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Performances of Different Classification Algorithms in Sex Determination from First Cervical Vertebra Measurements

Rendimiento de Diferentes Algoritmos de Clasificación en la Determinación del Sexo a Partir de las Mediciones de la Primera Vértebra Cervical

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SUMMARY: In the present study, it is aimed to reveal the performances of different classification algorithms in sex determination from first cervical vertebra, that is, atlas measurements. The classification success of 4 different machine learning algorithms was comparatively examined for the purpose of sex determination by evaluating 22 atlas measurements on cone beam computed tomography (CBCT) images of 145 female and 145 male adults. Logistic regression (LR), classification and regression tree (CART), support vector machine (SVM) and neural network (NN) algorithms were used for sex diagnosis. Area under the ROC curve (AUC), classification accuracy (CA), F1-ratio, Precision and Recall indexes were used for model performances. Except for 2 measurements, there was a significant difference between men and women in terms of 20 other parameters ($p<0.05$). The adjusted effects of these parameters on sex determination were examined with multivariate models and algorithms, and the success of all 4 algorithms was quite good. The success of the NN algorithm (Accuracy 91.3 %; 0.87 Specificity, 0.85 Sensitivity) in correctly classifying male and female was the highest, followed by the LR algorithm (Accuracy 90.9 %; 0.86 Specificity, 0.83 Sensitivity). It was found that the machine learning algorithm applied to the variables of the atlas gave high accuracy regarding sex and the NN model was highly effective in sex determination. In addition, a large morphometric database of atlas was presented in our results.

KEY WORDS: Atlas; Cone beam computed tomography; First cervical vertebra; Sex determination; Machine learning algorithms.

INTRODUCTION

The first cervical vertebra, known as the atlas, is an important element of the vertebral column as it connects the cranial base to the cervical column (Gupta *et al*., 2017; Palancar *et al*., 2020) and has anatomical features different from other cervical vertebrae. This vertebra has a unique shape, but its integrity is difficult to preserve in the fossil record due to its fragility (Rao *et al*., 2013; Palancar *et al*., 2020). Bone analysis may provide the only way to access biological sex in poorly preserved and decomposed corpses in establishing the biological profile of the deceased (Gama *et al*., 2015). Sex estimation is a key element in the analysis of unknown skeletal remains (Aura *et al*., 2023). Research conducted for sex prediction has shown that the pelvis and skull bones have a high accuracy rate (Ekizoglu *et al*., 2021). Evaluation of various anatomical structures belonging to other skeletal parts such as vertebrae has contributed to sex determination (Meyvaci *et al*., 2020, 2021). When we examine the studies that aimed to determine sex by evaluating the vertebrae, it is seen that the vertebrae of the cervical, thoracal and lumbar regions were examined (Garoufi *et al*., 2020; Azofra-Monge & Alemán Aguilera, 2020; Karaca *et al*., 2023).

Although there are studies examining cervical vertebrae to determine sex, studies evaluating the atlas are limited (Gama *et al*., 2015; Rozendaal *et al*., 2020; Karaca *et al*., 2023). Studies examining the atlas have reported differences between both sexes (Marino, 1995; Meyvaci *et al*.,2020). Although it is advantageous for the atlas to have characteristic features in sex estimation, it is a disadvantage that it is difficult to reach the vertebra with preserved integrity due to its fragility. For this reason, there is a need for studies to be carried out by taking into account many anatomical points and parameters in the atlas.

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The aim of this study is to evaluate the parameters of the atlas using machine learning algorithms, which is a current method in sex determination, and to reveal the performances of these different classification algorithms in sex determination.

MATERIAL AND METHOD

For this study, first of all, ethical approval was received from Bolu Abant Izzet Baysal University Clinical Research Ethics Committee with decision number 2023/81. In our retrospective study, we analyzed the cone beam computed tomography (CBCT) images of 145 female adults with an average age of 37.55±16.08 and 145 male adults with an average age of 41.93±17.56, who applied to the Department of Oral and Maxillofacial Radiç).

During the measurements, firstly, the locations of the points specified in Table I were determined using the appropriate multiplanar sections and linnear measurements of the distance between the two points were made. Examples of P1-6 measurements are shown in Figure 1A-F.

