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Machine Learning Algorithms for Sex Classification by Using Variables of Orbital Structures: A Computed Tomography Study

Algoritmos de Aprendizaje Automático para la Clasificación del Sexo Mediante el Uso de Variables de Estructuras Orbitales: Un Estudio de Tomografía Computarizada

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SUMMARY: Since machine learning algorithms give more reliable results, they have been used in the field of health in recent years. The orbital variables give very successful results in classifying sex correctly. This research has focused on sex determination using certain variables obtained from the orbital images of the computerized tomography (CT) by using machine learning algorithms (ML). In this study 12 variables determined on 600 orbital images of 300 individuals (150 men and 150 women) were tested with different ML. Decision tree (DT), K-Nearest Neighbour (KNN), Logistic Regression (LR), Random Forest (RF), Linear Discriminant Analysis (LDA), and Naive Bayes (NB) algorithms of ML were used for unsupervised learning. Statistical analyses of the variables were conducted with Minitab® 21.2 (64-bit) program. ACC rate of NB, DT, KNN, and LR algorithms was found as % 83 while the ACC rate of LDA and RFC algorithms was determined as % 85. According to Shap analysis, the variable with the highest degree of effect was found as BOW. The study has determined the sex with high accuracy at the ratios of 0.83 and 0.85 through using the variables of the orbital CT images, and the related morphometric data of the population under question was acquired, emphasizing the racial variation.

KEY WORDS: Sex determination; Machine learning; Orbital aperture; Three-dimensional computed tomography.

INTRODUCTION

Forensic anthropology aims to reconstruct the biological profile of anatomical structures which have been disintegrated and the primary step of this process is sex determination (Can *et al*., 2022). Literature reports have indicated that the skeletal part that reflects the sexual dimorphism best is the pelvis, followed by cranium, upon performing forensic sex determination (Ragab Slima & Ragab Abdou, 2020; Can *et al*. 2022). Moreover, the variables related to width in particular at the head and face regions has revealed the best results in sexual dimorphism (Ragab Slima & Ragab Abdou, 2020). Although DNA analysis is a valuable method in sex determination, it is not preferred much in major disasters such as natural disasters and war, due to the long duration and cost of the process (Mani *et al*., 2020). Anthropology also makes classifications by using machine learning algorithms (MLA), which have increasingly been used in sex determination processes in recent years (Toy *et al*., 2022).

The orbit is very vital component of the craniofacial skeleton for clinicians due to its complex anatomy in nature, and proximity to intracranial regions, nose, and paranasal sinuses (Pirinç *et al*., 2022; Khani *et al*., 2023). Studies have proven that the craniofacial region measurements, including orbital variables provide good results in sex determination (Fang *et al*., 2011).

However, it has been noted that there are limited number of studies focusing on sex determination out of the craniofacial region by using MLA method in Turkish population, and as to our knowledge, there is no report particularly focusing on the orbit (Curate *et al*., 2017; Toy *et al*., 2022; Senol *et al*., 2023). This study therefore has been designed to acquire the relationship between the orbit and sex determination by using morphometric variables of three-dimensional computed tomography (CT) images. The data obtained hereby surely create a database about Turkish population and be a reference for future studies.

MATERIAL AND METHOD

The study was initiated with 2023/93 numbered approval of Clinical Research Ethics Committee. A number of 600 orbit CT images of 300 individuals (150 women, 150

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men) randomly chosen from the Picture Archiving and Communication Systems (PACS) archive were used in the study. Images taken between January 2021 and April 2023 in Dicom format were chosen from the system and transferred to personal workstation Radiant Dicom Viewer (RDV) program. In RDV program, images with a section thickness of 0.625 mm were converted into 3D MPR. In the study, maximum distance between the upper and lower walls of the right orbit (ULDR), maximum distance between the upper and lower walls of the left orbit (ULDL), maximum distance between the inner and outer walls of the right orbit (IODR), maximum distance between the inner and outer walls of the left orbit (IODL), interorbital width (IOW), distance between the right infraorbital foramen and the lower wall of the right orbit (FIR), distance between the left infraorbital foramen and the lower wall of the left orbit (FIL), right orbital height (OHR), left orbital height (OHL), right orbital width (OWR), left orbital width (OWL), biorbital width (BOW) were measured. The variables measured are shown in Figure 1.

