

Gender estimation using machine learning algorithms and artificial neural networks based on parameters obtained from the sphenoid sinus

Predicción del sexo usando algoritmos de aprendizaje automático y redes neuronales artificiales a partir de parámetros obtenidos del seno esfenoidal

Oguzhan Harmandaoglu¹, Yusuf Secgin², Seren Kaya³, Deniz Senol^{4*}, Zual Oner⁵, and Omer Onbas⁶

¹Department of Therapy And Rehabilitation, Çatalzeytin Vocational School, Kastamonu University, Kastamonu; ²Department of Anatomy, Faculty of Medicine, Karabük University, Karabük; ³Department of Anatomy, Faculty of Medicine, Düzce University, Düzce; ⁴Department of Anatomy, Faculty of Medicine, Düzce University, Düzce; ⁵Department of Anatomy, Faculty of Medicine, İzmir Bakırçay University, İzmir; ⁶Department of Radiology, Faculty of Medicine, Düzce University, Düzce. Turkey

Abstract

Objective: The aim of this study is to estimate gender using parameters obtained from the sphenoid sinus in computed tomography (CT) images, utilizing Machine Learning (ML) algorithms and Artificial Neural Networks (ANNs). **Method:** In this study, length, width, and volume measurements of the sphenoid sinus were evaluated from CT images of 300 individuals (150 males and 150 females) aged 18-65 years. Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis, Logistic Regression (LR), Extra Tree Classifier, Random Forest, Decision Tree (DT), Gaussian Naive Bayes (GaussianNB), K-Nearest Neighbors (k-NN) algorithms, and ANN model were used for gender prediction. **Results:** The length, width, and volume of the sphenoid sinus on both the left and right sides were found to be significantly higher in males compared to females ($p < 0.05$). The performance values of the ML algorithms were found as follows: LDA 0.82; k-NN 0.80; LR 0.84; GaussianNB 0.80; DT 0.82; and ANN 0.82. **Conclusions:** Morphometric measurements of the sphenoid sinus, when analyzed with the LDA, LR, DT, and ANN algorithms, showed high accuracy and provided reliable data for sex estimation.

Keywords: Artificial neural networks. Machine learning algorithms. Gender estimation. Sphenoid sinus.

Resumen

Objetivo: Predecir el sexo mediante el uso de algoritmos de aprendizaje automático y redes neuronales artificiales a partir de parámetros del seno esfenoidal medidos en imágenes de tomografía computarizada (TC). **Método:** Se evaluaron las mediciones de longitud, ancho y volumen del seno esfenoidal de imágenes de TC de 300 individuos, 150 hombres y 150 mujeres, con un rango de edad de 18 a 65 años. Se utilizaron los algoritmos de análisis discriminante lineal (LDA), análisis discriminante cuadrático (QDA), regresión logística (LR), clasificador de árbol extra (ETC), bosque aleatorio (RF), árbol de decisión (DT), Gaussian Naive Bayes (GaussianNB), vecinos más próximos (k-NN) y modelo de redes neuronales artificiales (ANN) para la predicción del sexo. **Resultados:** Las longitudes, anchuras y volúmenes del seno esfenoidal izquierdo y derecho fueron significativamente mayores en los hombres que en las mujeres ($p < 0.05$). Los valores de rendimiento de los algoritmos de aprendizaje automático fueron los siguientes: LDA 0.82, k-NN 0.80, LR 0.84, GaussianNB 0.80, DT 0.82 y ANN 0.82. **Conclusiones:** Las medidas morfométricas del seno esfenoidal, analizadas con los algoritmos LDA, LR, DT y ANN, mostraron alta precisión y proporcionaron datos fiables para la predicción del sexo.

Palabras clave: Redes neuronales artificiales. Algoritmos de aprendizaje automático. Predicción del sexo. Seno esfenoidal.

*Correspondence:

Deniz Senol

E-mail: denizanatomi@gmail.com

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Introduction

Determining gender is one of the crucial steps in identifying an individual. Therefore, gender estimation based on measurements obtained from bones of the human skeleton is widely used, particularly in forensic medicine¹⁻³. Due to the preservation of sinuses in deep locations during cases such as burns, paranasal sinuses play a prominent role in gender determination⁴.

