Int. J. Morphol.,
43(2):494-501, 2025.

Sex Prediction in Turkish Population with Anthropometric Measurements of Scapula on MDCT Images Using Machine Learning Algorithms

Predicción del Sexo en la Población Turca con Mediciones Antropométricas de la Escápula en Imágenes de TCMD Utilizando Algoritmos de Aprendizaje Automático

Halide Temelci[1]; Aynur Emine Cicekcibasi [2]; Zulal Oner[1]; Yusuf Secgin[3]; Serkan Oner[4] & Gulay Acar[2]

TEMELCI, H.; CICEKCIBASI, A. E.; ONER, Z.; SECGIN, Y.; ONER, S. & ACAR, G. Sex prediction in Turkish population with anthropometric measurements of scapula on MDCT images using machine learning algorithms. *Int. J. Morphol., 43(2)*:494-501, 2025.

SUMMARY: Identification studies progress more accurately and easily after sex estimation is realized. Therefore, sex determination is the first step in identification studies. The aim of our study is to perform sex estimation from the scapula using machine learning (ML) algorithms with parameters obtained from multidetector computed tomography (MDCT) images of the Turkish population. The study was performed on MDCT images of 300 individuals (150 females and 150 males) aged between 20 and 60 years. MDCT images of the scapula were imported into the Radiant DICOM Viewer program and the following parameters were measured: the maximum length of the scapula (SML), the maximum width of the scapula (SMW), the length of the scapular spine (SSL), the length of the glenoid cavity (GCL), the width of the glenoid cavity (GCW), the distance from the coracoid process to the inferior angle (CPIA), the distance from the acromion to the inferior angle (AIA), the distance from the glenoid cavity to the inferior angle (GCIA), the thickness of the lateral margin (LBT), the height of the supraspinous fossa (SSH), the height of the infraspinous fossa (ISH), the maximum length of the acromion (AML), and the maximum width of the acromion (AMW). The obtained data were used for sex prediction using ML algorithms. All parameters measured on the scapula were found to have a significant difference in terms of sex ($p<0.05$). It was determined that the parameters used in sex estimation using ML models had an accuracy rate of 97 %. Using the SHAP solver of the Random Forest algorithm, the parameter of the SSH was found to have the greatest contribution to accuracy. As a result of our study, we think that we can obtain results close to the pelvic morphometry, which is seen as the most dimorphic bone in the literature, when sex determination is made based on scapula morphometry with ML analysis. We believe that our study will make a great contribution to forensic sciences and literature.

KEY WORDS: Scapula; Machine learning algorithms; Computed tomography; Sex prediction; Anthropometry.

INTRODUCTION

Forensic anthropology is the branch of science that enables the identification of living or non-living individuals, revealing their personal characteristics in order to determine their difference from other individuals (Çeker, 2017). Sex determination is one of the most fundamental stages of identification. This is because estimation of weight, height, age, age at death and ancestry is mostly based on sex-specific data (Paulis & Abu Samra, 2015; Zhang *et al*., 2016). Although DNA analysis is currently preferred as one of the most reliable methods for defining the biological profile, it is expensive, time-consuming and requires expertise. Therefore, osteometric methods, which are highly reliable, do not require expertise, are effective, cost-effective, easy to access, and can be used for quick decision-making, are coming to the forefront (Giurazza *et al*., 2013; Oner *et al*., 2019).

In these cases where a large number of human fragmented bones are found together, all bones should be identified, eliminated and matched according to their size, appearance, articulation characteristics and pathological condition (Giurazza *et al*., 2013). Almost the entire human

[1]Izmir Bakırçay University Faculty of Medicine Department of Anatomy Izmir, Türkiye.
[2]Necmettin Erbakan University Faculty of Medicine Department of Anatomy Konya,Türkiye.
[3]Karabük University Faculty of Medicine Department of Anatomy Karabük, Türkiye.
[4]Izmir Bakırcay University Faculty of Medicine Department of Radiology Izmir, Türkiye.

Received: 2024-08-31 Accepted: 2024-12-27

skeletal structure has been used for sex determination, and the structure with the highest accuracy has been identified (Oner *et al*., 2019). It has been reported that pelvic and cranial skeletons provide the highest accuracy in sex determination studies to date. The pelvic skeleton is very fragile but has high accuracy compared to skull bones (Torimitsu *et al*., 2015). Since the scapula is among the short and flat bones, it is preferred because it is resistant to trauma compared to the long bone structure and does not change even after the development is completed (Giurazza *et al*., 2013).

Machine learning (ML) algorithms are a modern grouping tool generally preferred in the field of engineering and are now frequently used in the healthcare sector (Lewis, 2017). Computed tomography (CT) scanning is the most reliable radiographic method for osteometry studies (Giurazza *et al*., 2013). Identification studies based on CT images are frequently used by forensic anthropologists because they are fast, low-cost, more accurate and reproducible than traditional methods, allow visualization of each part of the bone, and provide the most accurate results in calculating the length-angle and coordinates of the bone (Badr El Dine & Hassan, 2016; Ali *et al*., 2018).