Unsupervised learning machine learning Decision tree (DT), K-Nearest Neighbour (KNN), Logistic Regression (LR), Random Forest (RF), Linear Discriminant Analysis (LDA), and Naive Bayes (NB) algorithms were used in the study. Precision (pre), recall (rec), F1 score (F1), accuracy (acc) values were used as evaluation criteria. Machine learning algorithms were written with a computer that had Huawei Matebook 13 Ryzen 7 (64 bit) 16 gb ram 512 gb ssd specifications.

Statistical Analyses. Statistical analyses of the variables were conducted with Minitab® 21.2 (64-bit) program. Normality of the variables was tested with Anderson Darling test. Mean and standard deviation (sd) values of parametric data and median, minimum (min), maximum (max) values of nonparametric data were calculated. Differences between sexes were tested with two simple t test in parametric variables, while nonparametric variables were tested with Mann Whitney u test. Logarithmic transformations of nonparametrically determined variables were made. As a result of transformation, variance analysis was tested with Cochran q test. As a result of the test, the variables with equal variances for women and men were back transformed and 95 % confidence intervals were calculated based on a standard deviation.

RESULTS

Median value of the age variable was calculated as 46 in men and as 44 in women. Table I shows descriptive statistics of the variables, and p values as a result of two simple t test and Mann Whitney u test. As far as the sex was concerned, the difference was statistically significant among all the parameters of the variables other than the age variable.

While ACC rate of NB, DT, KNN and LR algorithms was found as % 83, that of LDA and RFC algorithms was found as % 85. Tables II and III shows the results of algorithms and Kfold cross validation results (ACC %). Confusion matrix (cm) and ROC curve as a result of

