other sinus ostia, opened in most cases in the frontal sinus cavity. If the ostial blockage happens, an inflammatory or infectious response may develop. Manea & Mladina (2016) studied crista gali sinusitis in 196 chronic rhinosinusitis patients aged between 18 and 81 years by using CT. Crista galli pneumatization was seen in 59 patients (30.1 %). In the same study, There was no significant difference between sex in CG anteroposterior length. The craniocaudal length of the CG was longer in males than in females. Also, the width of the CG was shorter in females than in males. Manea & Mladina (2016) reported that pneumatization of the CG should take into consideration and the variability degree could be shown. In this study, pneumatization was found in 34 males and 13 females. There was no pneumatization in 68 males [(34 %); in 85 females (42.5 %)]. Also, there was a significant difference between sexes (p=0.001). The presence of pneumatized CG may be accepted as low prevalence (17 % in males; 6,5 % in females). Additionally, the prevalence of CG pneumatization in Type 1 was recorded as 29 (61.7 %) and in Type 2, 16 (34.0 %), and in Type 3, 2 (4.3 %). There was no seen CG pneumatization in 153 subjects (33 subjects in Type 1; 97 subjects in Type 2 and 23 subjects in Type 3). A significant difference was found between the morphological classification (p<0.001). The prevalence of CG pneumatization in Type 1 was seen in 3 subjects (6.4 %); in Type 2, 26 subjects (55.3 %); and in Type 3, 18 subjects (38.3 %). There was no CG pneumatization in 153 subjects (20 subjects in Type 1 (13.1 %); in Type 2, 68.6 %; and in Type 3,18.3 %). There was a significant difference between pneumatization status and Keros classification (p=0.013). In a study performed by Mladina *et al*. (2017), there were no significant differences in the pneumatized CG width, length and height mean values and recorded as p=0.460, 0.170, and 0.752 between the pneumatized group and pneumatized and spongiosis group. Also, in the pneumatized group, the CG height was found as significant (p=0.013), while the width of the CG and length of the CG showed no significant difference between CG width and length (Mladina *et al*., 2017). In the present study, all three morphometric measurements of CG were higher in the pneumatized group than in the non-pneumatized group. Pneumatized CG was more common in men than in women. Also, the type with the highest rate of pneumatization was teardrop 29 (61.7 %) in the morphological classification, and Type 2, 26 (55.3 %) in the Keros classification.

There are few studies investigated CG morphometry and morphology (Mladina *et al*., 2017; Gölpınar *et al*., 2022; Uçar *et al*., 2021; Okumus *et al*., 2022). Findings about age-related changes in CG morphometry and morphology obtained from those studies were not found. Sex-related changes in CG morphometry and morphology were not clear. When age groups were compared in the present study, there were significant differences only between Group 1 and Group 3 in terms of CGH and CGL CG measurements. In a study performed by Mladina *et al*. (2017) with 102 dry skulls of the Croatia population using CT, the CG height showed the significance between sex (p=0.013; p<0.05), but, there was no significant difference in the CG width and length parameters (p=0.345; p=0.791) in the pneumatized group. Gölpınar *et al*., performed a study that measured CG's morphometry and morphology with 207 preserved adult skulls of Anatolia origin (108 males, 99 females). The anteroposterior and superoinferior lengths of the CG were significantly higher in males than females, whereas the CG width was significantly lower in males than in females. The CG height, length, and with were 13.64 mm, 16.10 mm, and 2.84 mm in males respectively. The same values were found in 10.24 mm, 14.12 mm and 4.64 mm, respectively in females (Gölpınar *et al*.). In a study performed with 400 healthy subjects aged between 44.10 years used by CT, the CG height, length, and width were measured as 16.35 mm, 12.97mm, and 4.97 mm in females, while the same values were found as 16.01 mm, 12.87 mm and 4.53 mm in males, respectively. Additionally, the CG height and length values were higher in females but a significant difference was not found between sex. Conversely, there was a significant difference between sexes in the CG width parameter which was higher in females also (Okumus¸, 2022). In a retrospective study of radiological evaluation of CG, CT images of 300 healthy populations were determined, and the mean length CG value was 14.02 mm and 14.05 mm in females and males, respectively. The CG mean width values were measured as 3.77 mm and 3.69 mm in females and males, respectively. There was no significant difference between sex and both two values. In addition, a very weak negative correlation was found between CG length and width parameters (Uçar *et al*., 2021). In a study performed by Akiyama & Kondo (2020) evaluated 300 CT images of Japanese patients (154 females, 146 males) having a brain tumor, the CG length, width, and height were found as 13.5 mm, 4.9 mm, and 15.9 mm, respectively. Also, the Crista galli pneumatization length, width, and height were measured as 4.7 mm, 3.1mm, and 5.2 mm, respectively (Akiyama & Kondo, 2020).

