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Original Research

Gender Estimation with Parameters Obtained From the Upper Dental Arcade by Using Machine Learning Algorithms and Artificial Neural Networks

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ABSTRACT

Objective: The aim of this study is to predict gender with parameters obtained from the upper dental arch by using machine learning algorithms (ML) machine learning algorithms and artificial neural networks to provide optimum aesthetics, functionality, long-term stability, diagnosis and treatment intervention in orthodontics, forensic medicine and anthropology.

Methods: The study was conducted on cone-beam computed tomography (CBCT) images of 176 individuals between the ages of 18 and 55 who did not have any pathologies or surgical interventions in their upper dental arcade. The images obtained were transferred to RadiAnt DICOM Viewer program in Digital Imaging and Communications in Medicine format and all images were brought to orthogonal plane by applying 3D Curved Multiplanar Reconstruction. Length and curvature length measurements were performed on these images brought to orthogonal plane. The data obtained were used in ML algorithms and artificial neural networks input and rates of gender estimation were shown.

Results: In the study, an accuracy ratio of 0.86 was found with ML models linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), logistic regression (LR) algorithm and an accuracy ratio of 0.86 was found with random forest (RF) algorithm. It was found with SHAP analyser of RF algorithm that the parameter of width at the level of 3rd molar teeth contributed the most to gender. An accuracy rate of 0.92 was found as a result of training for 500 times with multi-layer classifier perceptron (MLCP), which is an artificial neural network (ANN) model.

Conclusion: As a result of our study, it was found that the parameters obtained from the upper dental arcade showed a high accuracy in estimation of gender. In this context, we believe that the present study will make important contributions to forensic sciences.

Keywords: Upper dental arcade, cone-beam computed tomography, estimation of gender, machine learning algorithms, artificial neural networks

INTRODUCTION

Identification of individuals is one of the most important and challenging situations that can be encountered when an accident or disaster occurs. In such cases, biological profile should be created for forensic identification and morphological identification. Biological profile includes gender, ancestry, bone-tooth age, height and physical structure. Gender estimation approaches are also used in anthropological studies in addition to forensic studies. Estimation of gender by using human bones is one of the important tasks that anthropologists must fulfil in identification process for forensic scientists and law enforcement officers [1]. For this reason, adding new ones to the bones which are known to show sexual dimorphism becomes an important issue.

The importance of the maxilla in the facial skeleton results from its central position providing structural support to the face and the importance of the upper jaw in facial structure [2, 3]. The hard palate is formed by the fusion of the two palatine processes of the maxilla and the two horizontal parts of the palatine bone [3, 4]. Fusion of the palatine processes forms the anterior nasal floor and the anterior inferior border of the pyriform aperture [2, 3]. Incisive, canine, premolar, molar teeth mandibular and maxillary arch lengths are important parameters that can be used in gender determination. Especially canine and molar teeth are known to be widely used for gender determination due to their morphological variability and durability [5]. They are considered as a reliable source according to a large number of researchers [5-7]. The formation and development of dental arches is affected by a large number of factors such as unbalanced muscle strength in the face and mouth, vital habits, type of malocclusion, eruption changes of teeth, movement of teeth after eruption, other bones in the face, gender and ethnicity. In particular, there is a research topic for the explanation of dental arch forms and different features of the upper anterior teeth [8-11].

Structures of the upper dental arcade can retain their integrity after death or even after severe damage. Although it can be seen that gender dimorphism of the hard palate has been the subject of research for many years, it can also be seen that a complete consensus has not been reached [12-15].

Main Points;

- Can gender be predicted with high accuracy and reliability using machine learning algorithms from upper dental arcade?
- Can gender be predicted with high accuracy and reliability using neural networks from the upper dental arcade?
- Is upper dental arcade an important biomarker in determining gender?