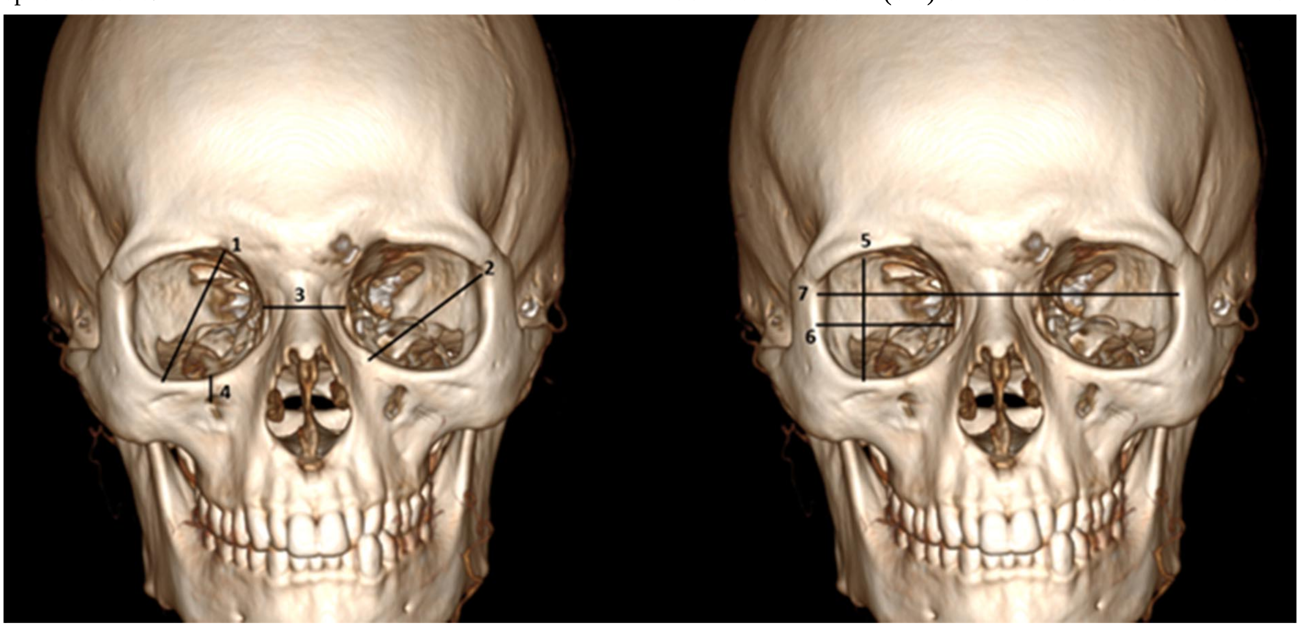

Fig. 1. Demonstrations of the variables; 1- ULDR, 2- IODL, 3- IOW, 4- FIR, 5- OHR, 6- OWR, 7- BOW. ULDR: Maximum distance between the upper and lower walls of the right orbit, IODL: Maximum distance between the inner and outer walls of the left orbit, IOW: Interorbital width, FIR: Distance between the right infraorbital foramen and the lower wall of the right orbit, OHR: Right orbital height, OWR: Right orbital width, BOW: Biorbital width.

algorithms are shown in sure 2 and 3. Shap analysis found that BOW variable had the highest effect degree (Fig. 4).

Table I. Descriptive statistics results and p values of the variables.

Variables	Male (n: 150)	Female (n: 150)	p value
Age	46.00 (20.00-55.00)[a]	44.00 (20.00-55.00)[a]	0.774[c]
ULDR	3.84±0.28[b]	3.62±0.28[b]	< 0.001[d]
ULDL	3.83±0.27[b]	3.64±0.27[b]	< 0.001[d]
IODR	3.52±0.27[b]	3.41±0.26[b]	< 0.001[d]
IODL	3.49±0.26[b]	3.39±0.24[b]	< 0.001[d]
IOW	2.57±0.27[b]	2.37±0.30[b]	< 0.001[d]
FIR	0.99±0.18[b]	0.88±0.15[b]	< 0.001[d]
FIL	1.01 (0.53-9.90)[a]	0.86 (0.55-8.37)[a]	< 0.001[c]
OHR	3.32±0.25[b]	3.16±0.27[b]	< 0.001[d]
OHL	3.26±0.23[b]	3.10±0.27[b]	< 0.001[d]
OWR	3.63±0.19[b]	3.40±0.19[b]	< 0.001[d]
OWL	3.66±0.21[b]	3.46±0.18[b]	< 0.001[d]
BOW	10.11 (10.04-10.18)[e]	9.31 (9.45-9.58)[e]	< 0.001[d]

a: median (min-max), b: mean±sd, c: p value as a result of Mann Whitney u test, d: p value as a result of two simple t test, e: 95 % confidence interval calculated based on Logaritmic transformation. ULDR (between the upper and lower walls of the right orbita), ULDL (between the upper and lower walls of the left orbita), IODR (between the inner and outer walls of the right orbita), IODL (between the inner and outer walls of the left orbita), IOW (interorbital width), FIR (between the right foramen infraorbitale and the lower wall of the right orbita), FIL (between the left foramen infraorbitale and the lower wall of the left orbita), OHR (right orbital height), OHL (left orbital height), right orbital width (OWR), left orbital width (OWL), BOW (biorbital width).

Table II. Analysis results of machine learning algorithms (%).