Table I. Description of landmarks.

Landmark	Definition
1	The most lateral point of the right transverse processes
2	The most lateral point of the left transverse processes
3	Most anterior point on the anterior tubercle
4	Most posterior point on the posterior tubercle
5	The dorsal most point of the anterior arch
6	The ventral most point of the posterior arch
7	Most lateral point on the right side of vertebral foramen
8	Most lateral point on the left side of vertebral foramen
9	Most lateral point of the right transverse foramen
10	Most lateral point of the left transverse foramen
11	Most medial point of the right transverse foramen
12	Most medial point of the left transverse foramen
13	The anterior end point of the right superior articular surface
14	The posterior end point of the right superior articular surface
15	The anterior end point of the left superior articular surface
16	The posterior end point of the left superior articular surface
17	The lateral end point of the right superior articular surface
18	The medial end point of the right superior articular surface
19	The lateral end point of the left superior articular surface
20	The medial end point of the left superior articular surface
21	The anterior end point of the right inferior articular surface
22	The posterior end point of the right inferior articular surface
23	The anterior end point of the left inferior articular surface
24	The posterior end point of the left inferior articular surface
25	The lateral end point of the right inferior articular surface
26	The medial end point of the right inferior articular surface
27	The lateral end point of the left inferior articular surface
28	The medial end point of the left inferior articular surface
29	The most superior point on the anterior arcus in the midsagittal plane
30	The most inferior point on the anterior arcus in the midsagittal plane
31	The most superior point on the posterior arcus in the midsagittal plane
32	The most inferior point on the posterior arcus in the midsagittal plane
33	The most lateral point on the right side of anterior arcus
34	The most lateral point on the left side of anterior arcus
35	The most lateral point on the right side of posterior arcus
36	The most lateral point on the left side of posterior arcus

Statistical Analysis. Descriptive statistics of the variables were given as mean±standard deviation (SD), median and 25th-75th quartiles. Shapiro-Wilk test was used for the normality test of the numerical variables and it was determined that they have not normal distribution in both men and women. In the first step of the analysis, sexes were compared in terms of measured characteristics with the Mann-Whitney U test. After univariate analysis, logistic regression (LR) classification and regression tree (CART), support vector machine (SVM) and neural network (NN) algorithms were used for sex determination. The 5-fold cross-validation method for internal validation was used in the training and testing processes of the models. Model performances were evaluated by using area under the ROC curve (AUC), classification accuracy (CA), F1-ratio, Precision and Recall indexes were used.

RESULTS

Descriptive statistics of atlas measurements according to sex are presented in Table III. The mean ages of female and male were 37.55±16.08 and 41.93±17.56, respectively, and the mean age of men was significantly higher (p=0.034).

When Table III was examined, as a result of univariate analysis, a significant difference was found between men and women in terms of 20 parameters except P16 and P18 measurements. The corrected effects of these parameters on sex determination were examined with multivariate models and algorithms.

Classification of Male and Female using 22 atlas measurements: Results of machine learning algorithms

In the study, the classification success of 4 different machine learning algorithms was comparatively examined for the purpose of diagnosing sex with the help of 22 atlas measurements. For this purpose, LR, SVM, CART and NN were used. The confusion matrix showing the compatibility between the