Although machine learning algorithms (ML) have been a research topic of many years in the field of engineering, it is a recent issue in the field of health. Since ML algorithms are computer based algorithms, they can show the association between input and output with a higher accuracy than individual observations. Artificial neural networks (ANN) are also computer based models and they stand out as a result of their high estimation rate and good non-linear data processing [16-20]. In recent years, ANN and ML are technological developments that we frequently encounter and make great contributions to forensic medicine [21].

The aim of this study is to show the role of length and width parameters of canine, molar, upper dental arcade taken with cone-beam computed tomography (CBCT) by using machine learning algorithms and artificial neural networks on gender estimation in Turkish population.

MATERIALS AND METHODS

Study population and CBCT scanning protocol

The study was conducted with the 2023/4337 issued decision of non-interventional local ethics committee. CBCT images of 86 female and 90 male between the ages of 18 and 55 were included in the study. Exclusion criteria were determined as not being within the predetermined age range and not having surgical intervention and pathology in the upper dental arcade.

CBCT images were obtained by using NewTom 5G (Verona, Italy) device. Screening protocol was determined as110 kVp, 1-11 mA, 3.6 s.

Image processing

The images that met the inclusion criteria between 2020 and 2023 taken from the Picture Archiving Communication Systems (PACS) of the hospital were reviewed retrospectively. The scanned images were transferred to personal work station Windows based RadiAnt DICOM Viewer program in Digital Imaging and Communications in Medicine (DICOM) format. The transferred images were obtained by using the 3D Curved Multiplanar Reconstruction (MPR) console of the program and three images were obtained in axial, coronal and sagittal planes. All images were brought to the orthogonal plane by determining the line passing through the palatine process of maxilla in the images. Length and curvature length measurements were performed by overlapping the axial image in the orthogonal plane (Figure 1).

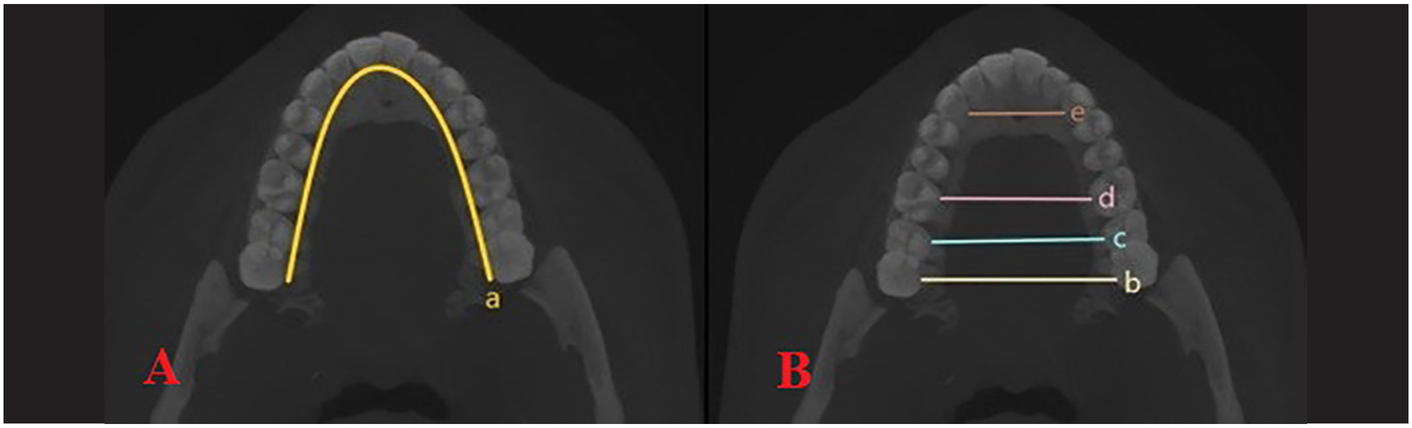

Figure 1. Demonstration of parameters (Figure 1-A, a: Curvature length of the upper dental arcade, Figure 1-B, b: Width at the level of third molars, c: Width at the level of second molars, d: Width at the level of first molars, e: Intercanine width)