Algorithm	Precision	Recall	F1 score	Accuracy
NB	0.83	0.83	0.83	0.83
DT	0.86	0.83	0.83	0.83
KNN	0.83	0.83	0.83	0.83
LDA	0.85	0.85	0.85	0.85
LR	0.83	0.83	0.83	0.83
RFC	0.85	0.85	0.85	0.85

Naive Bayes (NB), Decision tree (DT), K-Nearest Neighbour (KNN), Linear Discriminant Analysis (LDA), Logistic Regression (LR) and Random Forest (RF).

Table III. Kfold cross validation results (ACC %).

Testing set	LR	DT	KNN	LDA	NB	RF
1	0.60	0.63	0.80	0.67	0.70	0.80
2	0.80	0.53	0.60	0.80	0.77	0.67
3	0.67	0.73	0.80	0.67	0.73	0.73
4	0.90	0.83	0.83	0.87	0.90	0.83
5	0.60	0.80	0.70	0.60	0.87	0.70
6	0.53	0.77	0.73	0.60	0.73	0.80
7	0.73	0.63	0.83	0.77	0.77	0.87
8	0.70	0.83	0.67	0.67	0.73	0.87
9	0.87	0.63	0.77	0.87	0.73	0.80
10	0.70	0.60	0.77	0.67	0.77	0.77
Mean	0.71	0.70	0.75	0.72	0.77	0.78
Std	0.12	0.11	0.08	0.10	0.06	0.07

Logistic Regression (LR), Decision tree (DT), K-Nearest Neighbour (KNN), Linear Discriminant Analysis (LDA), Naive Bayes (NB), Random Forest (RF) and ACC %: Accuracy rate.

DISCUSSION

The location and topography of the needs to be paid attention in ophthalmology, and maxillofacial and neurosurgery due to its internal and surrounding structural peculiarities. The risk of injury to the nerves in or around the orbit is quite high during surgical operations. Because of these facts, morphometric parameters of it have been the subject of the research for years. Moreover, sex determination studies out of the orbital morphometry have recently been accumulating even though no such study has been conducted in focusing on the topic through machine learning method. With this in mind, our study is the first research methodologically aiming at sex determination using the orbital morphometry by ML. In the study, while the accuracy rate in sex determination found by this method was 83 % and 85 %, it was determined that the parameter with the highest effect on these rates was BOW.

Studies conducted on Turkish population (Kaya *et al*., 2014; Sinanoglu *et al*., 2016; Açar *et al*., 2019), have shown that the orbital height is statistically higher in males than females (p?0.05). Likewise, in another study conducted to evaluate the orbital width and height in the Turkish population, no statistically significant results have been found between women and men; in the side comparison made in the same study, the right side (Özer *et al*., 2016). Another research also conducted in the Turkish population, has determined the mean orbital width as 32.94 mm in women and 34.66 mm in men (Can *et al*., 2022). In our study, the orbital width and height parameters have been evaluated separately as the right and left, finding to be significantly higher in men than in women, displaying similarity with the literature.

Similarly, in another study on skulls obtained from medieval cemeteries in Poland, the orbital heights of the right and left sides have been evaluated, finding the fact that the parameter of the left side is significantly higher ($p<0.05$). On the other hand, there have been reports in the literature indicating no significant difference between the orbital heights of the Indian and Egyptian populations as far as the sides are concerned (Rajangam *et al*., 2012; Senthil Kumar & Gnanagurudasan, 2015; Ghorai *et al*., 2017; Attia *et al*., 2019; El-Farouny *et al*., 2021). Contrarily, this parameter has been documented in our study to be

