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Determination of Sex Differences Using Machine Learning Algorithms and Artificial Neural Networks with Parameters Obtained from Basilar Artery

Determinación de Diferencias de Sexo Mediante Algoritmos de Aprendizaje Automático y Redes Neuronales Artificiales con Parámetros Obtenidos de la Arteria Basilar

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SECGIN, Y.; ERKARTAL, H. S.; TATLI, M.; TOY, S.; ONER, Z. & ONER, S. Determination of sex differences using machine learning algorithms and artificial neural networks with parameters obtained from basilar artery. *Int. J. Morphol., 42(5)*:1295-1300, 2024.

SUMMARY: The determination of sex differences in anatomical structures is critical in establishing gold standard morphometric data in basic medical sciences, and in surgical and internal sciences in selecting the right area during invasive intervention and applying the correct intervention methodology appropriate to the area. The aim of this study is to determine the sex difference using Machine learning (ML) algorithms and Artificial neural networks (ANN) with parameters obtained from basilar artery. The study was performed on computed tomography angiography images of 63 women and 94 men. The following parameters were measured on the images: initial width of the right vertebral artery, initial width of the left vertebral artery, termination width of the right vertebral artery, termination width of the left vertebral artery, basilar artery width, and basilar artery length. The measurements were used in ML algorithms and ANN input to determine sex differences. As a result of the study, a sex difference rate of 0.84 was determined with the ML algorithms Random Forest (RF), Quadratic Discriminant Analysis (QDA), Extra Tree Classifier (ETC) and 0.84 with the Multilayer Perceptron Classifier (MLCP) algorithm of ANN. As a result of the study, sex difference was found with an accuracy rate of 0.84 using ML algorithms and ANN with parameters obtained from basilar artery. In this context, we think that this study will shed light on basic and clinical medical sciences.

KEY WORDS: Basilar artery; Machine learning algorithms; Artificial neural networks; Sex difference.

INTRODUCTION

The basilar artery, which supplies the brain together with the internal carotid artery, derives its name from its location and is an important artery for the posterior supply of the brain formed by the vertebral artery that joins at the pontomedullary junction. It extends to the upper margin of the pons and then divides into two posterior cerebral arteries at variable levels (Standring, 2021). The normal morphology of this artery, which is considered to be the main blood supply of the hindbrain (pons, inner ear, cerebellum, temporal and occipital lobes), is an important criterion in cerebral circulation (Nagawa *et al*., 2018).

Problems in the circulation of the vertebrobasilar system can lead to inadequate blood flow in the posterior circulation of the brain and subsequent significant neurological consequences, dysfunction of many organs and even death (Einstein *et al*., 2016; Piccinin & Munakomi, 2023). Therefore, it is important to understand the anatomy and clinical significance of the vertebrobasilar system for many reasons, including evaluating neurologic syndromes, preoperative neurosurgical planning and preventing complications. Differences in the angle of origin, length and age of the basilar artery, which may be due to age, sex and variations, may predispose patients to posterior circulatory paralysis (Vasovic *et al*., 2013). Furthermore, the posterior cerebral circulation has less sympathetic innervation than the anterior cerebral circulation, resulting in less trophic support in the arterial wall, which may make the posterior cerebral vessels more vulnerable to morphological deformation when subjected to increases in pressure and blood flow (Gutierrez *et al*., 2011; Washio *et al*., 2020).

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Studies have shown that the length and tortuosity of the basilar artery have a high degree of variability (Pai *et al*., 2007), however it is noteworthy that the causes of these changes have not been determined in the literature and only aging and hemodynamic factors have been suggested to be responsible. Although there is limited literature associating changes in the basilar artery with aging (Nishikata *et al*., 2004; Jeong *et al*., 2015) it is important to note that there is no publication that reveals the differences between the sexes and deals with which parameter may be the most likely cause of these differences. Nowadays, with the development in technology, studies are carried out with Machine learning (ML) algorithms and Artificial neural networks (ANN) using many anatomical structures on the body and parameters on these structures in order to detect anatomical differences and reveal differences in sex (Secgin *et al*., 2022; Erkartal *et al*., 2023; Senol *et al*., 2023a,b; S¸enol *et al*., 2023).

In this study, we aimed to evaluate the basilar artery parameters obtained from computed tomography (CT) angiography images with ML algorithms and ANN to reveal the differences between sexs. In addition, the basic anatomical data to be obtained were also aimed to help alleviate the complications of endovascular treatment during diagnostic, surgical and interventional radiologic procedures.

