Gender Prediction from Angular and Linear Parameters in Cranium Lateral View by using Machine Learning Algorithms: A Computed Tomography Study

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Abtsract: The purpose of the study was to predict a gender by using Machine Learning Algorithms (MLA) with variables of the lateral view of the cranium from Computed Tomography (CT) images.

A total of 5 parameters (3 linear and 2 angular) of the lateral view of the cranium were evaluated on CT images of 200 female and 200 male adult individuals in the present study. These parameter measurements were analyzed with MLA and Logistic Regression (LR), Random Forest (RF), Linear Discriminant Analysis (LDA), K-Nearest Neighborhood (KNN) and Naive Bayes (NB) models were used. Accuracy (Acc), Sensitivity (Sen), Specificity (Spe) and F1 scores (F1) were used as the evaluation criteria in the study.

As a result of MLA, the Acc ratio was found to be 0.77 for the KNN algorithm, 0.84 in the NB algorithm, 0.85 in the LDA algorithm, 0.70 in the RF algorithm and 0.81 in the LR algorithm. As a result of the analysis, 0.85 Acc, 0.85 Sen, Spe 0.85 and 0.85 F1 values were found in the LDA algorithm with the highest accuracy. When the significance level of the variables in the study was examined, it was found that variable A had the best effect.

It was found that the MLA used for the variables of the lateral view of the cranium yielded high accuracy regarding gender and the LDA Model was effective in predicting gender.

Keywords: Artifical Neural Networks, Sex Estimation, Cranial Landmarks, Lateral Cranial View, Computed Tomography.

INTRODUCTION

Identifying the personality traits that help define individuals and make them be noticed by other individuals is called identification [1]. Forensic anthropology aims to identify gender, age, ethnicity and height information when identifying individuals by using skeletal remains. The main step of the biological profiling process is defined as gender determination [2]. Although DNA analysis is among the most valuable methods for sex determination, it is not preferred much because of reasons such as contamination, insufficient probes, biological material required for comparison and lack of financial resources [3]. When sex determination studies were examined, it was found that many bones such as the skeletal femur, mandible, vertebra and crus were used in the accuracy of sex determination and comparisons between populations [4-7]. The cranium, which comes after the pelvis in sex determination and gives population-specific results, is the most investigated skeletal part in anthropology [3, 7].

Establishing a robust method to determine sex by using the cranium is crucial in demonstrating the population specificity of variable sexual dimorphism for forensic anthropology, especially in this area of migration, travel and globalization when different populations mix with each other in one region [8]. When the studies conducted with cranium were examined, it was found that although many parameters were examined, studies focused on using one single cranium aspect were limited and were valuable for forensic anthropology, which aims to identify people with certain profile characteristics [9]. Machine Learning is a growing field in medicine and encompasses multiple statistics-based techniques for radiology researchers such as classification and clustering, which are useful for researchers and can complement Deep Learning approaches [9, 10]. The machine learning algorithms (MLA) Method, which includes more than one type of learning, is a modern method used widely in forensic anthropological studies in recent years [7]. The study was designed to evaluate the accuracy of sex determination from angular and linear variables of the lateral view of the cranium on Computed Tomography (CT) images. It was also aimed that the data obtained at the end of the study would create a database for the Turkish population and be a reference source to support future research.

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MATERIALS AND METHODS

The study was conducted on Carotid CT Angiography images of 400 individuals (200 females, 200 males) aged 20-55 years who applied to Bolu Abant Izzet Baysal University Training and Research Hospital for various reasons, without any traumas related to the cranium. CT images were randomly selected from January 2019 to November 2022 and were transferred to the Radiant Dicom Viewer (RDV) program, which is a personal workstation, in Dicom format and measurements were made. After all the images were transferred to the RDV program, the images were brought to the orthogonal plane and the measurements were made after obtaining MIP: 910, WL: 1568, and WW: 2316 values.