The sphenoid sinus begins to develop in the 3rd-4th month of gestational age, and it contains no air in newborns. Its development starts around 3-4 years after birth and continues until adolescence (12-16 years)^{5,6}. By connecting the viscerocranium and neurocranium bones through its articulations, it occupies a crucial and deeper position among the skull bones⁷. Particularly in cases where the maxillary and frontal sinuses are damaged or absent, the deeper position of the sphenoid sinus makes it an important structure for gender estimation^{7,8}. Of the paranasal sinuses, especially the maxillary and frontal sinuses have been widely evaluated for sex prediction⁹⁻¹¹. Several studies have evaluated the accuracy and reliability of sphenoid sinus morphometric features for gender estimation using various methods^{5,6,12}. Research investigating the accuracy of the sphenoid sinus for gender prediction across different populations has used methods such as discriminant function analysis and logistic regression (LR)^{7,13,14}.

In anthropology and forensic sciences, machine learning (ML) algorithms are increasingly used to evaluate the accuracy and reliability of gender estimation from human remains with unknown gender, alongside traditional methods such as discriminant function analysis or linear regression analysis^{2,3,15-17}. In ML, various algorithms, each with advantages and disadvantages, achieve prediction results using statistical, probabilistic, and optimization methods applied to large data sources^{18,19}. Decision Tree (DT), one of the oldest algorithms, is a descriptive and predictive supervised learning method consisting of roots, decision nodes, branches, and leaves. Random Forest (RF) combines the decisions of multiple trees through randomization¹⁸. Extra Trees Classifier (ETC) is similar to RF. However, it differs from tree-based algorithms in that it randomly splits the nodes and uses all the learning data to grow the trees²⁰. LR estimates the probability of a sample belonging to a specific class¹⁹. Gaussian Naive Bayes (GaussianNB) calculates the probability of a state based on prior knowledge of the conditions relevant to that state¹⁹. K-Nearest Neighbors (k-NN) is a supervised

algorithm that predicts the classification of unlabeled data by considering the characteristics of the training data²¹. Linear Discriminant Analysis (LDA) categorizes new members by typifying the differences between groups through linear combinations of predictive data that best separate the groups²². Quadratic Discriminant Analysis (QDA) is used when the covariance matrices of the groups are different²³. Artificial neural networks (ANN) are a subset of ML that simulates the signaling process of neurons in the human brain¹⁸.

There are studies on gender prediction using deep learning neural networks from the volume of all paranasal sinuses, and specifically from the frontal and maxillary sinuses^{16,24}. However, no study in the accessible literature has been found that evaluates the accuracy and reliability of gender estimation from the sphenoid sinus using ML methods.

Various imaging methods, including conventional radiography, CT, and cone beam CT, are employed in forensic medicine to predict gender based on morphometric data from the human skeleton. CT is considered the gold standard for imaging paranasal sinuses^{5,12,25}. CT scans enable better identification of craniometric points, making it easier to calculate morphometric features such as length, area, and volume²⁵.

Based on the knowledge gathered from our research, this study aims to investigate whether the length, width, and volume measurements of the sphenoid sinus from CT images exhibit sexual dimorphism and to evaluate the accuracy and reliability of ML methods and ANNs in predicting gender using morphometric data from the sphenoid sinus.

Method

This study was conducted using CT images of the sphenoid sinus from 110 female and 110 male individuals, aged 18-50 years. The CT images were randomly selected from the Picture Archiving and Communication Systems (PACS) archive at Düzce University Hospital between 2021 and 2024, and the measurements were performed.

CT images from patients who had undergone surgery on the sphenoid sinus, presented artifacted images, exhibited abnormal asymmetry in the region, or displayed positional errors during the scan were excluded from the study. This retrospective study was approved by the local non-invasive ethics committee of Düzce University on 18 December 2023, with the decision number 2023/196.

The CT scans were obtained using a Siemens (model Somatom Definition AS) 128-slice CT device.

The scanning parameters were as follows: kV (kilovoltage): 100, mAs (milliampere-seconds): 49, scan time: 2 s, field of view: 163 mm, and slice thickness: 0.6mm.