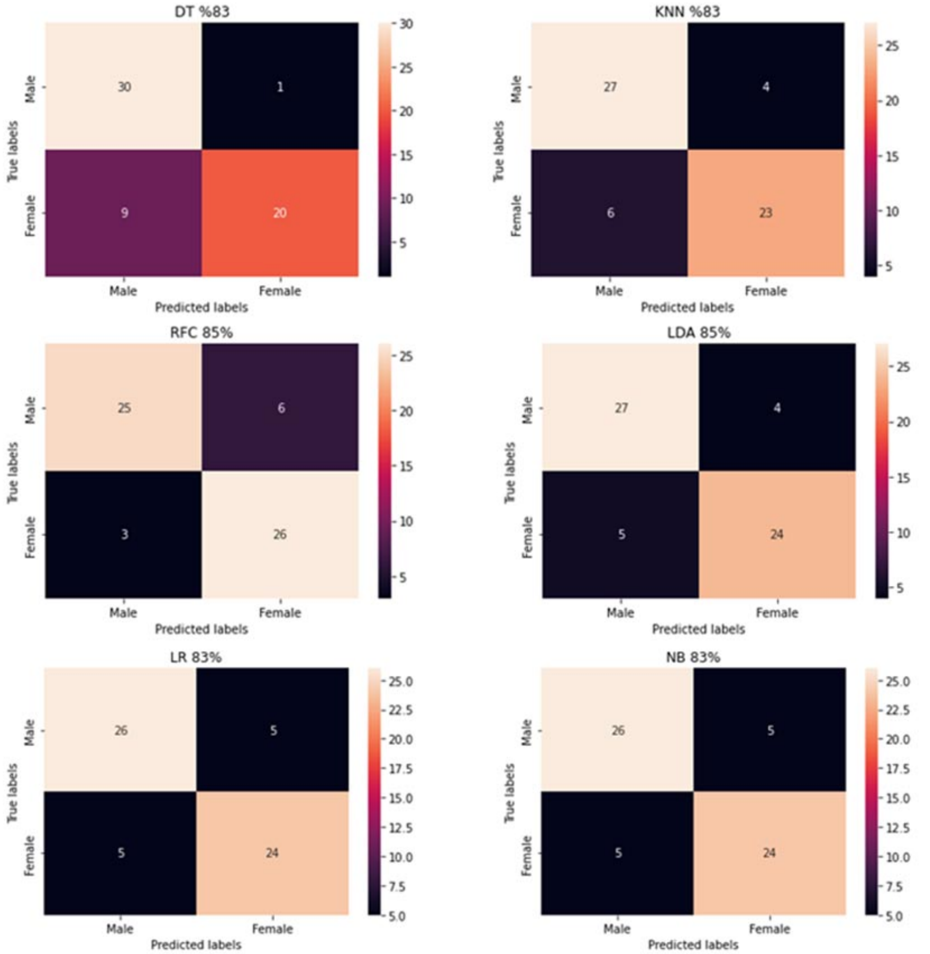

Fig. 2. Algorithm results.Logistic Regression (LR), Decision tree (DT), K-Nearest Neighbour (KNN), Linear Discriminant Analysis (LDA), Naive Bayes (NB), Random Forest (RF).