A total of 5 variables (2 angular and 3 linear) were measured in the present study by considering 4 anatomical points: Bregma (b), Nasion (n), Lambda (l), and Opisthion (o) of the lateral view of the cranium, which was referenced in the study. The visuals of the measured variables are given in Figure **1**. Ethical approval was obtained from the Bolu Abant Izzet Baysal University Clinical Researches Ethics Committee Approval for the study (2022/213).

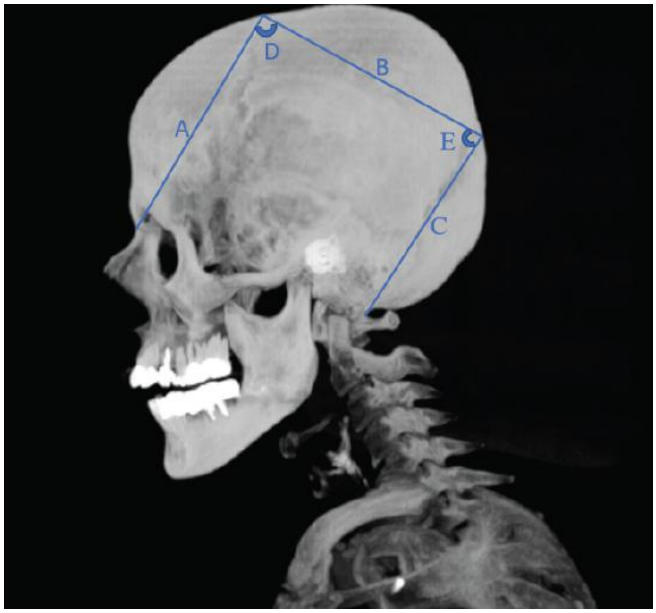

Figure 1: The measurements (A: n-b, B: b-l, C: l-o, D: the angle between the lines connecting n-b and the line connecting b-l, E: the angle between the line connecting b-l and the line connecting l-o.

Measured Linear Parameters

1. A: The length of the line connecting the points n-b
2. B: The length of the line connecting the points b-l
3. C: The length of the line connecting the points l-o

Measured Angular Parameters

4. D: Angle between line (n-b) and line (b-l)
5. E: Angle between line (b-l) and line (l-o)

Computed Tomography Protocol

CT images were acquired through a 64-slice Multi-Detector Computed Tomography (MDCT) device (Revolution EVO, GE Healthcare, Waukesha, WI, USA) at the Department of Radiology in Bolu Abant Izzet Baysal University. The cross-section thickness was 0.625, tube voltage 120 kVp, mA 300, gantry rotation time 0.5 s, and pitch 0.984 mm/rot. The images were transferred to the Radiant Dicom Viewer program, which is a personal workstation in Dicom format and the measurements were performed in this way.

Machine Learning Algorithms

The classification algorithms Logistic Regression (LR), Random Forest (RF), Linear Discriminant Analysis (LDA), K-Nearest Neighborhood (KNN) and Naive Bayes (NB) were used in the present study. Accuracy (Acc), Sensitivity (Sen), F1 score (F1) and Specificity (Spe) were used as the evaluation criteria. An MLA Huawei Matebook 13 Ryzen 7 (64-bit) with 16 GB ram and 512 GB SSD specifications was used in the study. The code is written in the open source python software directory. The data set is divided into 80% training and 20% testing. The calculation formulas of the evaluation criteria are given in Equation 1.

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

$$\mathrm{Spe} = \frac{\mathrm{TP}}{\mathrm{TP+FP}}$$

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

$$\mathrm{F1} = 2*\frac{\mathrm{SPE*SEN}}{\mathrm{SPE+SEN}}$$

Equation 1. Calculation formulas for Acc, Spe, Sen, and F1 (True Negative (TN), False Negative (FN), False Positive (FP), True Positive (TP))

Statistical Analysis

The conformity of the variables to the normal distribution was tested with the Anderson-Darling Test.