Parameters were;

- Curvature length of the upper dental arcade (UDA-CL): Curvature length of all teeth starting from right and left maxillary third molars
- Intercanine width (IC-W): Width between inner edges of left and right maxillary canines
- Width at the level of first molars (M1-W): Width between inner edges of right and left first molars
- Width at the level of second molars (M2-W): Width between inner edges of right and left second molars
- Width at the level of third molars (M3-W): Width between inner edges of right and left third molars

Implementing ML Algorithms and ANN

Python 3.9 programming language and scikit-learn1.1.1 framework were used in ML and ANN modelling. The modelling was performed by using Monster Abra A7 V12.5 model personal computer with i5 processing system and 8 Gb Ram. In ML and ANN modelling, test set was determined as 20%, while the training set was determined as 80%. Linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), logistic regression (LR), random forest (RF) algorithms were used in ML modelling. No extracting or cleaning was applied on the data for the ANN model to reflect the reality. Multi-layer classifier perceptron (MLCP) was preferred as ANN model. Six neurons were used in the input layer, while 2 neurons and 2 hidden layers (first with 18 neurons and second with 12 neurons) were used in the output layer. The network in this topology was retrained for 100, 500 and 1000 times for a real learning to occur. Accuracy (Acc), Specificity (Spe), Sensitivity (Sen), F1 score (F1) values were used as performance criteria in both models (ML-ANN). In our study, the effect of each parameter on the overall result was evaluated using the SHAP analyzer of the RF algorithm.

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

Statistical Analysis

In descriptive statistics of the parameters, mean and standard deviation were included for those with normal distribution, while median, minimum and maximum values were included for those that were not normally distributed. Normality distribution was tested with Anderson Darling test. Minitab 17 package program was used for descriptive statistics.

RESULTS

In the study conducted on 86 female and 90 male between the ages of 18 and 55, it was found that the parameters of age and UDA-CL were not normally distributed, while the other parameters were normally distributed. Descriptive statistics of the parameters which were not normally distributed are shown in Table 1.

Descriptive statistics of the normally distributed parameters are shown in Table 2.

As a result of ML algorithms, the highest Acc rate was founds as 0.86 with LR, LDA, QDA algorithms (Table 3).

Confusion matrix obtained as a result of ML algorithms is shown in Figure 2.

Table 2. Descriptive statistics of the normally distributed parameters

Parameters (cm)	Gender	Mean	Standard Deviation
IC-W	Male	2.560	0.217
	Female	2.402	0.218
M1-W	Male	3.655	0.312
	Female	3.532	0.356
M2-W	Male	4.002	0.377
	Female	4.050	0.384
M3-W	Male	4.257	0.386
	Female	4.793	0.430

Table 3. Performance criteria obtained as a result of machine learning algorithms

Algorithms	Acc	Spe	Sen	F1
RF	0.81	0.81	0.81	0.81
LR	0.86	0.86	0.86	0.86
LDA	0.86	0.87	0.86	0.86
QDA	0.86	0.87	0.86	0.86

The effect of parameters on the overall result was examined with SHAP analyser of RF algorithm and it was found that M3-W parameter had the highest contribution (Figure 3).

Table 4 includes the mean performance criteria obtained as a result of training for 100, 500 and 1000 times in MLCP model. The highest mean performance was obtained as a result of training for 500 times.

Figure 4 shows the confusion matrix table obtained as a result of training for 500 times.

Higher accuracy results were obtained with the MLCP model than the ML model.