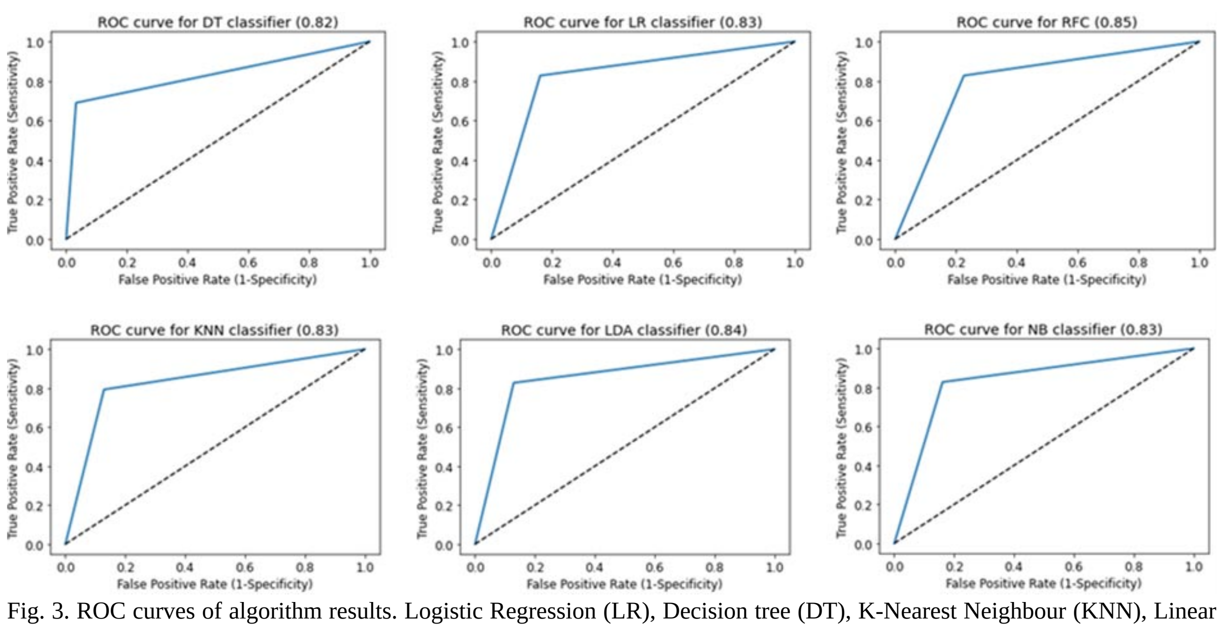

Fig. 3. ROC curves of algorithm results. Logistic Regression (LR), Decision tree (DT), K-Nearest Neighbour (KNN), Linear Discriminant Analysis (LDA), Naive Bayes (NB), Random Forest (RF).

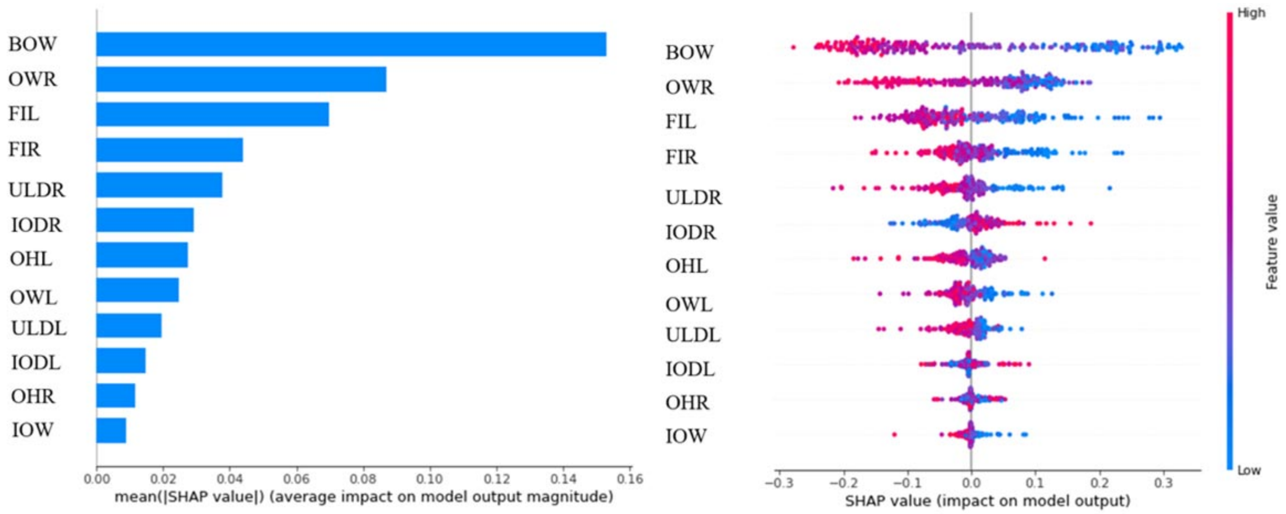

Fig. 4. SHAP analysis results. BOW: Biorbital width, OWR: Right orbital width, FIL: Distance between the left infraorbital foramen and the lower wall of the left orbit, FIR: Distance between the right infraorbital foramen and the lower wall of the right orbit, ULDR: Maximum distance between the upper and lower walls of the right orbit, IODR: Maximum distance between the inner and outer walls of the right orbit, OHL: Left orbital height, OWL: Left orbital width, ULDL: Maximum distance between the upper and lower walls of the left orbit, IODL: Maximum distance between the inner and outer walls of the left orbit, OHR: Right orbital height, IOW: Interorbital width.