Table 1: The Descriptive Statistics Results of the Variables, p-Value in Two Simple t-Test Results, and p-Value in Mann Whitney U Test Results

Variables	Gender	n		p-value
Age	Male	200	49.5 (20-55)[c]	0.919[a]
	Female	200	48 (22-55)[c]	
A	Male	200	114.43 (89.7-128.4)[c]	0.001[a]
	Female	200	108.7 (94.4-130.1)[c]	
B	Male	200	115.7 (94.1-134.3)[c]	0.001[a]
	Female	200	112.2 (90.8-131)[c]	
C	Male	200	94.5 (78.7-111.9)[c]	0.001[a]
	Female	200	91.6 (76.2-115.8)[c]	
D	Male	200	92.3 (81.2-106)[c]	0.001[a]
	Female	200	90.5 (79.9-103.9)[c]	
E	Male	200	96.8±4.3[d]	0.100[b]
	Female	200	96.1±3.9[d]	

[a]The p-value in Mann Whitney u test result, [b]the p-value in Two Simple t-test Mann Whitney u test result, [c]median (min-max), [d]Mean±SD.

Table 2: Acc, Spe, Sen, and F1 Results of the Machine Learning Algorithms

Algorithm	KNN	NB	LDA	RF	LR
Acc	0.75	0.84	0.85	0.79	0.81
Spe	0.76	0.84	0.85	0.81	0.81
Sen	0.75	0.84	0.85	0.79	0.81
F1	0.75	0.84	0.85	0.79	0.81

Mean and standard deviation (SD) of the parametric variables, median, minimum (min) and maximum (max) values for the nonparametric variables were calculated in this test. Two simple t-tests were used in the analyses between genders for parametric variables and Mann Whitney U Test was used for nonparametric variables. The statistical significance level was taken as $p<0.05$.

RESULTS

A total of 5 parameters (2 angular and 3 linear) of the cranium of 200 female and 200 male were measured in the present study. As a result of the analyzes in both genders, it was determined that these measurements showed parametric and nonparametric variable properties. The male and female comparison results for each of the measurements of the cranium are given in Table **1**. In the age variable, the value of female was found to be 48 (22-55), and the value of male was 49.5 (20-55). No significant gender differences were detected regarding the age and D variables, but there was a significant gender difference in the A, B, C and E variables.

It was found that the KNN algorithm result was 0.77, the NB algorithm result was 0.84, the LDA algorithm result was 0.85, the RF algorithm result was 0.70 and the LR algorithm result was 0.81. The Acc, Spe, Sen, and F1 results of the algorithms are given in Table **2**.

Although the LR algorithm classified 29 of 36 male correctly, it classified 36 of 44 female correctly. In NB, 31 of 36 male and 36 of 44 female were guessed correctly. In RF, 32 out of 36 male and 31 out of 44 female were classified correctly. Also, KNN predicted 29 of 36 male and 31 of 44 female correctly. On the other hand, LDA correctly classified 30 of 36 male and 38 of 44 female.

According to the results of the Shap Analyzer to determine the significance of the variables in the study, it was found that the A variable had the best effect. The Shap Analyzer table is given in Figure **3**.