Our aim in this study is to estimate sex based on the morphometry of the scapula, a bone resistant to trauma, by using ML algorithms with parameters taken from multidetector CT (MDCT) images of the Turkish population.

MATERIAL AND METHOD

In this study, MDCT images of the scapula taken between 2018 and 2022 in the archive of the Department of Radiology, Faculty of Medicine, Izmir Bakırçay University were retrospectively evaluated. Images of 300 individuals (150 women and 150 men) aged between 20 and 60 years were included in the study. Patients under 20 and over 60 years of age, with previous trauma in this region, bone and joint disease, and surgical procedures around the shoulder and scapula were excluded. The analysis controlled for confounding variables such as diet, environmental exposures or similar factors. Informed consent was obtained from the individuals in accordance with the Declaration of Helsinki and the study was conducted with the permission of Necmettin Erbakan University Drug and Non-Medical Device Research Local Ethics Committee dated 07.10.2022 and numbered 161.

Image Processing. Images from the hospital's Picture Archiving Communication Systems (PACS) archive system were scanned retrospectively. The scanned images were transferred in Digital Imaging and Communications in Medicine (DICOM) format to Radiant DICOM Viewer (64-bit version), a personal workstation. Scapula morphometry was used to determine the maximum length of the scapula (SML), maximum width of the scapula (SMW), length of the scapular spine (SSL), length of the glenoid cavity (GCL), width of the glenoid cavity (GCW), coracoid process to inferior angle distance (CPIA), acromion to inferior angle

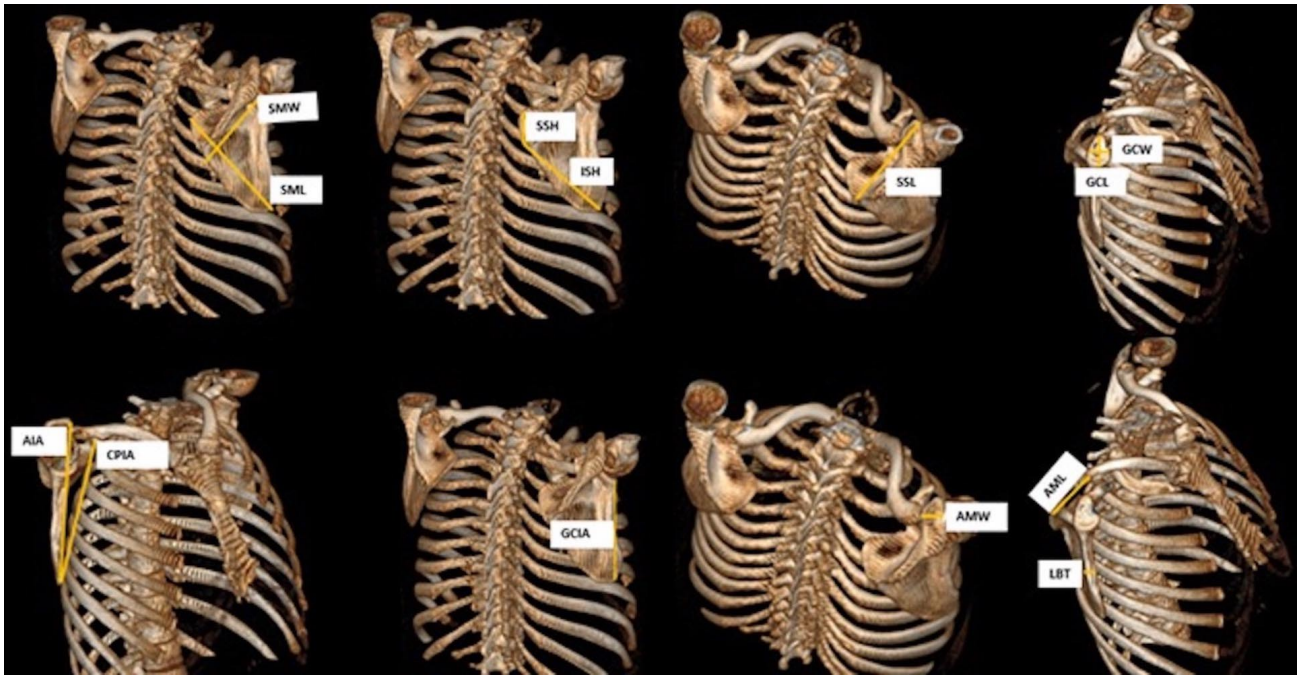

Fig. 1. Demonstration of parameters.

distance (AIA), glenoid cavity to inferior angle distance (GCIA), lateral margin thickness (LBT), supraspinous fossa height (SSH), infraspinous fossa height (ISH), acromion maximum length (AML), and acromion maximum width (AMW) parameters were measured (Fig. 1).

Modeling Machine Learning Algorithms. ML algorithm models such as K-Nearest Neighbors (k-NN), Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA), Decision Tree (DT), Logistic Regression (LR), Random Forest (RF), Gaussian Naive Bayes (GaussianNB) algorithms were used in the study. Accuracy (Acc), Specificity (Spe), Sensitivity (Sen), F1 score (F1) were preferred to test the performance of the models.