After examining the images in the PACS system, the following measurements were performed for the right and left sphenoid sinuses (Figs. 1 and 2):

1. Sphenoid sinus volume
2. Sphenoid sinus length
3. Sphenoid sinus width.

ML algorithms process

ML algorithms were executed on a personal computer with the Monster Abra i5 operating system. Python 3.9 programming language and scikit-learn 1.1.1 framework were used. Eighty percent of the raw data was used as the training set. The input layer for the ML algorithms consisted of measurement parameters, and the output layer was determined as gender. The following ML models were used: LDA, QDA, LR, ETC, RF, DT, GaussianNB, and k-NN. Accuracy (Acc), Specificity (Spe), Sensitivity (Sen), and F1 score (F1) were used as performance criteria. The Shapley Additive Explanations (SHAP) analyzer from the RF algorithm was used to evaluate the contribution of the parameters to the overall outcome. The Multilayer Perceptron Classifier (MLCP) was used as the ANN model. Six neurons were used in the input layer, two neurons in the output layer, ten neurons in the first hidden layer, and fifteen neurons in the second hidden layer. To reflect real learning in the network topology, re-training was performed 100, 500, and 1000 times. The same performance criteria as in ML were preferred.

$$Acc = \frac{TP}{TP + FN + FP + TN}$$

$$Sen = \frac{TP}{TP + FN}$$

$$Spe = \frac{TN}{TN + FP}$$

$$F1 = 2 \frac{Precision \times Recall}{Precision + Recall}$$

Equation 1. (TP; True positive, TN; True negative, FP; False positive, FN; False negative).

Statistical analysis

The normal distribution of the data was tested with the Anderson-Darling test, and for non-normally

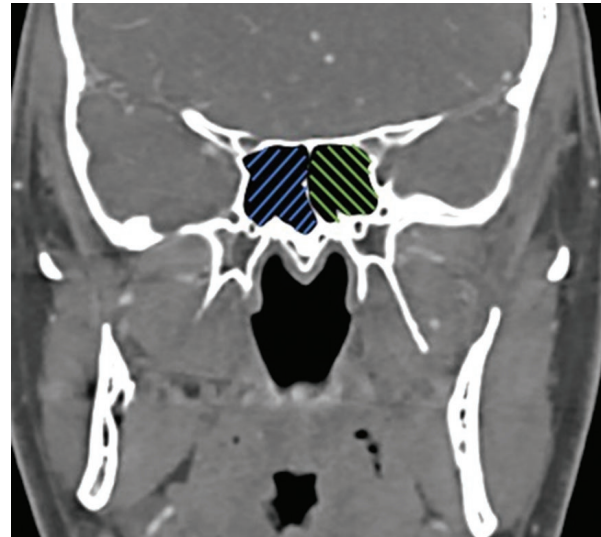


Figure 1. Right and left sphenoid sinus area in coronal section.

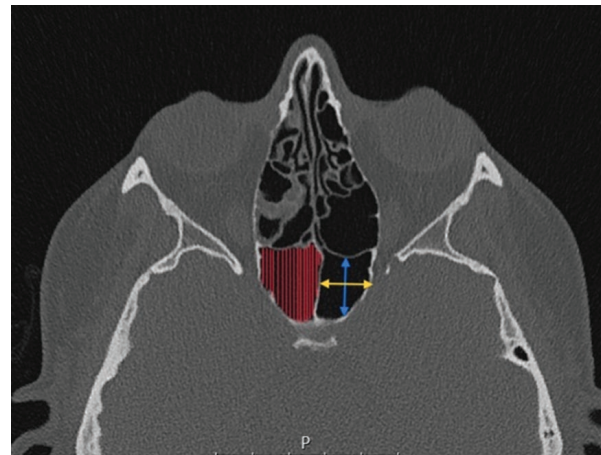


Figure 2. Red shaded area: Sphenoid sinus volume. Blue arrow: Sphenoid sinus length. Yellow arrow: Sphenoid sinus width.

distributed data, the median, minimum, and maximum values were used. For comparisons regarding gender, the Mann-Whitney U test was applied to non-normally distributed data. Minitab 17 statistical software was used for analysis, and $p < 0.05$ was considered statistically significant.

Results

The Anderson-Darling test revealed that none of the parameters followed a normal distribution. Descriptive statistics for the parameters and gender comparisons are presented in table 1.

The highest accuracy (Acc) rate from the ML algorithms was found to be 0.84 with the LR algorithm (Table 2).