MATERIAL AND METHOD

Study Population, Computed Tomography Scanning Protocol and Image Acquisition. The study was initiated with the 1203 decision of Izmir Bakırçay University local ethics committee numbered 1183. The study was performed using CT angiography images of 63 women and 94 men aged between 25 and 85 years. Individuals with vascular surgery and vascular pathology were excluded from the study.

Images were acquired using a 16-row Multidetector CT (Aquilion 16; Toshiba Medical Systems, Otawara, Japan) with a scan protocol of tube voltaje: 120 kV, gantry rotation: 0.75 s, and image slice thickness of 1 mm, pitch: 1.0 mm. Images were obtained retrospectively from Hospital Archiving Communication Systems (PACS) by scanning between 2018 and 2023. The scanned CT angiography images in Digital Imaging and Communications in Medicine (DICOM) format were transferred to the RadiAnt DICOM Viewer program and 3D Volume Rendering was applied. The basilar artery and vertebral artery were exposed using the Scalpel tool of the program. The following parameters were measured on the exposed vessels.

- Initial width of the right vertebral artery (a)
- Initial width of the left vertebral artery (b)
- Termination width of the right vertebral artery (c)
- Termination width of the left vertebral artery (d)
- Basilar artery width (e)
- Basilar artery length (f) (Fig. 1).

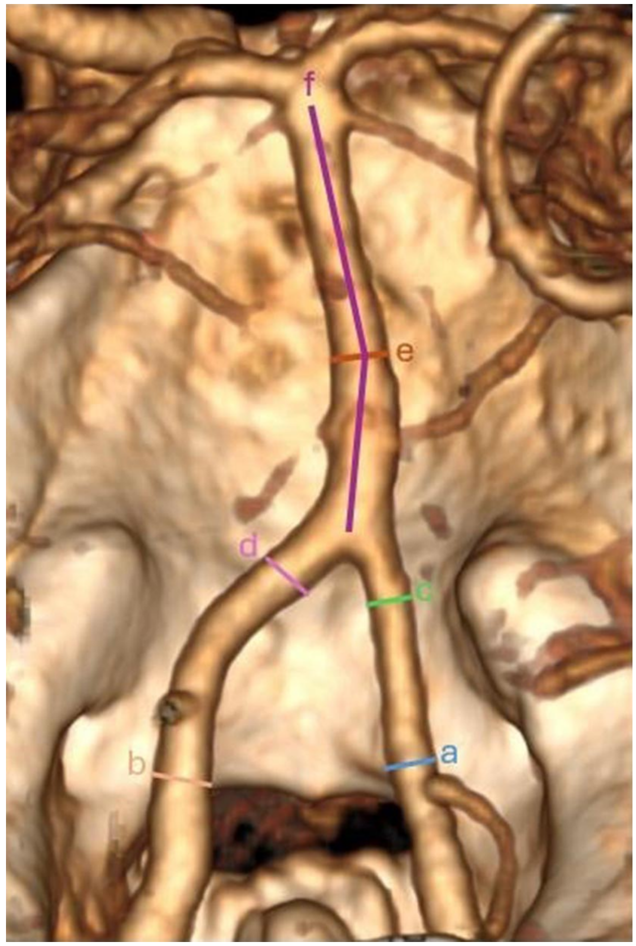


Fig. 1. Demonstration of parameters (a: initial width of the right vertebral artery, b: initial width of the left vertebral artery, c: termination width of the right vertebral artery, d: termination width of the left vertebral artery, e: basilar artery width, f: basilar artery length).

Implementation of Algorithms and Performance Criteria. ML and ANN modeling was performed using a Monster Abra A7 computer with 8 Gb Ram. Modeling was performed using Python 3.9 programming language and scikit-learn 1.1.1 framework. In the modeling, 20 % of the data was used as a test set. Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA), Logistic Regression (LR), Decision Tree (DT), Random Forest (RF), Extra Tree Classifier (ETC), K-nearest Neighbors Algorithms (k-NN) were used in the ML model. Multilayer perceptron classifier (MLCP) was preferred for the ANN model. In MLCP, 6 neurons in the input layer, 2 neurons in the output layer and 2 hidden layers (10 neurons in the first layer and 15 neurons in the second layer) were used. The data was retrained 100, 500 and 1000 times to ensure that the topology reflects reality. Accuracy (Acc), Specificity

(Spe), Sensitivity (Sen), F1 score (F1) were used as performance criteria.