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

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

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

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

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

Machine Learning Algorithms Process. The numerical data obtained from the parameters were passed in Excel format to a Monster Abra A7 model computer with i5 operating system and 8 Gb Ram. The numerical data was processed using Python 3.9 programming language and scikit-learn 1.1.1 framework and 20 % of the data was evaluated as a test set in all ML algorithms during processing. We also evaluated the individual contributions of the parameters to the overall result using the SHAP analyzer of the RF algorithm.

Ethical approval. Informed consent was obtained from the individuals in accordance with the Declaration of Helsinki and the study was conducted with the permission of Necmettin Erbakan University Drug and Non-Medical Device Research Local Ethics Committee dated 07.10.2022 and numbered 161.

Statistical Analysis. The compatibility of the numerical data obtained as a result of the measurements with normal distribution was evaluated by Anderson Darling test. Mean±standard deviation results were used to analyze normally distributed data, and median (minimum-maximum) values were used to analyze non-normally distributed data. When analyzing pairwise comparisons of data, Two Simple T test values were used for normally distributed data and Mann Whitney-U test was used for non-normally distributed data. Pearson correlation test was used to analyze the relationship between normally distributed data and Spearman rho correlation test was used to analyze the relationship between non-normally distributed data. ROC analysis was used to evaluate the contribution of the parameters in predicting sex. In the analyses, $p<0.05$ was considered statistically significant. Analyses were tested using Minitab 17 and SPSS 21 programs.

RESULTS

In the study on the scapula parameters of 300 individuals between the ages of 20-60 years, it was determined that the median value of all parameters was higher in male and all parameters except the age parameter had a significant difference in the comparison of the parameters in terms of sex ($p<0.05$). Descriptive statistics and Two Simple T test results of these parameters are given in Table I.

The relationship between the parameters in terms of sex was analyzed by Spearman rho correlation test. A very high correlation ($p<0.05$) was found between 16 parameters including SML-SSL, SML-GCL, SMW-SMW, SMW-ISH, SSL-SML, SSL-ISH, SSL-AMW, AMW-SSL, AMW-CPIA, AML-SML, AML-SMW, AML-ISH, GCW-SML, GCW-SMW and GCW-ISH.

ML modeling with the selected parameters resulted in an Acc rate of 0.97, which is much higher than any of the algorithms tested (Table II).

ROC curves of GaussianNB, DT, k-NN, k-NN, LDA, LR and QDA algorithms for sex using ML models are given in Figure 2.

In the LDA, DT, LR and QDA algorithms, 29 of the 31 male individuals in the dataset were correctly predicted and all 29 female individuals were correctly predicted. In the other RF, k-NN and GaussianNB algorithms, 30 of the 31 male individuals in the dataset were correctly predicted and 28 of the 29 female individuals were correctly predicted. The confusion matrix for LDA, DT, LR, QDA, RF, k-NN and GaussianNB algorithms are shown in Figure 3.

Using the SHAP solver of the RF algorithm, the effect of each of the parameters on the overall result was tested. The SSH parameter was found to have the largest contribution to Acc and the SSL parameter the smallest (Fig. 4).

Table I. Comparison of normally distributed parameters according to sex and descriptive analysis results

Parameters	Sex	Minimum	Median	Maximum	p
Age	Male	20.00	43.50	60.00	0.91
	Female	20.00	42.00	60.00	
SML	Male	12.84	15.69	18.44	**0.00**
	Female	11.22	13.70	15.32	
SMW	Male	8.93	11.13	12.40	**0.00**
	Female	7.08	9.43	10.99	
SSL	Male	9.60	13.93	16.65	**0.00**
	Female	9.79	12.38	14.35	
GCIA	Male	9.19	13.51	16.53	**0.00**
	Female	8.51	11.21	13.53	
SSH	Male	4.14	5.46	6.98	**0.00**
	Female	2.71	4.26	5.58	
ISH	Male	9.37	11.28	13.89	**0.00**
	Female	7.84	9.64	11.47	
AMW	Male	1.47	3.18	4.55	**0.00**
	Female	1.61	2.51	3.46	
AML	Male	2.46	4.75	6.26	**0.00**
	Female	2.81	3.84	5.18	
GCL	Male	3.09	4.21	5.48	**0.00**
	Female	2.60	3.30	4.23	
GCW	Male	1.86	3.20	3.98	**0.00**
	Female	1.60	2.53	3.23	
LBT	Male	1.00	1.63	2.16	**0.00**
	Female	0.49	1.02	2.20	
CPIA	Male	13.94	15.81	19.17	**0.00**
	Female	8.20	13.93	16.29	
AIA	Male	13.40	17.66	19.94	**0.00**
	Female	9.12	15.64	18.00	

*Two Simple T test. (p<0.05, SML: maximum length of the scapula, SMW: maximum width of the scapula, SSL: length of the scapular spine, GCL: length of the glenoid cavity, GCW: width of the glenoid cavity, CPIA: coracoid process to inferior angle distance, AIA: acromion to inferior angle distance, GCIA: glenoid cavity to inferior angle distance, LBT: lateral border thickness, SSH: supraspinous fossa height, ISH: infraspinous fossa height, AML: acromion maximum length, AMW: acromion maximum width).