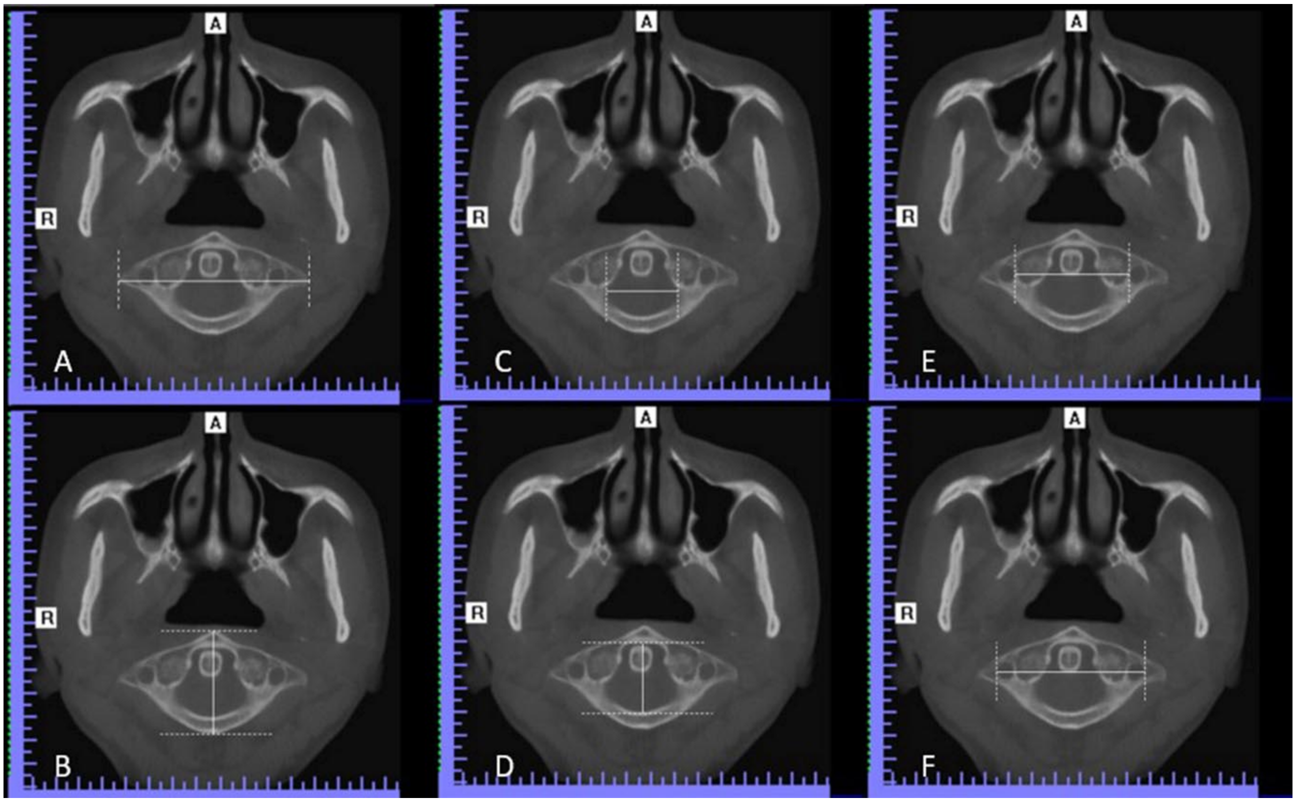

Fig. 1. A. Maximum transverse diameter; B. Maximum anterior-posterior diameter: C. Transverse diameter of foramen vertebrale; D. Anteroposterior diameter of foramen vertebrale; E. Inner diameter of transverse foramen; F. Outer diameter of transverse foramen.

Table II. Description of anatomic parameters of the atlas.

Parameters	Landmark	Definition
P1	1-2	Maximum transverse diameter
P2	3-4	Maximum anteroposterior diameter
P3	5-6	Transverse diameter of vertebral foramen
P4	7-8	Anteroposterior diameter of vertebral foramen
P5	9-10	Inner diameter of transverse foramen
P6	11-12	Outer diameter of transverse foramen
P7	13-14	Maximum anteroposterior diameter of right superior articular surface
P8	15-16	Maximum anteroposterior diameter of left superior articular surface
P9	17-18	Minimum mediolateral diameter of right superior articular surface
P10	19-20	Minimum mediolateral diameter of left superior articular surface
P11	21-22	Maximum anteroposterior diameter of right inferior articular surface
P12	23-24	Maximum anteroposterior diameter of left inferior articular surface
P13	25-26	Minimum mediolateral diameter of right inferior articular surface
P14	27-28	Minimum mediolateral diameter of left inferior articular surface
P15	17-19	Maximum distance between the lateral edges of the superior articular surface
P16	18-20	Minimum distance between the lateral edges of the superior articular surface
P17	25-27	Maximum distance between the lateral edges of the inferior articular surface
P18	26-28	Minimum distance between the lateral edges of the inferior articular surface
P19	29-30	Height arcus anterior
P20	31-32	Height arcus posterior
P21	33-34	Diameter of the anterior arcus
P22	35-36	Diameter of the posterior arcus

Table III. Sex differences in terms of atlas measurements.