The other method (Keros classification) divided the depth of the olfactory fossa into three categories as the height of the lateral lamella of the cribriform plate (Keros, 1962; Okumus, 2022). The morphologic classification method includes the CG size measurements and the cavitary component presence. We used two classification methods; the morphologic classification and the Keros classification. According to the morphologic classification both male (n: 53, 52 %) and female (n: 60, 61 %) with mostly tubular type, and the least ossified type (males n:9, 8.8 %; females n: 16, 12.5 %). According to Keros classification, both females and males had Type 2 the most, and Type 1 at the lowest level. When the CG's morphological type comparisons of Gölpınar *et al*.'s study which was performed with 207 preserved skulls were analyzed, the most frequently seen type was tubular in males (40.74 %) and the least seen type was teardrop (27.78 %). The ossifies type was seen as 31.48 %. In females, the most seen CG type was teardrop (78.79 %), whereas the least seen type was the ossified type (6.06 %). Also, the tubular type of females was seen at 15.15 % (Gölpınar *et al*., 2022). There was a significant difference between sex in terms of CG morphological types (p<0.001). In another study, the tubular type CG was seen as 50.6 %, the tear drop type was 46.4 % and the ossified type was seen as 3.0 % in females. The tubular type CG was found as 50.3 %, the tear drop type CG was calculated as 45.5 % and the ossified type CG was 4.2 % in males. The most frequent type was tubular CG both in females and males. But, the morphological classification no showed a significant difference between sexes (p>0.815) (Okumus¸, 2022). The 300 CT scans were analyzed by Alazzawi *et al*. (2012), in Malay, Chinese and Indian populations with a mean age of 48.31 years. According to the distribution of Keros classification according to sex, Keros Type I was seen in 103 sides in males and 137 sides in females. Keros Type II was seen in 47 sides in males and 13 sides in females. A significant difference was observed in Type II between males and females (p<0.001). Indian males (21 subjects) had a higher prevalence of Keros Type II compared to Malay (14 subjects) and Chinese males (12 subjects). Also, Chinese females (48 subjects) had a higher prevalence of Keros Type I compared to Indian (46 subjects) and Malay females (43 subjects) (Alazzawi *et al*., 2012).

Crista galli morphometric measurements were higher in males than in females. Pneumatized CG rates were found to be more in males compared to females. In addition, while there was a significant difference between the sexes in terms of morphological classification, there was no significant difference in Keros classification. According to the classification algorithms of the data set, it is possible to argue that CG morphometric measurements can give an idea about sex.

**VURALLI, D.; POLAT, S.; ÖGÜT, E.; ISIK, E. I˙.; ÖKSÜZLER, M.; ÖZEL, A. S. & GÖKER, P.** Crista galli morfometría y morfología: un estudio de aplicación anatómica, radiológica y de aprendizaje automático. *Int. J. Morphol., 41(3)*:749-757, 2023.

**RESUMEN:** En el estudio se propuso examinar la morfometría y la morfología de la crista galli del hueso etmoides usando tomografía computarizada de haz cónico (CBCT) y aplicar un nuevo análisis, técnicas de aprendizaje automático supervisado para encontrar las respuestas a las preguntas de investigación "¿Se puede determinar el sexo con mediciones morfométricas de la crista galli?" o "¿Qué tan efectivas son las medidas morfométricas de la crista galli para determinar el sexo?". Las dimensiones de la crista galli, incluidas los diámetros anteroposterior, superoinferior y laterolateral, se midieron y realizaron en 200 sujetos adultos sanos (98 mujeres; 102 hombres) con edades comprendidas entre los 18 y los 79 años. La crista galli se clasificó con dos métodos llamados tipos morfológicos y clasificación de Keros. En este estudio, se realizaron la prueba de Chi-cuadrado, la prueba t de Student y ANOVA de una vía. Adicionalmente, se aplicaron técnicas de Machine Learning. Las medias de CGH, CGW y CGL se encontraron en 14,96 mm; 3,96 mm y 12,76 mm en hombres, respectivamente. Los mismos valores fueron 13,54 mm; 3,51 mm y 11,59 ± 1,61 mm en mujeres, respectivamente. Las medidas morfométricas del CG de los hombress fueron más altas que las de las mujeres. Hubo una diferencia significativa entre sexos en cuanto al tipo de clasificación morfológica. Además, cuando se analizó la asignación de sexo de JRip, de 102 instancias masculinas, 62 de ellas se predijeron correctamente, y de 98 instancias femeninas, 70 de ellas se predijeron correctamente de acuerdo con las mediciones de CG. El JRip encontró la siguiente regla de clasificación para el conjunto de datos dado: "si CGH<=14.4, por tanto el sexo es femenino, de lo contrario, el sexo es masculino". La precisión de esta regla no es alta, pero da una idea de la relación entre las medidas del CG y el sexo. Aunque la pregunta si las medidas morfométricas CG se pueden usar en la determinación del sexo sigue aún siendo controvertida. Se concluyó en el análisis que las medidas morfométricas CG se pueden usar en la determinación del sexo. Además, las técnicas de aprendizaje automático dan una idea de la relación entre las medidas de CG y el sexo

**PALABRAS CLAVE: Morfometría; Crista galli; Clasificación de Keros; Clasificación morfológica; Determinación del sexo.**

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