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

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

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

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

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

Statistical analysis. The compatibility of the parameters with normal distribution was tested by using Anderson Darling test and mean and standard deviation values for normally distributed data and median, minimum and maximum values for non-normally distributed data were included. Two Simple T test was used to compare normally distributed data in terms of sex and Mann Whitney U test was used to compare non-normally distributed data. ROC analysis was performed to find the contribution of the parameters to the overall result. Minitab 17 package program was used for the analyses.

RESULTS

The ages of male and female subjects were 64 (31-85) and 65.5 (25-85) years, respectively, and there was no significant difference between the ages in terms of sex (p=.497). As a result of Anderson Darling test, it was found that the parameters of right vertebral artery initial width, left vertebral artery initial width and left vertebral artery termination width were normally distributed. When the parameters were compared in terms of sex, a significant difference was found in all normally distributed parameters (Table I) ($p \leq 0.05$).

Basilar artery length, basilar artery width, right vertebral artery termination width parameters were not normally distributed. When the parameters were compared in terms of sex, a significant difference was found in all non-normally distributed parameters (Table II) ($p \leq 0.05$).

As a result of ROC analysis, it was determined that the basilar artery length parameter had the highest contribution in differentiating the sexes (Fig. 2).

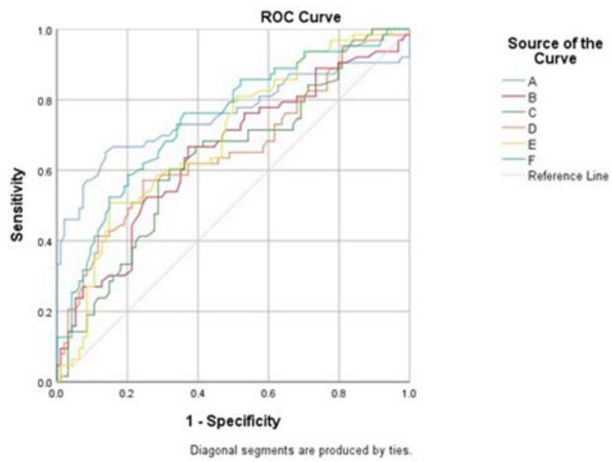


Fig. 2. ROC Graph.

Table I. Descriptive statistics of parameters fitting the normal distribution.

Parameters (mm)	Sex	Mean	Standard Deviation	p*
Right vertebral artery initial width	Male	3.384	0.673	.003
	Female	3.046	0.712	
Left vertebral artery initial width	Male	3.588	0.775	
	Female	3.034	0.823	.000
Left vertebral artery termination width	Male	3.131	0.674	.000
	Female	2.552	0.573	

*Two Simple T test.

Table II. Descriptive statistics of parameters that do not fit the normal distribution

Parameters (mm)	Sex	Median	Minimum	Maximum	p**
Basilar artery length	Male	30.400	15.800	44.500	.000
	Female	26.100	18.800	34.200	
Basilar artery width	Male	3.850	2.020	7.980	.002
	Female	3.470	2.310	5.060	
Right vertebral artery termination width	Male	2.810	1.000	6.230	.001
	Female	2.390	1.100	6.960	

**Mann Whitney U test

As a result of the ROC analysis of the analyzed parameters, it was found that the basilar artery length parameter made the highest contribution of 0.76 in differentiating the sexes (Table III).

As a result of ML algorithms, the highest Acc rate was 0.84 with QDA, ETC, RF algorithms (Table IV).

As a result of the ML algorithms, the algorithms with the highest Acc correctly distinguished 9 out of 12 men and 18 out of 20 women in the test set (Table V).

With the SHAP solver of the RF algorithm, the basilar artery length parameter was found to have the highest contribution to the overall result (Fig. 3).

As a result of MLCP modeling of ANN, the highest accuracy rate was 0.84 in 1000 and 500 times training (Table VI).

Table III. ROC analysis performance values.

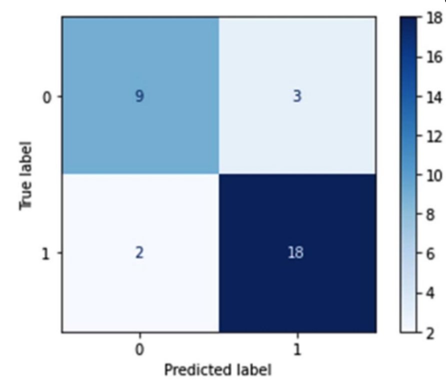
Parameters (mm)	AUC (95%)	Cutt off	p	Sen	Spe
Basilar artery length	0.758 (0.671-0.844)	27.75	.000	69.8	70.2
Basilar artery width	0.650 (0.560-0.739)	3.615	.002	63.5	63.8
Right vertebral artery initial width	0.633 (0.544-722)	3.195	.005	63.5	62.8
Right vertebral artery termination width	0.656 (0.566-0.746)	2.515	.001	61.9	62.8
Left vertebral artery initial width	0.693 (0.610-0.777)	3.22	.000	61.9	62.8
Left vertebral artery termination width	0.744 (0.665-0.823)	2.805	.000	68.3	69.1

Table IV. Performance metrics obtained as a result of ML algorithms.