Table 1. Descriptive statistics of the parameters and gender comparisons

Parameters	Gender	Median (Min.-Max.)	p
Left sphenoid sinus length	Female	21.700 (11.100-42.800)	0.5825
	Male	22.400 (10.400-31.900)	
Left sphenoid sinus width	Female	15.600 (8.300-26.300)	0.284
	Male	16.300 (9.160-25.300)	
Left sphenoid sinus volume	Female	5.400 (2.940-11.800)	0.000
	Male	4.860 (1.110-7.560)	
Right sphenoid sinus length	Female	19.350 (10.300-32.500)	0.000
	Male	23.500 (10.800-32.700)	
Right sphenoid sinus width	Female	15.250 (9.200-26.900)	0.010
	Male	16.700 (8.000-27.400)	
Right sphenoid sinus volume	Male	5.425 (1.180-11.100)	0.001
	Female	5.050 (1.340-8.540)	

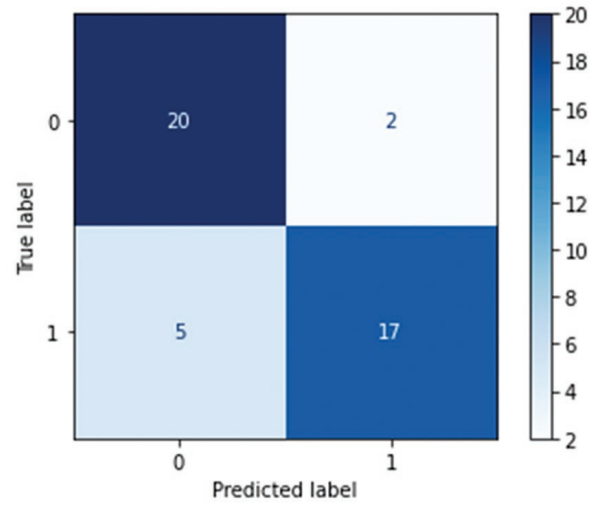
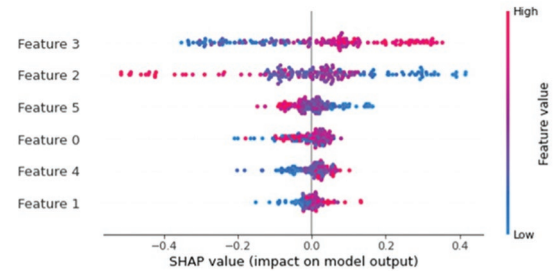
Table 2. Machine learning algorithms performance results

Algorithms	Acc	Spe	Sen	F1
LDA	0.82	0.82	0.82	0.82
QDA	0.75	0.75	0.75	0.75
k-NN (k=5)	0.80	0.80	0.80	0.80
LR	0.84	0.85	0.84	0.85
GaussianNB	0.80	0.80	0.80	0.80
RFC	0.75	0.75	0.75	0.75
DT	0.82	0.82	0.82	0.82
ETC	0.77	0.77	0.77	0.77

Acc: accuracy; Spe: specificity; Sen: sensitivity; F1: f1 score; LDA: linear discriminant analysis; QDA: quadratic discriminant analysis; LR: logistic regression; ETC: extra tree classifier; RF: random forest; DT: decision tree; GaussianNB: gaussian naive bayes; k-NN: k-nearest neighbors.

The confusion matrix of the LR algorithm with the highest Acc rate is shown in figure 3. Out of 22 male individuals, 20 were correctly predicted, while 17 out of 22 female individuals were correctly predicted.

The contribution of the parameters to the overall outcome was evaluated using the SHAP analyzer, revealing that the right sphenoid sinus length, left sphenoid sinus volume, right sphenoid sinus volume, left sphenoid sinus length, right sphenoid sinus width, and left sphenoid sinus width contributed in this order (Fig. 4).

**Figure 3. Confusion matrix table****Figure 4. SHAP analyzer (feature 0: right sphenoid sinus volume, 1: left sphenoid sinus width, 2: right sphenoid sinus length, 3: left sphenoid sinus volume, 4: right sphenoid sinus width, 5: left sphenoid sinus length).**

The highest Acc rate in the ANN's MLCP model was found to be 0.82 after 1000 training iterations (Table 3).

Discussion

Forensic anthropologists use various parts of the body to determine the gender of unidentified skeletons, one of which is the paranasal sinuses. Sinuses are often preserved even in cases of severe skull damage, making them a valuable tool in gender determination²⁶. In this study, the length, width, and volume measurements of the sphenoid sinus on both the right and left sides were obtained from CT images, and the performance values of the ML algorithms were found to be: LDA 0.82; k-NN 0.80; LR 0.84; GaussianNB 0.80; DT 0.82; and ANN 0.82. These accuracy rates are considered acceptable in forensic science, where gender estimation accuracy is generally between 80% and 90%²⁷. However, the QDA and RFC algorithms,

Table 3. Artificial neural networks performance

Learning number	Acc	Spe	Sen	F1
100	0.80	0.81	0.80	0.79
500	0.80	0.80	0.80	0.80
1000	0.82	0.83	0.82	0.82

Acc: accuracy; Spe: specificity; Sen: sensitivity; F1: f1 score.

with accuracy rates of 0.75, and the ETC algorithm with 0.77, were found to be less reliable for gender estimation in this study compared to other methods.