Table 4. MLCP mean performance criteria

Number of Education	Acc	Spe	Sen	F1
100	0.86	0.86	0.86	0.86
500	0.92	0.92	0.92	0.92
1000	0.83	0.83	0.83	0.83

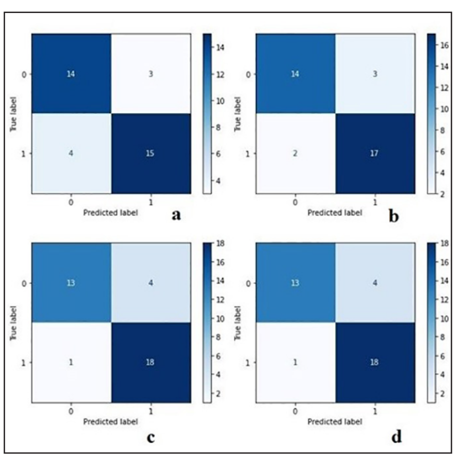

Figure 2. Confusion Matrix table of the ML modelling (a: Random Forest, b: Logistic Regression, c: Linear Discriminant Analysis, d: Quadratic Discriminant Analysis)

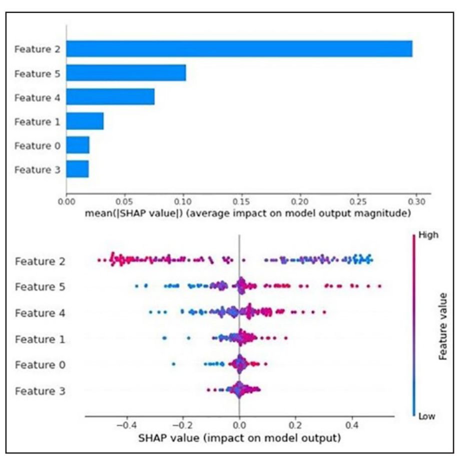

Figure 3. SHAP analyser *Feature 2: Width at the level of third molars, 5: Intercanine width, 4: Width at the level of first molars, 1: Curvature length of the upper dental arcade, 0: Age, 3: Width at the level of second molars

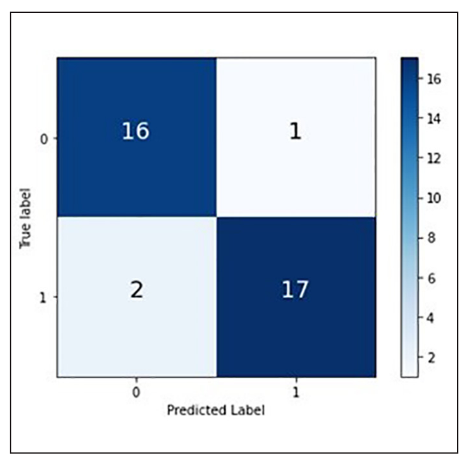

Figure 4. Confusion matrix table of MLCP training for 500 times

DISCUSSION

When the data obtained in the study were transferred to ML and ANN, the highest accuracy rate for a possible gender estimation was found by MLCP, which is used as ANN model. In the measurements, accuracy rate was found as 0.92 when MLCP was trained 500 times. When these results were examined and the related parameters were added, it was found that MLCP trained 500 times could estimate the gender of 92 individuals out of 100 correctly. All of the parameters were examined one by one with SHAP analyser of RF algorithm and their effects on the general result were analyzed and it was found that M3-W was the parameter that increased accuracy rate most. The effects of the other parameters on accuracy rate can be listed as follows: the parameter with the highest effect after M3-W was IC-W, followed by M1-W, UDA-CL, age and finally M2-W with the lowest effect. An accuracy rate of 0.86 was found as a result of LR, LDA, QDA algorithms obtained with ML.

In a study conducted by Bishara et al. [22], individuals were divided into certain age groups, their maxillary arch lengths were measured and maxillary arch length was found as 73.2 mm in males and as 71.1 mm in females for 26 years of age, while it was found as 72.2 mm in males and as 70.1 mm in females for 45 years of age. In another maxillary arch length measurement study conducted by Alam et al. [23] with their own reference points, maxillary arch length was found as 77.4 mm in males and as 74.5 mm in females. In a study conducted by Hashim et al. [24], mean maxillary arch length was found as 74.01 mm in males and as 72.36 mm in females. According to the measurement found in the study, mean UDA-CL median value was found as 11.090 cm in males and as 11.130 cm in females. In our study, unlike general data, it was found that females had higher maxillary arch length than males. The parameters used, changes in populations and differences in methods may have caused the different results.