	Male						Female						
		Mean	SD	Percentiles				Mean	SD	Percentiles			
	N			25th	Median	75th	N			25th	Median	75th	P*
Age	145	41.93	17.56	25.50	42.00	58.00	145	37.55	16.08	22.00	33.00	50.00	0.034
P1	145	81.31	4.01	78.95	81.00	84.00	145	74.50	3.99	72.00	74.50	77.05	<0.001
P2	145	47.82	2.88	46.00	47.70	49.55	145	44.49	2.51	43.00	44.50	46.00	<0.001
P3	145	31.83	2.82	30.00	31.80	33.80	145	29.96	2.05	28.45	30.00	31.35	<0.001
P4	145	32.75	2.16	31.25	33.00	34.00	145	30.80	2.25	29.50	31.00	32.00	<0.001
P5	145	47.33	3.17	45.00	47.00	49.00	145	44.22	3.46	41.85	44.00	46.00	<0.001
P6	145	62.90	3.79	60.00	63.00	65.25	145	58.44	4.01	55.90	59.00	61.00	<0.001
P7	145	15.36	1.70	14.40	15.00	16.00	145	14.69	1.39	13.50	14.70	15.70	0.001
P8	145	15.14	1.55	14.00	15.00	15.90	145	14.55	1.46	13.50	14.50	15.50	0.001
P9	145	11.69	1.29	10.50	11.50	12.60	145	11.19	1.28	10.20	11.20	12.00	0.003
P10	145	11.72	1.36	10.80	11.50	12.60	145	11.39	1.32	10.50	11.30	12.30	0.048
P11	145	12.36	1.53	11.40	12.30	13.20	145	11.75	1.20	11.00	11.70	12.50	0.001
P12	145	12.00	1.40	11.00	11.70	12.90	145	11.43	1.26	10.50	11.40	12.30	0.002
P13	145	10.56	1.19	9.90	10.50	11.25	145	10.20	1.13	9.40	10.00	10.80	0.012
P14	145	10.68	1.17	9.90	10.50	11.25	145	10.25	0.97	9.60	10,20	10.80	0.004
P15	145	48.47	3.69	45.60	48.00	51.00	145	45.58	3.37	43.20	45.00	47.75	<0.001
P16	145	17.68	3.58	16.00	17.00	18.60	145	17.28	3.01	15.50	17.00	18.40	0.243
P17	145	44.52	4.82	43.00	45.00	47.00	145	41.78	4.97	40.00	42.60	44.00	<0.001
P18	145	16.84	3.76	15.00	16.50	17.70	145	16.88	4.18	15.00	16.00	17.75	0.425
P19	145	12.47	1.24	11.50	12.50	13.00	145	11.31	1.36	10.45	11.10	12.00	<0.001
P20	145	10.30	1.61	9.00	10.20	11.25	145	9.66	1.49	8.50	9.50	10.50	0.001
P21	145	6.95	1.01	6.00	7.00	7.50	145	6.41	0.93	5.70	6.30	7.00	<0.001
P22	145	7.54	1.75	6.00	7.50	8.90	145	7.00	1.61	5.70	6.90	8.00	0.007

*: Mann-Whitney U test

predicted values of the algorithms used to diagnosing sex and the actual results is given in Table IV. According the results, 145 male and 145 female were included in the study and the number of individuals correctly assigned and incorrectly assigned to their sex according to 4 different algorithms.

The criteria presented in Table V were evaluated of the diagnostic success of the algorithms. The success of the algorithms in distinguishing female was defined by sensitivity, and the success of the algorithms in distinguishing men was defined by specificity. In addition, the overall diagnostic success of the algorithms used was explained by the area under the ROC curve (AUC), and the overall diagnostic success of the artificial NN and LR algorithm was found to be the highest. F1 ratio and Positive predictive value (Precision), which are success criteria, were lowest in the CART algorithm, but the results of the other 3 algorithms were found to be very similar to each other. In addition, when false negatives and false positives, which show incorrect classification rates, are evaluated, it is seen that all four algorithms used in the study have a lower rate of false positives, that is, identifying female as female when they are actually male. As a result of evaluating both false negativity and false positivity together, it is observed that the CART algorithm gives the least successful result. The success of the NN algorithm in correctly classifying male and female was the highest, followed by the LR algorithm. As a result, the success of all 4 algorithms was quite good. The success criteria of the algorithms are given in Table V.