Table II. Performance results of machine learning models.

Algorithms	Acc	Spe	Sen	F1
LDA	0.97	0.97	0.97	0.97
QDA	0.97	0.97	0.97	0.97
LR	0.97	0.97	0.97	0.97
DT	0.97	0.97	0.97	0.97
RF	0.97	0.97	0.97	0.97
k-NN	0.97	0.97	0.97	0.97
GaussianNB	0.97	0.97	0.97	0.97

Acc: accuracy, Spe: specificity, Sen: sensitivity, F1: F1 score, LDA: linear discriminant analysis, QDA: quadratic discriminant analysis, LR: logistic regression, DT: decision tree, RF: random forest, k-NN: k-nearest neighbors, GaussianNB: gaussian naive bayes.

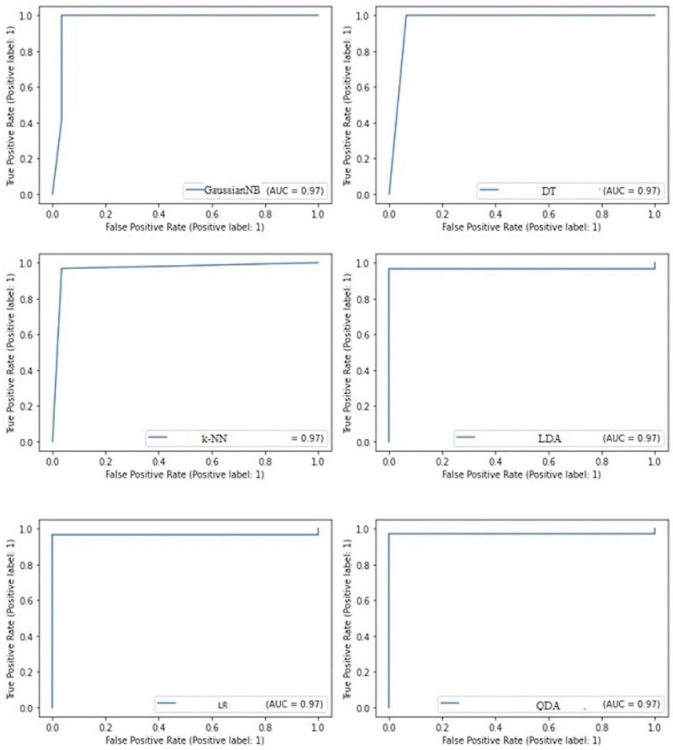

Fig. 2. ROC curves for GaussianNB, DT, k-NN, LDA, LR and QDA algorithms (Gaussian NB: gaussian naive bayes, DT: decision tree, k-NN: k-nearest neighbors, LDA: linear discriminant analysis, LR: logistic regression, QDA: quadratic discriminant analysis).

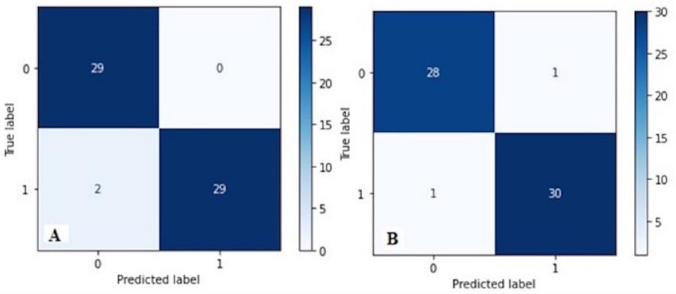

Fig. 3. Confusion matrix table of models with accuracy rate (A)LDA: linear discriminant analysis, DT: decision tree, LR: logistic regression, QDA: quadratic discriminant analysis (B) RF: random forest, GaussianNB: gaussian naive bayes, k-NN: k-nearest neighbors.

DISCUSSION

In this study, in which we aimed to perform sex estimation from scapula using ML algorithms with parameters obtained from MDCT images, we achieved a high Acc rate of 97 % using DT, LR, RF, k-NN, GaussianNB, LDA and QDA algorithms with the selected parameters. As a result of the confusion matrix, 29 of the 31 male individuals and all 29 female individuals in the dataset were correctly predicted in the LDA,