Algorithms*	Acc	Spe	Sen	F1
DT	0.69	0.67	0.67	0.67
RF	0.84	0.84	0.82	0.83
ETC	0.84	0.86	0.81	0.82
k-NN	0.72	0.72	0.66	0.66
LR	0.81	0.81	0.78	0.79
LDA	0.81	0.81	0.78	0.79
QDA	0.84	0.84	0.82	0.83

*(DT: Decision Tree, RF: Random Forest, ETC: Extra Tree Classifier, LR: Logistic Regression, LDA: Linear Discriminant Analysis, QDA: Quadratic Discriminant Analysis, Acc: Accuracy, Spe: Specificity, Sen: Sensitivity).

Table V. Confusion Matrix table for ML modeling.



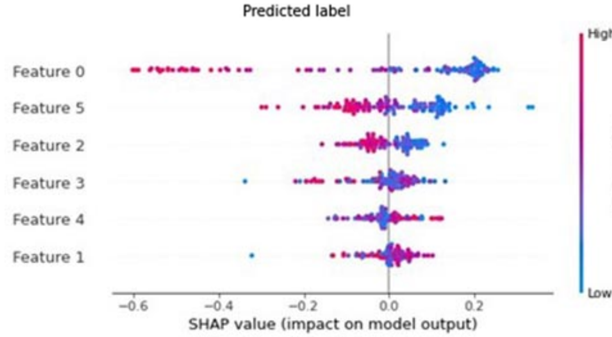


Fig. 3. SHAP analyzer *Feature 0: basilar artery length, 1: basilar artery width, 2: right vertebral artery initial width, 3: right vertebral artery termination width, 4: left vertebral artery initial width, 5: left vertebral artery termination width.

Table VI. ANN model performance criteria.

Number of Trainings	Acc	Spe	Sen	F1
100	0.81	0.81	0.78	0.79
500	0.84	0.84	0.82	0.83
1000	0.84	0.84	0.82	0.83

Acc: Accuracy, SP: Specificity, Sen: Sensitivity,

DISCUSSION

In this study, differences between sexs were revealed by using ML and ANN algorithms with vertebral and basilar artery parameters obtained from CT angiography images. DT, RF, ETC, k-NN, LR, LDA and QDA algorithms from ML models and MLCP algorithm from ANN models were used. Accuracy rates ranging from 0.69 to 0.84 were achieved in all methods used. The weakest prediction ability in ML algorithm models was seen in DT algorithm with 0.69, followed by k-NN with 0.72, LR and LDA with 0.81, RF, ETC and QDA algorithms with 0.84. In the use of MLCP, which is one of the ANN models, the accuracy rate obtained in 100 repetitive trainings was 0.81, while the accuracy rate was 0.84 in 500 and 1000 repetitive trainings.

According to this result, the highest hit rates were seen in RF, ETC and QDA for ML algorithms, while the highest hit rates were seen in MLCP's 500 and 1000 repetitive training for ANN algorithms.

Since dissecting and fusiform aneurysms in the vertebrobasilar system are frequently seen in the basilar artery in the literature, it is important to increase the level of radioanatomical knowledge in the surgical approach to the artery (Seçkin *et al*., 2018). When the length of the basilar artery parameter was examined, a study by Vijayakumar *et al*. (2020) found a sex-independent mean basilar artery length of 31 mm. In a study by Krishnamurthy *et al*. (2006) the mean basilar artery length was found to be 26.5±3.48 mm in a sex-neutral measurement. A morphologic study was performed on cadavers by Wankhede *et al*. (2014) and the mean basilar artery length was found to be 29.9±2.9 mm. In a study by Pai *et al*. (2007) the mean basilar artery length was found to be 24.9 mm. In our study, the median value of the basilar artery was found to be 30.40 mm in men and 26.10 mm in women. Although there are no studies comparing both sexes in the literature, the data we obtained are compatible with the literature.