Table IV. Number of individuals classified correctly and incorrectly according to four different algorithms.

		Predicted											
		LR*			CART*			SVM*			NN*		
		Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Actual	Male	125	**20**	145	117	**28**	145	123	**22**	145	126	**19**	145
	Female	**24**	121	145	**33**	112	145	**30**	115	145	**24**	121	145
	Total	149	141	290	150	140	290	153	137	290	150	140	290

*: LR: Logistic regression, CART: Classification and regression tree, SVM: Support vector machine, NN:Neural network.

Table V. Success criteria of algorithms in sex determination.

Model	AUC	CA	F1	Precision (PPV)*	Recall (sensitivity)	Specifity	FP*	FN*
LR	0.909	0.848	0.848	0.858	0.834	0.862	0.138	0.165
CART	0.817	0.790	0.790	0.800	0.772	0.807	0.193	0.227
SVM	0.895	0.821	0.821	0.839	0.793	0.848	0.152	0.207
NN	0.913	0.852	0.852	0.864	0.853	0.869	0.131	0.165

*: FN: False negative; FP: False positive; PPV: Positive predictive value; Positive group is Female, Negative group is Male.

In addition, when the internal validity of the findings was evaluated with 5-fold cross-validation, it was seen that similar findings were obtained.

When the success of the algorithms used for diagnosing of the sex were evaluated with the ROC curve, the graph shown in Figure 2 was obtained. Each curve represents the success of an algorithm. The AUC values in Table V correspond to the area under these curves. In addition, the values on the curve are the cut-off values of the probabilities in sex determination obtained from the algorithms.

The diagnostic tree of the CART algorithm is given in Figure 3. When Figure 3 is examined, those written "0" in the upper left corner of the boxes represent groups in which male are in the majority, and those written "1" represent groups in which female are in the majority. Binary undivided boxes are called terminal nodes, and the relevant box defines the classification condition of whichever sex it belongs to.

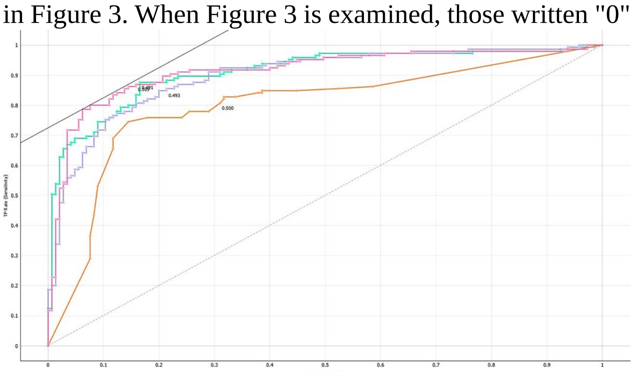

Fig. 2. ROC curves of algorithms.

According to tree

- The first box contains a total of 290 people and the cut-off value of the P1 feature was taken into account as 77.1 mm and divided into two groups. When the 127 people in red on the left are taken again as cut-off 76.5 mm for P1, it is seen that 5 out of 9 people are male. According to this result, it can be said that 5 of the 9 people with a P1 value greater than 76.5 mm, that is, the majority, can be separated by looking only at this feature.
- Of the remaining 118 people, 5 of the 7 people with a P1 value less than 76.5 mm, P2 less than 45.5 mm and P3 less than 26.8 mm were diagnosed as female, and 75 of the 78 people with a P3 value greater than 26.8 mm were diagnosed as female.
- In addition, all 11 people whose P1 value was less than 76.5 mm, P2 was greater than 45.5 mm, and P8 was less than 14.7 mm were correctly classified as female.
- On the other hand, 5 of the 5 people whose P1 value was