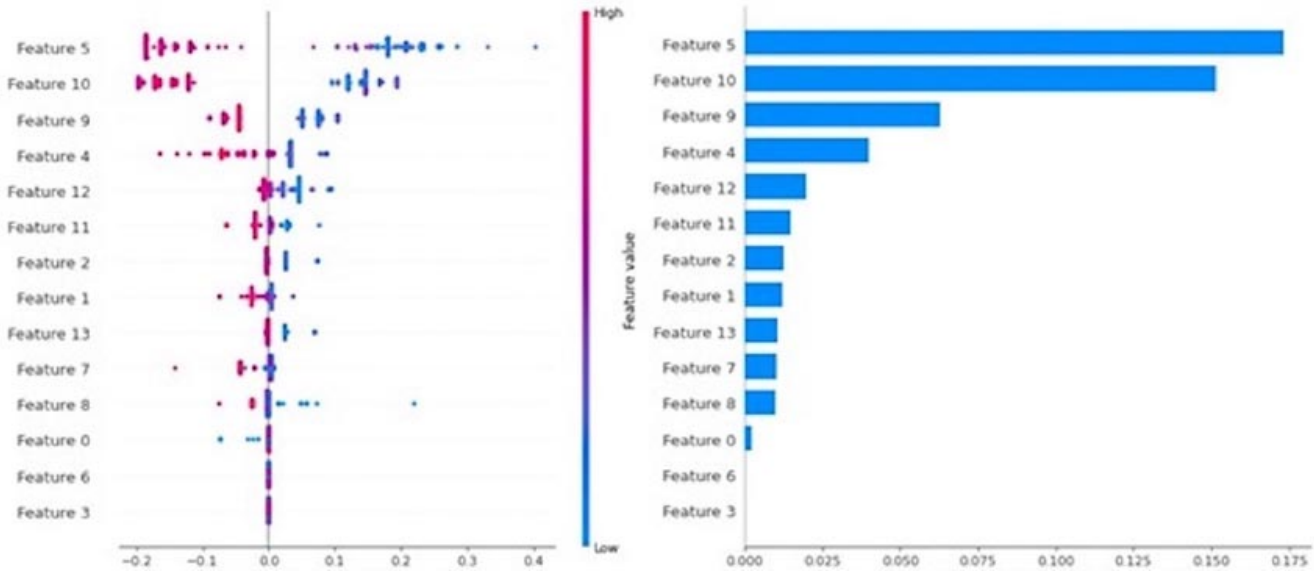

Fig. 4. SHAP analyzer of the RO algorithm (*Feature 0: age, 1: SML, 2: SMW, 3: SSL, 4: GCIA, 5: SSH, 6: ISH, 7: AMW, 8: AML, 9: GCL, 10: GCW, 11: LBT, 12: CPIA, 13: AIA).

DT, LR and QDA models with 97 % Acc rate. In the other RF, k-NN and GaussianNB models with 97 % Acc rate, 30 of the 31 male individuals in the dataset were correctly predicted and 28 of the 29 female individuals were correctly predicted. When the effect of the parameters on the overall result was evaluated using the SHAP analyzer, it was found that the SSH parameter had the greatest contribution to the Acc.

Ghasemi *et al*. (2020) reported that right-handed individuals were in the majority in their study population and that right-handed work, which is predominant in male, has a great effect on the anthropometric standards of the right shoulder because physical strength is greater on this side. In sex estimation studies, right scapula measurements are thought to have a higher Acc rate than the left. In this study, sex estimation was performed on the right scapula due to the predominance of right-handed individuals (Torimitsu *et al*., 2016; Ghasemi *et al*., 2020).

When identifying unidentifiable individuals, such as after fire, plane crashes, physical violence, war, etc., sex estimation reduces the potential identification data by approximately 50 % (Decker *et al*., 2019). More accurate and practical decisions are made after sex is determined. In cases where there are mass deaths, anatomical points should be determined more accurately and more practically because there are soft tissue losses or deformities when performing sex estimation studies. Identification studies using CT images are frequently preferred by forensic anthropologists because they allow visualization of each part of the bone, provide the most accurate results in measuring the length-angle and coordinates of the bone, can be applied quickly, and have reconstruction possibilities (Badr El Dine & Hassan, 2016; Ali *et al*., 2018).

In the sex estimation studies conducted so far, almost all bones of the human skeletal structure have been measured and an accuracy rate of 98 % has been obtained from pelvis bones + skull bones, 95 % from pelvis + long bones, 90-95 % from long bones + skull bones, 95 % from pelvis bones, 90 % from skull bones, and 80-90 % from long bones only (Torimitsu *et al*., 2015).

Er *et al*. (2020) measured SML, SMW, SSL, GCL, GCW, LBT, AML and ISH parameters in 152 individuals between the ages of 22 and 80 years whose CT images were taken. SML was 95.5 mm in female and 108 mm in male, SMW was 140.1±8.1 mm in female and 161.5±8.5 mm in male, SSL was 127.8±6.3 mm in female and 144.7±7.5 mm in male, GCW was 23.9 mm in female and 28.4 mm in male, GCL was 32. 6 mm in female and 37.5 mm in male, LBT 8.4±0.9 mm in female and 11.1±1.7 mm in male, AML 40.6±3.5 mm in female and 48.5±4.8 mm in male, ISH 106.1±7.6 mm in female and 116.4±9.1 mm in male. When they analyzed the data with stepwise discriminant function equations, they found an Acc rate of 96 % (Er *et al*., 2020). In our study, we found that there was a significant difference in the median values in male compared to female in terms of sex in all measurements of SML, SMW, SSL, GCL, GCW, LBT, AML and ISH

($p<0.05$). In our study, the effect of each parameter on the overall result was evaluated using the SHAP analyzer of the RF algorithm and we found that the SSH parameter had the greatest contribution to the Acc, followed by the GCW parameter. In DT and GaussianNB analyses of all measurement parameters, we found that the overall Acc rate for both male and female sex determination was 97 %. When we look at the results of both studies, we think that the scapula is highly dimorphic in sex prediction studies in the Turkish population. However, according to the basic statistical data analysis, we concluded that the studies performed with ML algorithms reflect the truth more.