significantly smaller in the left side, yielding to the suggestion that the orbital height is affected by the race in terms of sides.

In a study conducted in Turkey, BOW was measured as 95.07 mm in men and 90.51 mm in women (Can *et al*., 2022). Another research performed on Indian population calculated the orbital height (OH), orbital width (OW), and BOW and IOW parameters, without considering the sides, as OH: 32.670±1.468 and 32.211±1.741, OW: 39.083±1.848 and 37.836±1.179, BOW: 96.187±3.345 and 93.158±2.580, IOW: 20.395±1.907 and 19.793±1.677, in men and women, respectively (Saini *et al*., 2011). Yet, another paper examined the relationship between the orbital parameters and sex and age in five different age groups (10-19, 20-29, 30-39, 40-49, 50-59) by using a total of 200 digital radiography images of 107 men and 93 women, revealing no significant sex and age-related data. Hereby, the right orbital height and width were found to be greater than left, but the difference was insignificant. Additionally, the right and left orbital height and width, interorbital and biorbital distances were found to be higher in males than females, again showing insignificant differences. In the analysis of age groups, it was stated that there was no significant relationship between the parameters defined by age change, except for one age group (10-19 years) ($p > 0.05$) (Patra *et al*., 2021). Likewise, in our study, the results were as follows in men and women, respectively; OHR; 33.2 and 31.6, OHL; 32.6 and 31.0, OWR; 36.3 and 34.0, OWL; 36.6 and 34.6, BOW; 101.1 and 93.1, IOW; 25.7 and 23.7. Even though these results are numerically higher than the data in the literature, the difference is insignificant.

Literature has amply documented the anatomical structures and width measurements in the facial region regarding sex dimorphism (Steyn & Is¸can, 1998; Rogers *et al*., 2005; Kranioti *et al*., 2008). Both the orbital parameters and foramen magnum have been evaluated in a sex determination study performed on 300 cranial CTs in the Egyptian population, including 168 men and 132 women (Ragab Slima & Ragab Abdou, 2020). This study has stated the significant differences in the orbital height and width between the sexes. It has also stressed that evaluating the orbital parameters together with other skull parameters such as foramen magnum in sex determination increases the accuracy rates.

BOW value has been found as 95.07 mm in men and 90.51 mm in women in sex determination research from the parameters acquired out of the orbital CT images in the Turkish population (Can *et al*., 2022). This study has stated that the most determinant parameter reflecting sexual dimorphism is indeed BOW, with 73 % rate of classifying sex correctly. Yet, the same study has indicated the IOW value to be the least dimorphic parameter. Likewise, another study (Saini *et al*., 2011) has focused on the sex determination by the use of orbital height (OH), orbital width (OW), BOW and IOW parameters without making any distinction as right and left, revealing the results as follows for men and women, respectively; OH: 32.670±1.468 and 32.211±1.741, OW: 39.083±1.848 and 37.836±1.179, BOW: 96.187±3.345 and 93.158±2.580, IOW: 20.395±1.907 and 19.793±1.677. Again, this paper has indicated the BOW value as the most sexually dimorphic parameter. Inparallel with the literature indicated above, the results of Sharp analysis in our study has also found that the parameter with the highest dimorphism is BOW, and the parameter with the lowest dimorphism is IOW.