In the literature, gender estimation from paranasal sinuses has been conducted using different methods, yielding varying accuracy rates. In Sancaklı's study, right and left sphenoid sinus volume measurements were performed. The right sphenoid sinus volume was found to be higher in males aged 20-30 years than in females, but this difference was not statistically significant. However, in males aged 30-40 years, the right sphenoid sinus volume was significantly higher than in females, consistent with our study. The left sphenoid sinus volume was also significantly higher in males compared to females in both the 20-30 and 30-40 age groups²⁸. Similarly, Digilli's study found that the sphenoid sinus volume was significantly higher in males than in females, aligning with our results²⁹. In Banihashem et al.'s study, sphenoid sinus volumes were measured using the 3D slicer method, and the results showed significantly higher volumes in males compared to females, in agreement with our findings. They determined that the ability of the sphenoid sinus volume to predict gender was 86% for males and 92.9% for females¹³. Tuang et al. also measured the sphenoid sinus volume in CT images and found that it was significantly higher in males than in females, consistent with our study¹⁴. Özer et al.'s study also showed that the right and left sphenoid sinus volumes were higher in males compared to females, in line with our results⁷. In Topal's study, the right sphenoid sinus length was found to be significantly higher in males compared to females, similar to our findings. The left sphenoid sinus length was also higher in males, but did not show a statistically significant difference ($p > 0.05$). The right sphenoid sinus width was significantly higher in males, consistent with our study, while the left sphenoid sinus width was higher in males but not statistically significant in our results³⁰. In our study, the most decisive variable for gender estimation was the right sphenoid sinus length, while the least decisive was the left sphenoid sinus width.

Ahmed et al. measured the length and width of the frontal and sphenoid sinuses and used stepwise discriminant function analysis for gender determination. They found that the equation derived from stepwise discriminant function analysis could aid in gender determination with an accuracy of 76.5%⁵. Gurlek Celik and Akman measured the volumes of the sphenoid and ethmoid sinuses using the 3D slicer method and found that the left sphenoid sinus volume was significantly higher in males, consistent with our study¹². Hekimoğlu et al. found that the paranasal sinus volumes were significantly higher in males compared to females, consistent with our findings. They reported that the frontal sinus contributed the most to gender determination, while the sphenoid sinus contributed the least¹⁶. In our study, the left sphenoid sinus volume was found to be more decisive for gender determination compared to the right sphenoid sinus volume. Wanzeler et al. measured the volumes of the frontal, maxillary, and sphenoid sinuses using the ITK-SNAP method. They found that the volumes of the maxillary, frontal, and sphenoid sinuses were significantly smaller in female subjects compared to male subjects. When the volumes of the evaluated paranasal sinuses were combined, the chance of correctly determining gender was found to be 96.2% for males and 92.7% for females⁶. In our study, left sphenoid sinus volume was found to be more determinative than right sphenoid sinus volume in sex determination.

In Şimşek et al.'s study, the height, width, volume, depth, and anteroposterior length of the frontal sinus were found to be significantly higher in males than in females. The thickness of the anterior wall of the frontal sinus was also higher in males, but was not statistically significant. The authors concluded that the frontal sinus dimensions were larger in males than in females, with a gender estimation accuracy of 78.8%³¹. In another study by Şimşek et al., all dimensions of the left maxillary sinus were significantly higher in males, except for the right maxillary sinus volume. Gender was correctly identified with 65% accuracy in females, 70% in males, and 67.5% overall; however, these results were considered insufficient for gender estimation¹⁰. In Michel et al.'s study, the frontal sinus volume was measured using CT images, and their model classified 72.5% of cases correctly by gender⁹. Among the paranasal sinuses, our study found that the sphenoid sinus demonstrated high accuracy for gender estimation.