Torimitsu *et al*. (2016) obtained an Acc rate of 91 % in a study conducted in a Japanese population by using Anova on the data of 218 cadavers aged 23-91 years on CT image of the scapula. They found that SMW was 102.27±5.13 mm in female and 114.03±5.19 mm in male, SML was 137.76±7.72 mm in female and 158.43±7.79 mm in male, SSL was 126.71±6.65 mm in female and 142.53±6.52 mm in male, GCL was 30.65±2.64 mm in female and 33.73±2.1 mm in male. They preferred ANOVA for sex determination and found that the overall Acc rate was 91 % (Torimitsu *et al*., 2016). In our study, we found that SMW was 90.43±20.35 mm in female and 110.13±29.2 mm in male, SML was 130.70±20.48 mm in female and 150.69±29.75 mm in male, SSL was 120.38±29.72 mm in female and 130.93±40.93 mm in male, GCL was 30.30±9.30 mm in female and 40.21±10.27 mm in male. We determined an Acc rate of 97 % using LDA and QDA model based on these parameters measured in our study. We think that the use of different preferred method and statistical analysis minimizes the error in determining different Acc rates between the two studies; we believe that studies with ML models in sex determination studies can be more reliable and higher accuracy rates can be obtained.

In other sex determination studies using scapula morphometry in the literature, scapula morphometry of 191 individuals aged between 19-96 years showed an Acc rate of 83-88 %; scapula morphometry of 290 individuals aged between 18-101 years showed an Acc rate of 94.5 % (Peckmann *et al*., 2017; Ali *et al*., 2018). In our study, the ossification of the scapula was completed between the ages of 20-25 years, so scapula images below the age of 20 years were not included. Using DT, LR, RF, k-NN, GaussianNB, LDA and QDA models, an Acc rate of 97 % was obtained for all parameters measured on the scapula. We think that the reason for the high Acc rate in our study is that the age of the population was chosen according to the age of ossification of the scapula and the preferred statistical analysis and the method we applied were different.

Ghasemi *et al*. (2020) in their sex estimation study with CT scapula images of 200 individuals (100 females and 100 males) in Iranian population, found that the AIA parameter had the highest contribution to the Acc and the GCW parameter had the lowest contribution to the Acc with discriminant function analysis. In our study, we evaluated the effect of each parameter on the overall result using the SHAP analyzer of the RF algorithm and found that the SSH parameter had the greatest contribution to the Acc, followed by the GCW parameter and the SSL parameter had the least contribution to the Acc. We think that the differences between the two studies are due to environmental and genetic factors in the population.

Other sex prediction studies using scapula morphometry include Atamtürk *et al*. (2019) 90.5 % in the Turkish population, Ali *et al*. (2018) 94.5 % in a mixed population, Debnath *et al*. (2018) 93.5 % in the Canadian population, Hudson *et al*. (2016) reported 83-89 % accuracy in Mexican population, Peckman *et al*. reported 83-88 % accuracy in Thai population and Papaioannou *et al*. (2012) reported 95.9 % Acc in Greek population (Papaioannou *et al*., 2012; Hudson *et al*., 2016; Peckman *et al*., 2017; Ali *et al*., 2018; Debnath *et al*., 2018; Atamtürk *et al*., 2019).

Bytheway & Ross (2010) found the highest Acc rate of 98 % from the pelvic skeleton for both males and females in sex estimation studies conducted so far in the literature using osteometry technique. This study was evaluated by Mancova discriminant analysis and found to be the most reliable sex determination by osteometry method after DNA multiplex PCR test with 98 % Acc rate. d'Oliveira Coelho & Curate (2019), using pelvic morphometry, determined sex determination with 86 % Acc with RF analysis method from ML algorithms, which is a more reliable method. Since ML algorithms reflect the truth more and CT scanning is the most accurate and reliable radiographic technique for osteometry studies, Secgin *et al*. (2022) obtained reliable and highly accurate values for sex determination of 300 healthy individuals (150 females, 150 males) in the Turkish population by using pelvic morphometry on CT images; 90-96 % of DT, RF, LR, ADA, LDA and EAS analysis methods. In our study, 97 % Acc rate was determined by using DT, LR, RF, k-NN, GaussianNB, LDA and QDA models over all measured parameters of the scapula. In addition to pelvic morphometry being the most reliable bone in sex determination studies in the literature, we believe that scapula morphometry is a highly reliable and dimorphic bone in the Turkish population and other populations.

CONCLUSION

Measurements were made with a specific population sample. Therefore, we think it would be much more valuable to present data specific to each population. Although the small sample size is one of the limitations of our study, the high Acc, Spe, Sen and F1 values we obtained in our results show that the parameters we determined on scapula MDCT images will provide highly accurate and reliable data in the shortest estimation time when individuals need to be identified quickly, reliably and accurately using ML algorithms.