In a retrospective study of 100 3D CT images in Indian population including 50 women and 50 men, sex determination has been performed through using orbital morphometry (Mani *et al*., 2020). All parameters examined in the study except IOW have been found to be significant, with the prediction rate of 92.0 %. This study revealed that the orbital measurements are higher in men than in women, just as the case in our study.

Additionally, a study has examined the orbita by using 200 dry skulls, finding the extra-orbital distance to be the best parameter with the highest accuracy rate of 76.0 % (Jain *et al*., 2015) whereas in another study conducted on 92 skulls, only 68.5 % of cases were classified correctly (Sarkar & Mukhopadhyay, 2018). In addition, in the sex determination studies conducted by using the BOW parameter in the literature, it was found to be 67.9 % in the North Indian population (Saini *et al*., 2011), 72.5 % in the Croatian population (Radman *et al*., 2020), and 78.0 % in the USA population (Spradley & Jantz, 2011). However, this parameter has been found as 85 % through employing MLAs in our study, clearly expressing the fact that the MLAs is a very suitable tool for the sex determination. Limitations of the study, since our study has used images of the individuals with the same ethnic origin, no suggestion-conclusion can be made among the individuals with different ethnic origins. Indeed, increase in the sample size of the study will surely yield more concise results.

Consequently, geographical and racial differences have been stressed in the study. In addition to sex determination, our study also reveals the morphometric evaluation of the orbit, which is a very important region due to its neighbouring regions and the structures it contains, in Turkish population.

Sex determination is widely used in medicine (Demirkıran *et al*., 2014). The orbital variables give very successful results in classifying sex correctly. Upon evaluating both the literature and the data of this study, it is important to underline that not just the orbit, but the entire facial region should be analyzed in order to increase the accuracy rate of sex determination.

Recently, it has been reported that the risks of various diseases are determined by using artificial neural networks and MLAs [4,30,31,32] (Çetin *et al*., 2015; Er *et al*., 2015; Çetin & Temurtas¸, 2019; Toy *et al*., 2022). Overall, this study is the first research providing a sex determination data by evaluating orbital morphometry using MLAs.

SENOL, G.T.; KÜRTÜL, I.; RAY, A. & RAY, G. Algoritmos de aprendizaje automático para la clasificación del sexo mediante el uso de variables de estructuras orbitales: un estudio de tomografía computarizada. *Int. J. Morphol., 42(4)*:970-976, 2024.

RESUMEN: Dado que los algoritmos de aprendizaje automático dan resultados más fiables, en los últimos años han sido utilizados en el campo de la salud. Las variables orbitales dan resultados muy exitosos a la hora de clasificar correctamente el sexo. Esta investigación se ha centrado en la determinación del sexo utilizando determinadas variables obtenidas a partir de las imágenes orbitales de la tomografía computarizada (TC) mediante el uso de algoritmos de aprendizaje automático (AA). En este estudio se probaron 12 variables determinadas en 600 imágenes orbitales de 300 individuos (150 hombres y 150 mujeres) con diferentes AA. Se utilizaron algoritmos de AA de árbol de decisión (DT), K-Nearest Neighbour, regresión logística (RL), Random Forest (RF), análisis discriminante lineal (ADL) y Naive Bayes (NB) para el aprendizaje no supervisado. Los análisis estadísticos de las variables se realizaron con el programa Minitab® 21.2 (64 bits). La tasa de ACC de los algoritmos NB, DT, KNN y RL se encontró en % 83, mientras que la tasa de ACC de los algoritmos ADL y RFC se determinó en % 85. Según el análisis de Sharp, la variable con el mayor grado de efecto se encontró como BOW. El estudio determinó el sexo con alta precisión en las proporciones de 0,83 y 0,85 mediante el uso de las variables de las imágenes de TC orbitales, y se adquirieron los datos morfométricos relacionados de la población en cuestión, enfatizando la variación racial.

PALABRAS CLAVE: Determinación de sexo; Aprendizaje automático; Apertura orbital; Tomografía computarizada tridimensional.

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