The mean width of the basilar artery was found to be 3.6 mm in a study by Vijanakumar *et al*. (2020). The mean basilar artery width was found to be 2.73 mm in the study by Tanaka *et al*. (2013). In a study by Deng *et al*. (2012) the mean basilar artery width was found to be 3.2±0.5 mm in men and 3.0±0.5 mm in women. Wankhede *et al*. (2014) performed a morphologic study on cadavers and found the mean basilar artery width to be 3.53±0.22. In a study by Songur *et al*. (2008) the mean width of the basilar artery on cadavers was found to be 3.97±0.96 mm. In a study by Smoker *et al*. (1986) using high-resolution CT, the mean basilar artery width was found to be 3.17±0.72 mm. In a study by Pico *et al*. (2003) the mean basilar artery width was found to be 2.6±0.6 mm. In a study by Pai *et al*. (2007) the mean basilar artery width was found to be 4.3 mm. In our study, the median width of the basilar artery was found to be 3.85 mm in men and 3.47 mm in women. The values found in the literature are similar to our results and support our results.

In a literature review on the width of vertebral arteries, Geetharani *et al*. (2016) measured the width of vertebral arteries in a study on cadavers and found that the right vertebral artery was 3.12±0.08 mm and the left vertebral artery was 3.64±0.04 mm on average. In a study conducted by Songur *et al*. (2008) on cadavers, the mean width of the right vertebral artery was 2.85±0.99 mm and the mean width of the left vertebral artery was 3.02±0.81 mm. In a study by Pico *et al*. (2003) the mean right vertebral artery width was 2.2±0.7 mm and the mean left vertebral artery width was 2.3±0.7 mm. In a study by Pai *et al*. (2007) the mean width of the right vertebral artery was 2.9 mm and the mean width of the left vertebral artery was 3.4 mm. According to the results obtained in our study, the mean value of the initial width of the right vertebral artery was 3.38±0.67 mm and the median value of the ending width was 2.81 mm in men, while these values were found to be 3.04±0.71 mm and 2.39 mm in women, respectively. When we looked at the left vertebral artery, the initial width was found to be 3.58±0.77 mm and the final width was found to be 3.13±0.67 mm in men, and these values were found to be 3.03±0.82 mm and 2.55±0.57 mm in women, respectively. Our results are in parallel with the literature.

Although there is no study in the literature comparing the radioanatomical information of the vertebrobasilar system between sexs using ML and ANN algorithms, we concluded that both sexs can be distinguished with a high success rate of 0.84 and that the biggest difference between the two sexs is due to the length of the basilar artery.

The scarcity of images can be considered as a limitation of the study.

CONCLUSION

As a result of our study, it was concluded that the parameters obtained from the basilar artery and vertebral artery on CT angiography images are distinctive for sex and that these parameters can be used with ML and ANN algorithms to separate the vertebrobasilar systems in sexs, which can be used as the first step detailed anatomy information in endovascular surgeries.

Ethical approval. The study was initiated with the 1203 decision of Izmir Bakırçay University local ethics committee numbered 1183.

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RESUMEN: La determinación de las diferencias de sexo en las estructuras anatómicas es fundamental para establecer datos morfométricos de gold estándar, en las ciencias médicas básicas y en las ciencias quirúrgicas e internas para seleccionar el área correcta durante la intervención invasiva y aplicar la metodología de intervención correcta y apropiada. El objetivo de este estudio fue determinar la diferencia de sexo utilizando algoritmos de aprendizaje automático (ML) y redes neuronales artificiales (ANN) con parámetros obtenidos de la arteria basilar. El estudio se realizó sobre imágenes de angiografía por tomografía computarizada de 63 mujeres y 94 hombres. Se midieron en las imágenes los siguientes parámetros: ancho inicial de la arteria vertebral derecha, ancho inicial de la arteria vertebral izquierda, ancho de terminación de la arteria vertebral derecha, ancho de terminación de la arteria vertebral izquierda, ancho de la arteria basilar y longitud de la arteria basilar. Las mediciones se utilizaron en algoritmos de ML y entradas de ANN para determinar las diferencias de sexo. Como resultado del estudio, se determinó una tasa de diferencia de sexo de 0,84 con los algoritmos ML Random Forest (RF), Análisis Discriminante Cuadrático (QDA), Extra Tree Classifier (ETC) y 0,84 con el algoritmo Multilayer Perceptron Classifier (MLCP) de ANA. Como resultado del estudio, se encontró una diferencia de sexo con una tasa de precisión de 0,84 utilizando algoritmos ML y ANN con parámetros obtenidos de la arteria basilar. En este contexto, pensamos que este estudio será de utilidad en las ciencias médicas básicas y clínicas.

PALABRAS CLAVE: Arteria basilar; Algoritmos de aprendizaje automático; Redes neuronales artificiales; Diferencia de sexo.

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