As a result, to the best of our knowledge, there is no sex determination study in Turkish population using DT, LR, RF, k-NN, GNB, LDA and QDA analysis methods from ML algorithms for SML, SMW, SSL, GCIA, GCL, GCW, LBT, AML, AMW, SSH, ISH, CPIA and AIA parameters. In our study, 97 % Acc rate was estimated using DT, LR, RF, k-NN, GaussianNB, LDA and QDA model over all parameters. We believe that scapula morphometry can obtain reliable and accurate results in sex determination studies. In addition, we think that the morphometry of the scapula has been examined in a wide range with this study and scapula measurements can be used as a reference data set in case of any surgical procedure.

We believe that the scapula, which we think is highly dimorphic, can obtain high Acc rates in sex determination with other ML algorithms besides the ML algorithms we used, and we think that more studies are needed.

ACKNOWLEDGEMENTS. I would like to thank all the authors who contributed to the writing of this article.

TEMELCI, H.; CICEKCIBASI, A. E.; ONER, Z.; SECGIN, Y.; ONER, S. & ACAR, G. Predicción del sexo en la población turca con mediciones antropométricas de la escápula en imágenes de TCMD utilizando algoritmos de aprendizaje automático. *Int. J. Morphol., 43(2)*:494-501, 2025.

RESUMEN: Los estudios de identificación se desarrollan con mayor precisión y facilidad después de que se realiza la estimación de sexo. Por lo tanto, la determinación de sexo es el primer paso en los estudios de identificación. El objetivo de nuestro estudio fue realizar la estimación del sexo de la población turca a partir de la escápula utilizando algoritmos de aprendizaje automático (ML) con parámetros obtenidos a partir de imágenes de tomografía computarizada multidetector (MDCT). El estudio se realizó en imágenes MDCT de 300 individuos (150 mujeres y 150 hombres) entre 20 y 60 años de edad. Las imágenes MDCT de la escápula se importaron al programa Radiant DICOM Viewer y se midieron los siguientes parámetros: la longitud máxima de la escápula (SML), el ancho máximo de la escápula (SMW), la longitud de la espina escapular (SSL), la longitud de la cavidad glenoidea (GCL), el ancho de la cavidad glenoidea (GCW), la distancia del proceso coracoides al ángulo inferior de la escápula (CPIA), la distancia del acromion al ángulo inferior de la escápula(AIA), la distancia de la cavidad glenoidea al ángulo inferior de la escápula (GCIA), el grosor del margen lateral de la escápula (LBT), la altura de la fosa supraespinosa (SSH), la altura de la fosa infraespinosa (ISH), la longitud máxima del acromion (AML) y el ancho máximo del acromion (AMW). Los datos obtenidos se utilizaron para la predicción del sexo mediante algoritmos ML. Todos los parámetros medidos en la escápula tenían una diferencia significativa en términos del sexo ($p<0,05$). Se determinó que los parámetros utilizados en la estimación de sexo utilizando modelos ML tenían una tasa de precisión del 97 %. Utilizando el solucionador SHAP del algoritmo Random Forest, se encontró que el parámetro del SSH tenía la mayor contribución a la precisión. Como resultado de nuestro estudio, creemos que podemos obtener resultados cercanos a la morfometría pélvica, que se considera el hueso más dimórfico en la literatura, cuando la determinación de sexo se realiza con base en la morfometría de la escápula con análisis ML. Creemos que nuestro estudio será una importante contribución a las ciencias y la literatura forenses.

PALABRAS CLAVE: Escápula; Algoritmos de aprendizaje automático; Tomografía computarizada; Predicción del sexo; Antropometría.

REFERENCES

Ali, Z.; Cox, C.; Stock, M. K.; Zandee vanRilland, E. E.; Rubio, A. & Fowler, D. R. Estimating sex using metric analysis of the scapula by postmortem computed tomography. *J. Forensic Sci.; 63(5)*:1346-9, 2018.

Atamtürk, D.; Pelin, C. & Duyar, I˙. Estimation of sex from scapular measurements: use of the bone area as a criterion. *Eurasian J. Anthropol., 10(1)*:39-45, 2019.

Badr El Dine, F. M. M. & Hassan, H. H. M. Ontogenetic study of the scapula among some Egyptians: forensic implications in age and sex estimation using multidetector computed tomography. *Egypt. J. Forensic Sci., 6(2)*:56-77, 2016.

Bytheway, J. A. & Ross, A. H. A geometric morphometric approach to sex determination of the human adult os coxa. *J. Forensic Sci., 55(4)*:859-64, 2010.

Çeker, D. I˙nsan kemiklerinin analizi ve adli antropoloji'de kimliklendirmede önemi. *Masrop E-Dergi, 11(17)*:1-13, 2017.

Debnath, M.; Kotian, R. P. & Sharma, D. Gender determination of an ındividual by scapula using multi detector computed tomography scan in Dakshina Kannada population-A forensic study. *J. Clin. Diagnostic Res., 12(3)*:TC05-TC08, 2018.