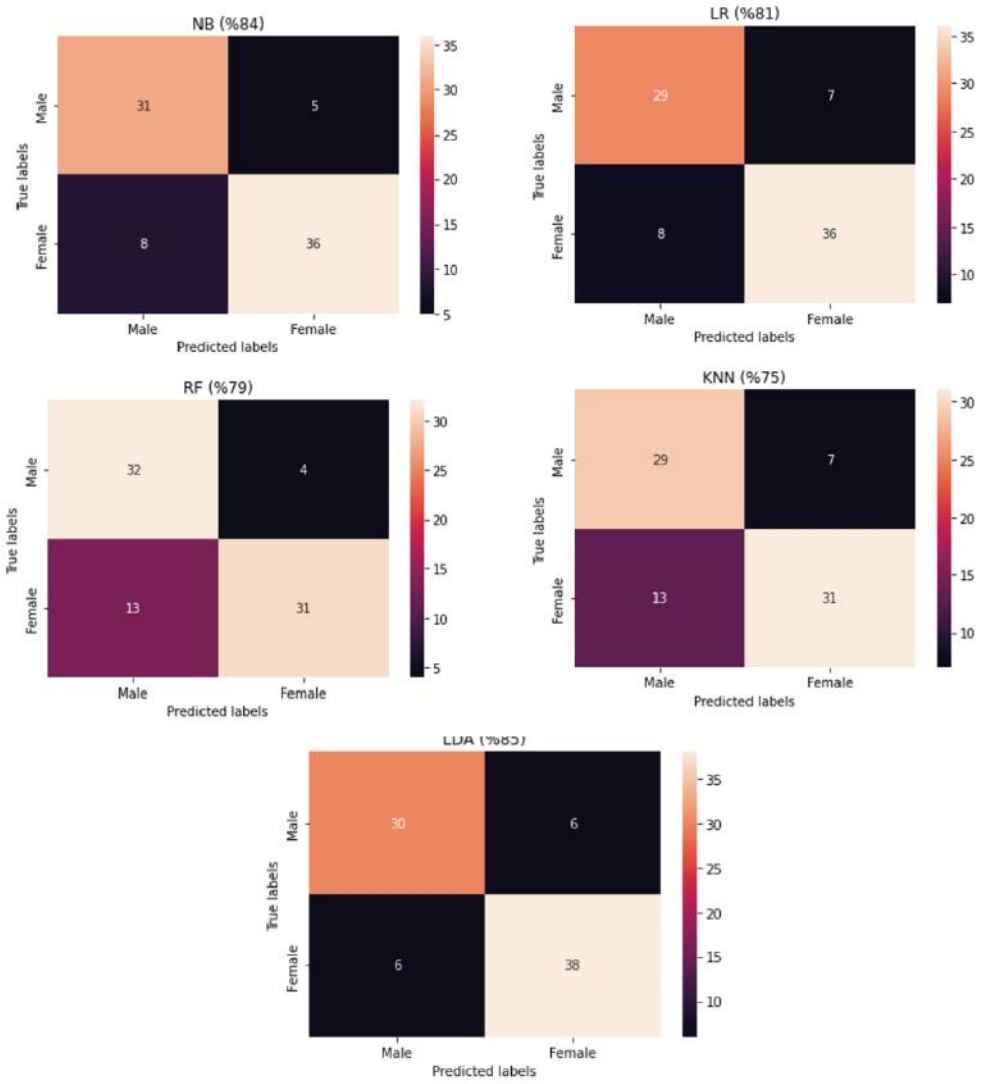

Figure 2: Confusion Matrix Tables of the NB, LDA, RF, KNN, and LR Algorithms.

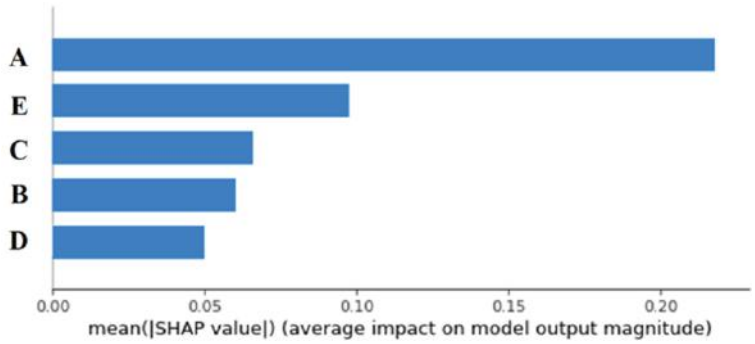

Figure 3: SHAP Analyzer (A: The length of the line connecting the points n-b, B: The length of the line connecting the points b-l, C: The length of the line connecting the points l-o, D: Angle between line (n-b) and line (b-l), E: Angle between line (b-l) and line (l-o)).