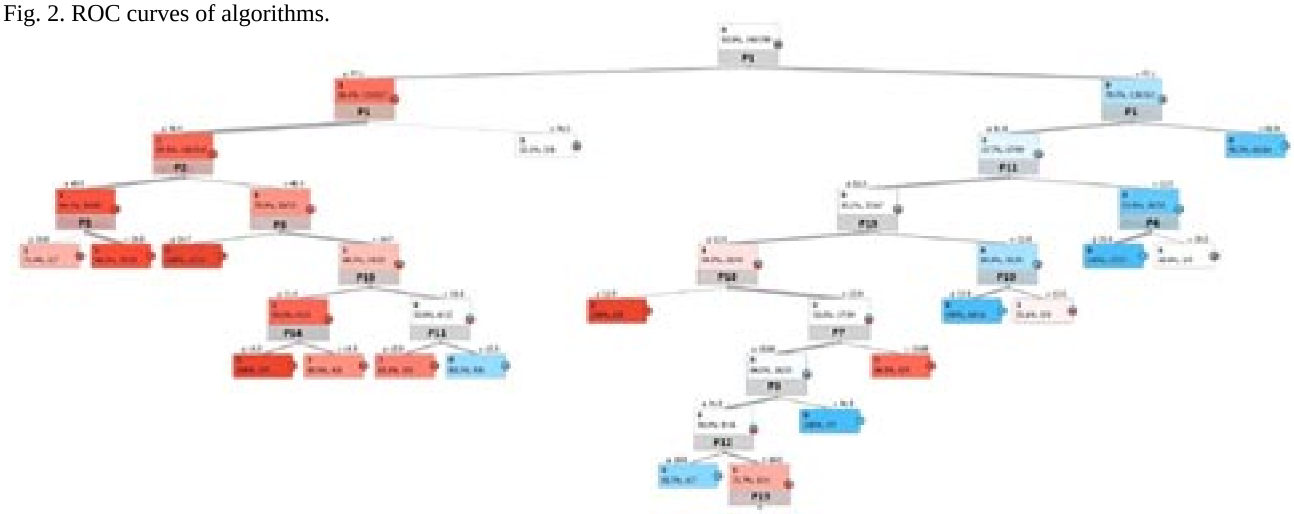

Fig. 3. CART diagnostic tree

less than 76.5 mm, P2 was greater than 45.5 mm and P8 was greater than 14.7 mm, P19 was less than 11.4 and P14 was less than 10.5 mm were female.

- 4 of the 5 people whose P1 value is less than 76.5 mm, P2 is greater than 45.5 mm and P8 is greater than 14.7 mm, P19 is less than 11.4 mm and P14 is greater than 10.5 mm are female.
- 5 of the 6 people with P1 value less than 76.5 mm, P2 greater than 45.5 mm and P8 greater than 14.7 mm , P19 measurement greater than 11.4 mm and P11 value less than 12.3 mm were female,
- It was observed that 5 of the 6 people with P1 value less than 76.5 mm, P2 greater than 45.5 mm and P8 greater than 14.7 mm , P19 measurement greater than 11.4 mm and P11 value greater than 12.3 mm were male.

Ultimately, the boxes that are no longer binary are the people assigned to the male and female groups represented by “0 and 1” in the upper right corner.

It is interpreted similarly in the boxes on the right, where those with a P1 value of 77.1 mm are classified, starting from the first box of the tree in question.

DISCUSSION

The fact that the morphometric parameters of the atlas, the upper segment of the cervical vertebrae, differ according to the population reveals the need for population-specific sex determination studies (Poodendan *et al*., 2023). Determination of morphometric values of atlas, taking into account sex, is important for the preoperative preparation of the clinician due to its close proximity to important anatomical structures such as medulla oblongata, C1 spinal nerve and vertebral vessels.

In a previous study which sex determination was carried out with the help of discriminant function analysis, it was reported that sex estimation could be made with 77-85 % accuracy by examining 100 dry atlas (Marino, 1995). In a study conducted with 200 individuals from the Turkish population (100 female, 100 male), atlas was examined with the help of neck computed tomography. By measuring the distance between both the medial and lateral edges of the transverse foramen, the accuracy of sex prediction was found to be 76-80 % (Meyvaci *et al*., 2020). In our study which we estimated sex, 22 parameters were examined on CBCT images of 290 individuals (145 female, 145 male) belonging to the Turkish population and it was determined that sex determination would be made with an accuracy rate of 82-91 %. It is seen that this result is higher than the accuracy rates determined by previous atlas studies (Meyvaci *et al*., 2020).