Decker, S. J.; Foley, R.; Hazelton, J. M. & Ford, J. M. 3D analysis of computed tomography (CT)–derived lumbar spine models for the estimation of sex. *Int. J. Legal Med., 133(5)*:1497-506, 2019.

d'Oliveira Coelho, J. & Curate, F. CADOES: An interactive machine-learning approach for sex estimation with the pelvis. *Forensic Sci. Int., 302*:109873, 2019.

Er, A.; Unluturk, O.; Bozdag, M.; Basa, C. D.; Kacmaz, I. E.; Oztop, B.; Cetinsel, E.; Kranioti, E. F. & Ekizoglu, O. Sex estimation of the scapula using 3D imaging in a modern Turkish population. *Rechtsmedizin, 30(4)*:209-18, 2020.

Ghasemi, B.; Ramezani, R.; Katourani, N.; Babahajian, A. & Yousefinejad, V. Anthropometric characteristics of scapula for sex determination using CT scans images in Iranian population. *Forensic Imaging, 23*:200408, 2020.

Giurazza, F.; Schena, E.; Del Vescovo, R.; Cazzato, R. L.; Mortato, L.; Saccomandi, P.; Paternostro, F.; Onofri, L. & Zobel, B. B. S*ex Determination from Scapular Length Measurements by CT Scans Images in A Caucasian Population*. Osaka, Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2013. pp.1632-5.

Hudson, A.; Peckmann, T. R.; Logar, C. J. & Meek, S. Sex determination in a contemporary Mexican population using the scapula. *J. Forensic Legal Med., 37*:91-6, 2016.

Lewis, D. *Machine Learning Made Easy with R: An Intuitive Step by Step Blueprint for Beginners*. California, CreateSpace Independent Publishing Platform, 2017.

Oner, Z.; Turan, M. K.; Oner, S.; Secgin, Y. & Sahin, B. Sex estimation using sternum part lenghts by means of artificial neural networks. *Forensic Sci. Int., 301*:6-11, 2019.

Papaioannou, V. A.; Kranioti, E. F.; Joveneaux, P.; Nathena, D. & Michalodimitrakis, M. Sexual dimorphism of the scapula and the clavicle in a contemporary Greek population: Applications in forensic identification. *Forensic Sci. Int., 217(1-3)*:231.e1-7, 2012.

Paulis, M. G. & Abu Samra, M. F. Estimation of sex from scapular measurements using chest CT in Egyptian population sample. *J. Forensic Radiol. Imaging, 3(3)*:153-7, 2015.

Peckmann, T. R.; Scott, S.; Meek, S. & Mahakkanukrauh, P. Sex estimation from the scapula in a contemporary Thai population: applications for forensic anthropology. *Sci. Justice, 57(4)*:270-5, 2017.

Secgin, Y.; Oner, Z.; Turan, M. K. & Oner, S. Gender prediction with the parameters obtained from pelvis computed tomography images and machine learning algorithms. *J. Anat. Soc. India, 71(3)*:204-9, 2022.

Torimitsu, S.; Makino, Y.; Saitoh, H.; Sakuma, A.; Ishii, N.; Inokuchi, G.; Motomura, A.; Chiba, F.; Hoshioka, Y. & Iwase, H. Estimation of sex in Japanese cadavers based on sternal measurements using multidetector computed tomography. *Legal Med. (Tokyo), 17(4)*:226-31, 2015.

Torimitsu, S.; Makino, Y.; Saitoh, H.; Sakuma, A.; Ishii, N.; Yajima, D.; Inokuchi, G.; Motomura, A.; Chiba, F.; Yamaguchi, R.; *et al*. Sex estimation based on scapula analysis in a Japanese population using multidetector computed tomography. *Forensic Sci. Int., 262*:285-e1-5, 2016.

Zhang, K.; Cui, J. H.; Luo, Y. Z.; Fan, F.; Yang, M.; Li, X. H.; Zhang, W. & Deng, Z. H. Estimation of stature and sex from scapular measurements by three-dimensional volume-rendering technique using in Chinese. *Legal Med. (Tokyo), 21*:58-63, 2016.

Corresponding author
Assoc. Prof. Oner Zulal
Gazi Mustafa Kemal District
Kaynaklar Street
Seyrek, Menemen
Izmir
TURKEY

E-mail:

ORCID iDs and e-mail addresses of the authors:

Halide Temelci: halide.temelci@bakircay.edu.tr / 0000-0002-1314-6485

Aynur Emine Cicekcibasi: acicekcibasi@erbakan.edu.tr / 0000-0002-1373-3065

Zulal Oner: zulal.oner@bakircay.edu.tr / 0000-0003-0459-1015

Yusuf Secgin: yusufsecgin@karabuk.edu.tr / 0000-0002-0118-6711

Serkan Oner: serkan.oner@bakircay.edu.tr / 0000-0002-7802-880X

Gülay Acar: gacar@erbakan.edu.tr / 0000-0002-9524-5056