DISCUSSION

Gender determination studies are used in many areas such as natural disasters, accidents and forensic investigations. It is thought that studies in this field will guide official institutions and organizations because they will have quality of being scientific data.

In the present study, which was conducted with the help of discriminant function analysis, measurements of

a total of 324 craniums from two different European populations were made on 3-dimensional images. A total of 154 individuals (79 females, 75 males) from the Greek population aged between 19 and 99 and 170 individuals (102 males, 68 females) from the Czech Republic population between the ages of 21-87 were included in the study. As a result of the analysis, it was found that the accuracy rates ranged between 70-92% [11]. In a study that evaluated the role of the cranium and mandible in sexual dimorphism, dimensional and figural gender dimorphism were examined by using a combination of metric and geometric morphometric methods. A total of 120 cranial CT images were investigated, including 63 male (25-82 years old) and 57 female (23-84 years old). As a result of the study, the accuracy rates were reported to be 90% in the cranium and 84.2% in the mandible [12]. The foramen magnum of 100 adults (53 females, 47 males) of the Brazilian population was examined in another study conducted with discriminant analysis. In the analysis, the difference between the sexes of the foramen magnum was found to be statistically significant, and the accuracy varied between 66-71% in the discriminant analysis result [13].

Five parameters of the cranium were examined on CT images of 400 individuals (200 female, 200 male) in the present study and it was found that sex determination would be made with an accuracy of 85%. This result is similar to the cranium studies.

When the literature was reviewed, it was seen that gender determination studies were conducted with various methods, which have expanded in light of technological developments. The technological progress we are experiencing today has also shown itself in this field. These advances formed the basis of the present study. In this context, 25 variables of the cranium were measured in a study conducted on cranial CT images, similar to the present study. After the measurements, sex determination was made by using MLA. LR, Decision Tree (DT), RF, LDA, Quadratic Discriminant Analysis (QDA) and Extra Tree Classifier (ETC) were used as MLA in this study. As a result of the analysis, the highest accuracy was found in LR with 0.90 and the accuracy of other algorithms was calculated as QDA 0.83, RF 0.88, DT 0.81, and ETC 0.85 [3].

Two separate datasets (BestFirst, GeneticSearch) and CT images of 393 Bulgarian (169 male, 224 female) adults were used in the study to create a sex determination model by using Support Vector Machines (SVM) and Artificial Neural Network (ANN). A total of 86 measurements of the cranium were made. As well as SVM and ANN, LR was also used as MLA. As a result of the study, the accuracy rate of the BestFirst dataset was found to be 90.7% for SVM, 90.0% for ANN, 90.9% for LR, 92.9% for GeneticSearch DVM, 91.6% for ANN, and 92.4% for LR [3].

In the present study, in which sex determination was performed from the variables of the cranium by using the MLA Method, five parameters of the cranium were examined by using different algorithms. As a result of the MLA, Acc ratios were found to be 0.77 with the KNN algorithm, 0.84 with the NB algorithm, 0.85 with the LDA algorithm, 0.70 with the RF algorithm and 0.81 with the LR algorithm. The highest accuracy was obtained with the LDA algorithm with 0.85 Acc, 0.85 Spe, 0.85 Sen and 0.85 F1 ratios. Although the number of parameters examined in the study was low, the accuracy rate was found to be high, making it more effective than other studies in contributing to the gender determination process.

As a result, in the present study in which the accuracy of sex determination was evaluated from the angular and linear variables of the lateral view of the cranium, it was found that the MLA method yielded high accuracy regarding gender and the LDA Model was effective in sex determination. It was also found that the cranium showed sexual dimorphism with high accuracy regardless of methodological differences. We think that, at times when it is necessary to determine the biological profile of people, such as migration, travel, and globalization, where different populations are mixed in a certain region, variable sexual dimorphism will constitute a robust method in the field of forensic anthropology to determine the specificity of a certain population.