In a study they got the measurements from buccal cusps, Burris et al. [25] found mean IC-W as 33.8 mm in males and as 32.6 mm in females. In a similar anthropometric measurement study Alvaran et al. [26] conducted on individuals aged between 5 and 17, mean IC-W was found as 33.3 mm in males and as 32.4 mm in females. In a study conducted by Rao and Kiran [27], mean IC-W was found as 35.08 mm in males and as 33.42 mm in females. Al-Omari et al. [28] found mean IC-W as 35.28 mm in males and as 33.92 mm in females. Muhammad et al. [29] found mean IC-W as 36.57 mm in males and as 35.82 mm in females. The results of the aforementioned studies and the present study are in parallel. In our study, mean IC-W was found as 2.560 in males and as 2.402 in females; mean M1-W was found as 3.655 in males and as 3.532 in females; mean M2-W was found as 4.002 in males and as 4.050 in females and mean M3-W was found as 4.257 in males and as 4.793 in females. We think that the small difference that occurs is due to the population difference.

In the literature, Burris et al. [25] found mean M1-W as 50.1 mm in males and as 48.0 mm in females and found that mean value was higher in males. In a study conducted on individuals aged between 5 and 17, Al-varan et al. [26] found that males had higher means than females. In a study based on their own measurement points, Adriana et al. [30] found mean M1-W as 49.36 mm in males and as 46.75 mm in females and found that M1-W was higher in males. In a study they conducted their own measurement points, Al-Omari et al. [28] found mean width between first molars as 48.18 mm in males and as 45.96 mm in males. In a study based on their own reference points, Mahasweta et al. [31] found mean M1-W as 32.67 mm in males, as 31.64 mm in females. According to the data found in our study, mean M1-W was 3.655 cm in males and 3.532 cm in females. Similar results were found in a large number of intermolar width measurements. It was found that males had higher maxillary M1-W than females and thus maxillary arch at the level of 1st molar was wider [32]. We think that the width in males may be caused by sex hormones.

In the study by Burris et al. [25], mean M2-W width was found as 55.7 mm in men and as 53.7 mm in females. Unlike other studies on mean M2-W, the results were higher in females than in males. In addition, unlike other studies, UDA-CL on maxillary bone was found to be longer in females than in males. We believe that these differences may be due to the ethnicity, living conditions, nutrition type of the individuals in the population measurements were made, anatomical differences of bones or different reference points and measurement methods. Sufficient information could not be found in the literature review conducted for M3-W.

CONCLUSION

Since the identity of individuals needs to be estimated quickly in events such as war, natural disasters or wars which deeply affect the society, CBCT technology and MLCP used as ANN model in this study showed that high accuracy can be obtained by minimizing this time. It is thought that the parameters taken from the maxilla in this study will contribute to studies on gender estimation and make these studies stronger.

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Informed Consent: The study is a retrospective study and was carried out by scanning the existing images in the hospital archive system.

Conflict of interest: There is no conflict of interest.

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Ethical Approval: This study was approved by the 2023/4337 decision of the Inonu University non-invasive local ethics committee.

Author Contributions: Conception: YS; ST - Design: YS; ST - Supervision: YS; ST - Fundings: -Materials: YS; HE; MT - Data Collection and/or Processing: SD; YS; HE; MT - Analysis and/or Interpretation: YS - Literature: HE; MT - Review: ST; SD; YS; HE; MT - Writing: ST; SD; YS; HE; MT - Critical Review: ST; SD; YS; HE; MT.

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