When the literature is examined, it is seen that sex determination studies are carried out with various methods in the light of technological developments. A study that estimated sex using machine learning algorithms, an up-to-date and reliable method, reported that 8 of the 12 measured parameters were significantly longer ($p<0.05$) in the male atlas. It has been emphasized that these parameters can predict sex with 82.6 % accuracy and that first cervical vertebrae-based sex prediction can provide the basis for human identification with an acceptable level of accuracy (Poodendan *et al*., 2023).

In our study, where sex was estimated from the atlas using machine learning algorithms, as a result of the evaluation of the measurements, a significant difference was found between male and female in terms of 20 parameters except 2 measurements ($p<0.05$). The corrected effects of these sexually dimorphic parameters on sex determination were examined with multivariate models and algorithms. The success of the entire algorithm, including LR (90.9 %), CART (81.7 %), SVM (89.5 %) and NN (91.3 %), was found to be quite good.

When we compared our study with Poodendan *et al*. (2023), which was conducted with a similar method, we found that the number of atlas parameters we evaluated had sexual dimorphic features was higher and the accuracy rates of these parameters were higher.

When we examined different classification algorithms in terms of their performance in sex determination from first cervical vertebra measurements, we found that NN (Accuracy 91.3 %; 0.87 Specificity, 0.85 Sensitivity) and LR (Accuracy 90.9 %; 0.86 Specificity, 0.83 Sensitivity) algorithms were the best. In the study of Poodendan *et al*. (2023), it was reported that the decision stump (Accuracy 82.6 %; root mean squared error = 0.38) and random forest (Accuracy 79.6 %; root mean squared error = 0.38) algorithms showed the best performance.

The large number of atlas parameters we examined in our research and the high accuracy of the classification algorithms we use in sex diagnosing make them more effective in contributing to the sex diagnosing process than other studies.

Accurate sex determination is very important for successful forensic identification (Oura *et al*., 2018), and atlas' unique features make this bone advantageous in sex estimation. In our study where we evaluated the accuracy of sex determination from morphological variables of atlas in the Turkish population, it was found that our machine learning model gave high accuracy for sex and the NN model was the most effective in sex determination. In addition, our preliminary results present the normative dimension value, taking into account sex-related differences, as the parameters of the atlas show sexual dimorphism with high accuracy, and the atlas has strategic importance due to its important anatomical neighborhoods.

SERTEL MEYVACI, S.; ANKARALI, H.; GÖLLER BULUT, D. & TASKIN, B. Rendimiento de diferentes algoritmos de clasificación en la determinación del sexo a partir de las mediciones de la primera vértebra cervical. *Int. J. Morphol., 42(5)*:1439-1445, 2024.

RESUMEN: El objetivo de estudio fue revelar el desempeño de diferentes algoritmos de clasificación en la determinación del sexo a partir de la primera vértebra cervical, el atlas. El éxito de la clasificación de 4 algoritmos diferentes de aprendizaje automático se examinó comparativamente con el fin de determinar el sexo mediante la evaluación de 22 mediciones de atlas en imágenes de tomografía computarizada de haz cónico (CBCT) de 145 mujeres y 145 hombres adultos. Para el diagnóstico de sexo se utilizaron algoritmos de clasificación y árbol de regresión (CART), máquina de vectores de soporte (SVM) y redes neuronales (NN). Para el rendimiento del modelo se utilizaron el área bajo la curva ROC (AUC), la precisión de clasificación (CA), la relación F1, los índices de precisión y recuperación. Excepto en dos mediciones, hubo una diferencia significativa entre hombres y mujeres en otros 20 parámetros (p<0,05). Los efectos ajustados de estos parámetros en la determinación del sexo se examinaron con modelos y algoritmos multivariados, y el éxito de los cuatro algoritmos fue bastante bueno. El éxito del algoritmo NN (Precisión 91,3 %; 0,87 Especificidad, 0,85 Sensibilidad) en clasificar correctamente a hombres y mujeres fue el más alto, seguido por el algoritmo LR (Precisión 90,9 %; 0,86 Especificidad, 0,83 Sensibilidad). Se encontró que el algoritmo de aprendizaje automático aplicado a las variables del atlas dio una alta precisión con respecto al sexo, y el modelo NN fue altamente efectivo en la determinación del sexo. Además, en nuestros resultados se presentó una importante base de datos morfométricos del atlas.