CONFLICT OF INTEREST

No conflict of interest.

REFERENCES

[1] Doğan Y, Aka PS. Authenticity of sex determination from mesiodistal and buccolingual tooth dimensions in forensic cases. Anthropology 2021; (41): 78-86. https://doi.org/10.33613/antropolojidergisi.907808

[2] Gülhan Ö. Sex Estimation from the Pelvis Using Radiological Methods: Turkish Sample. Anthropology 2018; 36: 53-69. https://doi.org/10.1501/antro_0000000358

[3] Toneva D, Nikolova S, Agre G, Zlatareva D, Hadjidekov V, Lazarov N. Machine learning approaches for sex estimation using cranial measurements. International Journal of Legal Medicine 2021; 135: 951-966. https://doi.org/10.1007/s00414-020-02460-4

[4] Ray A, Ray G, Kurtul I, *et al*. Sex estimation from the variables of talocrural joint by using machine learning algorithms. Journal of Forensic and Legal Medicine 2025; 114: 102912. https://doi.org/10.1016/j.jflm.2025.102912

[5] Sertel Meyvacı S, Göller Bulut D, Öztürk AT, Ankaralı H. Gender estimation from angular parameters of mandible in Turkish adults. Med J West Black Sea 2021; 5(2): 240-7. https://doi.org/10.29058/mjwbs.873771

[6] Sertel Meyvaci S, Ankarali H, Bulut DG, Taskin B. Performances of Different Classification Algorithms in Sex Determination from First Cervical Vertebra Measurements. International Journal of Morphology 2024; 42(5). https://doi.org/10.4067/S0717-95022024000501439

[7] Du Jardin P, Ponsaillé J, Alunni-Perret V, Quatrehomme G. A comparison between neural network and other metric methods to determine sex from the upper femur in a modern French population. Forensic Sci Int 2009; 192: 127-126. https://doi.org/10.1016/j.forsciint.2009.07.014

[8] Musilová B, Dupej J, Velemínská J, Chaumoitre K, Bruzek J. Exocranial surfaces for sex assessment of the human cranium. Forensic Science International 2016; 269: 70-77. https://doi.org/10.1016/j.forsciint.2016.11.006

[9] Peiffer-Smadja N, Rawson TM, Ahmad R, Buchard A, Georgiou P, Lescure FX, Birgand G, Holmes AH. Machine learning for clinical decision support in infectious diseases: a narrative review of current applications. Clinical microbiology and infection : the official publication of the European Society of Clinical Microbiology and Infectious Diseases 2020; 26(5): 584-595. https://doi.org/10.1016/j.cmi.2019.09.009

[10] Borstelmann SM. Machine Learning Principles for Radiology Investigators. Academic Radiology 2020; 27(1): 13-25. https://doi.org/10.1016/j.acra.2019.07.030

[11] Bertsatos A, Chovalopoulou ME, Brůžek J, Bejdová Š. Advanced procedures for skull sex estimation using sexually dimorphic morphometric features. International Journal of Legal Medicine 2020; 134(5): 1927-1937. https://doi.org/10.1007/s00414-020-02334-9

[12] Gillet C, Costa-Mendes L, Rérolle C, Telmon N, Maret D, Savall F. Sex estimation in the cranium and mandible: a multislice computed tomography (MSCT) study using anthropometric and geometric morphometry methods. International Journal of Legal Medicine 2020; 134(2): 823-832. https://doi.org/10.1007/s00414-019-02203-0

[13] Lopez-Capp TT, Rynn C, Wilkinson C, de Paiva LAS, Michel-Crosato E, Biazevic MGH. Sexing the cranium from the foramen magnum using discriminant analysis in a Brazilian sample. Brazilian Dental Journal 2018; 29(6): 592-598. https://doi.org/10.1590/0103-6440201802087

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