ANNs are advantageous as they allow for rapid classification evaluation based on data without depending

on individuals^{1,32}. In the MLCP model of ANN, the error rate is minimized through forward and backward propagation, allowing for re-evaluation. In this case, increasing the number of training iterations, adjusting the number of layers, and having a larger dataset enhances its effectiveness³³. Şenol et al. achieved the highest accuracy value of 0.82 in their study using measurements from the foramen incisivum, which they obtained after 500 training iterations³. Öner et al., in their study estimating gender from the sternum using the ANN method, reported an accuracy between 0.83 and 0.97¹. In another study comparing discriminant analysis and ANN methods for gender estimation from femur head circumference and transverse diameter, ANN showed higher accuracy rates³⁴. In Hamidi et al.'s study, paranasal sinus measurements were taken using the ITK-SNAP program. A hybrid model called the Genetic Algorithm-Deep Neural Network (GADNN) was proposed for feature selection and classification. LR, RF, multilayer perceptron neural network, and deep learning (DL) models were evaluated for their performance. GADNN showed 86% accuracy in gender estimation, while DL and RF showed 78% and 71% accuracy, respectively²⁴. Yaşar et al. conducted measurements of the maxillary sinuses and used latent class analysis (LCA) for gender determination. In their analysis, model 1, which included measurements and volume variables from the right and left maxillary sinuses, classified gender with 59.6% accuracy. Model 2, which used the width, depth, height, and total area measurements from the right and left maxillary sinuses, classified gender with 65.4% accuracy. Model 4, which used volume variables calculated by the elliptical method for the right and left maxillary sinuses, classified gender with 75% accuracy, but it could classify almost all women correctly while failing to classify men. Model 5, which included all variables with significant gender differences, classified gender with 67.3% accuracy¹¹. In this study, the data were also tested using the MLCP model of ANN, and an accuracy rate of 0.82 was achieved in training. The highest obtained accuracy value was 0.82, similar to the algorithms used in other ML models such as LDA and DT. Its performance was higher than methods like RFC, ETC, GaussianNB, QDA, and k-NN, but lower than LR.

Lentzen et al. found the mean volume of the sphenoid sinus to be 4.438 ± 2.434 and 4.809 ± 3.000 cm³ on the right and left, respectively. In the related study, the total volume of the sphenoid sinus was found to be statistically significantly higher in males³⁵. In another study, the mean volume of the left and right

sphenoid sinuses was measured as 4.58 cm³ and 5.00 cm³, respectively. The total volume was also found to be higher in males³⁶. Cohen et al. found the volume of the right and left sphenoid sinus to be 3.12 cm³ and 3.04 cm³ in females and 4.65 cm³ and 4.29 cm³ in males, respectively. The total volume was found to be statistically higher in males³⁷. These findings align closely with the results of our study.

One of the main limitations of this study, which was conducted on radiological images from a total of 220 individuals, is the sample size. We believe that increasing the sample size and the number of ANN tests for evaluating sphenoid sinus data would lead to higher performance values in gender estimation. We anticipate that our study will serve as a guide for future research with larger sample sizes, evaluating additional morphometric parameters of the sphenoid sinus or other sinuses.

Conclusions

Gender estimation, which is crucial in forensic anthropology, was performed in this study using morphometric data from the sphenoid sinus obtained from CT images, applying both ML and ANN algorithms. The highest performance values were found in the algorithms LDA (0.82), k-NN (0.80), LR (0.84), GaussianNB (0.80), and DT (0.82). The highest accuracy was achieved with the ANN algorithm. Especially in forensic medicine, sphenoid sinus data can be used to determine biological identity due to its deep location in cases such as burns and severe injuries. Furthermore, our study found that the dimensions of the sphenoid sinus were larger in males than in females in the Anatolian population. It contributes to the literature by addressing the anatomical differences between males and females in surgical interventions involving this region. This is the first study in the accessible literature to estimate gender using ML and ANN algorithms from sphenoid sinus morphometric data. This is the first study in the accessible literature to estimate gender using ML and ANN algorithms from sphenoid sinus morphometric data. It is believed that this study will serve as a guide for future research, which may use larger samples or evaluate different paranasal sinuses. In addition, future studies could examine the accuracy, specificity, sensitivity, and F1 score values by modifying the number of hidden layers in the MLCP model and increasing the sample size.

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Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of humans and animals. The authors declare that the procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation and with the World Medical Association and the Declaration of Helsinki. The procedures were authorized by the Institutional Ethics Committee.

Confidentiality, informed consent, and ethical approval. The authors have obtained approval from the Ethics Committee for the analysis of routinely collected and anonymized clinical data; therefore, individual informed consent was not required. Relevant ethical recommendations have been followed.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing or creation of the content of this manuscript.

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