PALABRAS CLAVE: Atlas; Tomografía computarizada de haz cónico; Primera vértebra cervical; Determinación de sexo; Algoritmos de aprendizaje automático.

REFERENCES

Azofra-Monge, A. & Alemán Aguilera, I. Morphometric research and sex estimation of lumbar vertebrae in a contemporary Spanish population. *Forensic Sci. Med. Pathol., 16(2)*:216-225, 2020.

Ekizoglu, O.; Hocaoglu, E.; Inci, E.; Karaman, G.; Garcia-Donas, J.; Kranioti, E.; Moghaddam, N. & Grabherr, S. Virtual morphometric method using seven cervical vertebrae for sex estimation on the Turkish population. *Int. J. Legal Med., 135(5)*:1953-64, 2021.

Gama, I.; Navega, D. & Cunha, E. Sex estimation using the second cervical vertebra: a morphometric analysis in a documented Portuguese skeletal sample. *Int. J. Legal Med., 129(2)*:365-72, 2015.

Garoufi, N.; Bertsatos, A.; Chovalopoulou, M. E. & Villa, C. Forensic sex estimation using the vertebrae: an evaluation on two European populations. *Int. J. Legal Med., 134(6)*:2307-18, 2020.

Gupta, C.; Radhakrishnan, P.; Palimar, V., & Kiruba, N. L. A quantitative analysis of atlas vertebrae and its abnormalities. *J. Morphol. Sci., 30(2)*:0-0, 2017.

Karaca, A. M.; Senol, E., & Eraslan, C. Evaluation of the usage of the cervical 7th vertebra in sex estimation with measurements on computerized tomography images. *Legal Med. (Tokyo), 62*:102220, 2023.

Marino, E. A. Sex estimation using the first cervical vertebra. *Am. J. Phys. Anthropol., 97(2)*:127-33, 1995.

Meyvaci, S. S.; Arifoglu, Y.; Gurel, S.; & Buber, A. Radio-anatomical examination from foramen transversarium of first cervical vertebra for sex estimation. *Forensic Sci. Int. Rep., 2*:100078, 2020.

Meyvaci, S. S.; Bulut, D. G.; Öztürk, A. T., & Ankaralı, H. Gender estimation from angular parameters of mandible in Turkish adults. *Med. J. West. Black Sea, 5(2)*:240-7, 2021.

Oura, P.; Karppinen, J.; Niinimäki, J.; & Junno, J. A. Sex estimation from dimensions of the fourth lumbar vertebra in Northern Finns of 20, 30, and 46 years of age. *Forensic Sci. Int., 290*:350.e1-350.e6, 2018.

Palancar, C. A.; Torres-Tamayo, N.; García-Martínez, D., García-Tabernero, A., Rosas, A., & Bastir, M. Comparative anatomy and 3D geometric morphometrics of the El Sidrón atlases (C1). *J. Hum. Evol., 149*:102897, 2020.

Poodendan, C., Suwannakhan, A., Chawalchitiporn, T.; Kasai, Y., Nantasenamat, C., Yurasakpong, L.; Iamsaard, S. & Chaiyamoon, A. Morphometric analysis of dry atlas vertebrae in a northeastern Thai population and possible correlation with sex. *Surg. Radiol. Anat., 45(2)*:175-81, 2023.

Rao, R. D.; Tang, S., Lim, C., & Yoganandan, N. Developmental morphology and ossification patterns of the C1 vertebra. *J. Bone Joint Surg. Am., 95(17)*:e1241-7, 2013.

Rozendaal, A. S., Scott, S.; Peckmann, T. R., & Meek, S. Estimating sex from the seven cervical vertebrae: An analysis of two European skeletal populations. *Forensic Sci. Int., 306*:110072, 2020.

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