Research Article / Araştırma Makalesi

Gender Prediction Using Machine Learning Algorithms with Parameters Obtained from Calcaneus

Calcaneus'tan Elde Edilen Parametrelerle Makine Öğrenme Algoritmaları Kullanılarak Cinsiyet Tahmini

İrem Nisa KORKMAZ [1], Zülal ÖNER [1], Yusuf SEÇGİN [2], Serkan ÖNER [3]

[1]İzmir Bakırçay University Graduate Education Institute, Department of Anatomy, İzmir, TÜRKİYE
[2]Karabük University Faculty of Medicine, Department of Anatomy, Karabük, TÜRKİYE
[3]İzmir Bakırçay University Faculty of Medicine Department of Radiology, İzmir,TÜRKİYE

Abstract

Background: Partial or total disruption of body integrity may occur in cases such as war, natural disasters and accidents. In such cases, the importance of the calcaneus bone, which has a hard and minimal structure, increases for identification. With this hypothesis, the aim of this study is to estimate gender from the calcaneus by utilising the current approach of machine learning (ML) algorithm.
Materials and Methods: The study was performed on X-Ray images of 200 female and 200 male subjects aged 18-65 years. Maximum length, facies articularis cuboidea height, maximum width, body width, minimum length, anteroposterior length of the calcaneus, posterior facet angle, anterior angle of the cuboid facet of the calcaneus, facet height, posterior facet length, anterior proces length, calcaneus inclination angle, talocalcaneal angle, Böhler angle, Gissane angle and calcaneus tuber angle were measured. Then the obtained data were used in the input of ML algorithms.
Results: As a result, a highly accurate and reliable sex prediction rate between 0.86-0.91 was obtained with ML algorithms. In addition, it was found that the maximum width of the calcaneus parameter made the highest contribution to sex prediction among the parameters with SHapley Additive exPlanations.
Conclusions: As a result of our study, it was found that calcaneus with minimal and rigid structure provided high accuracy in terms of gender prediction using ML algorithms. In this respect, we think that this study will be a reference for forensic and morphometric studies.

Keywords: Calcaneus, X-Ray, Machine learning algorithms, Gender prediction

Öz

Amaç: Savaş, doğal afetler ve kazalar gibi durumlarda vücut bütünlüğünün kısmen veya tamamen bozulması söz konusu olabilir. Bu gibi durumlarda sert ve minimal bir yapıya sahip olan kalkaneus kemiğinin kimlik tespiti için önemi artmaktadır. Bu hipotezle, bu çalışmanın amacı makine öğrenmesi (ML) algoritmasının güncel yaklaşımını kullanarak calcaneus'tan cinsiyet tahmini yapmaktır.
Materyal ve Metod: Çalışma 18-65 yaş arası 200 kadın ve 200 erkek bireyin X-Ray görüntüleri üzerinde gerçekleştirildi. Maksimum uzunluk, facies articularis cuboidea yüksekliği, maksimum genişlik, gövde genişliği, minimum uzunluk, calcaneus'un ön-arka uzunluğu, arka faset açısı, calcaneus'un küboid fasetinin ön açısı, faset yüksekliği, arka faset uzunluğu, ön proces uzunluğu, calcaneus inklinasyon açısı, talokalkaneal açı, Böhler açısı, Gissane açısı ve kalkaneus tuber açısı ölçüldü. Daha sonra elde edilen veriler ML algoritmalarının girişinde kullanıldı.
Bulgular: Sonuç olarak, ML algoritmaları ile 0,86-0,91 arasında oldukça doğru ve güvenilir bir cinsiyet tahmin oranı elde edilmiştir. Ayrıca SHapley Additive exPlanations ile parametreler arasında cinsiyet tahminine en yüksek katkıyı calcaneus'un maksimum genişliği parametresinin yaptığı tespit edildi.
Sonuç: Çalışmamız sonucunda minimal ve rijit yapıya sahip calcaneus'un ML algoritmaları kullanılarak cinsiyet tahmini açısından yüksek doğruluk sağladığı tespit edilmiştir. Bu açıdan bu çalışmanın adli ve morfometrik çalışmalar için referans olacağını düşünmekteyiz.

Anahtar Kelimeler: Calcaneus, X-Ray, Makine öğrenmesi algoritmaları, Cinsiyet tahmini

Corresponding Author / Sorumlu Yazar

Dr. Zülal ÖNER
İzmir Bakırçay University Graduate Education Institute, Department of Anatomy, İzmir, TÜRKİYE

E-mail: zulal.oner@bakircay.edu.tr

Received / Geliş tarihi: 22.01.2025

Accepted / Kabul tarihi: 20.03.2025

DOI: 10.35440/hutfd.1625105

This study was produced from a graduate thesis. The thesis was submitted to Izmir Bakırçay University Graduate School of Education on August 5, 2024 with thesis number 884483.

The study was presented as an oral presentation at the II. Health sciences student congress on December 14-15, 2023.

Introduction

Identity is a term that refers to the totality of personal knowledge and characteristics that allow an individual to distinguish themselves from other individuals. It defines a person's uniqueness, social status, cultural context and self-expression. At the same time, it reflects the relationships and ties of an individual with the groups and communities to which he/she belongs. In forensic anthropology case studies, gender estimation is one of the basic parameters and should be given priority in the examination of skeletal remains (1).

Forensic anthropologists frequently use morphological and metric methods for sex estimation of skeletal remains. It has been demonstrated that measurements taken directly from bones show higher reliability and reproducibility, and therefore sex estimation in this way is more reliable than other methods. The determination of sex using skeletal remains poses a major challenge for forensic experts, especially when a human body part is present. In forensic cases where decomposed corpses and human remains are brought for examination by forensic investigation authorities, identification is of great importance. The examination of bones and their anatomical measurements not only provides information on their origin, but also on ancestry, sex, height and age at death. It therefore helps to establish the identity of an individual (1-3).

In the literature, sex prediction studies have been performed using many bones and different methods. Although long bones, pelvis and cranium are the most frequently used bones in sex prediction, sexual dimorphism studies have also been performed on well-preserved bones such as calcaneus because bone integrity is deformed too much and good results have been obtained. When we look at the literature studies, calcaneus is seen as an important bone used in sex prediction (4-9).

Deoxyribonucleic acid (DNA) technologies, which are considered to be the most reliable method today, have many disadvantages due to accessibility and cost. For this reason, osteometry, which has a lower cost and easy access, is preferred for sex prediction. Machine learning (ML) is a specialised data analysis method that automates model building with machines that learn to use specific algorithms. In order to create a gender prediction model, classification is required and ML algorithms are one of the most commonly used methods for this classification. ML helps forensic experts, anatomists and anthropologists in many areas (10-14).

The aim of our study is to predict gender with high accuracy using ML algorithms with parameters obtained from calcaneus.

Materials and Methods

Population and Ethical Approvals

The study was performed with the decision of İzmir Bakırçay University Non-Interventional Local Ethics Committee dated 31.05.2023 and numbered 1064. Images were obtained randomly and retrospectively from the archive system of the Department of Radiology, İzmir Bakırçay University Çili Training and Research Hospital. The study was performed on direct radiographs (X-Rays) of 200 female and 200 male individuals aged 18-65 years. Verbal or written constant was not obtained from the patiens to use the X-Ray. Exclusion criteria were pathology and/or surgical intervention in the calcaneus.

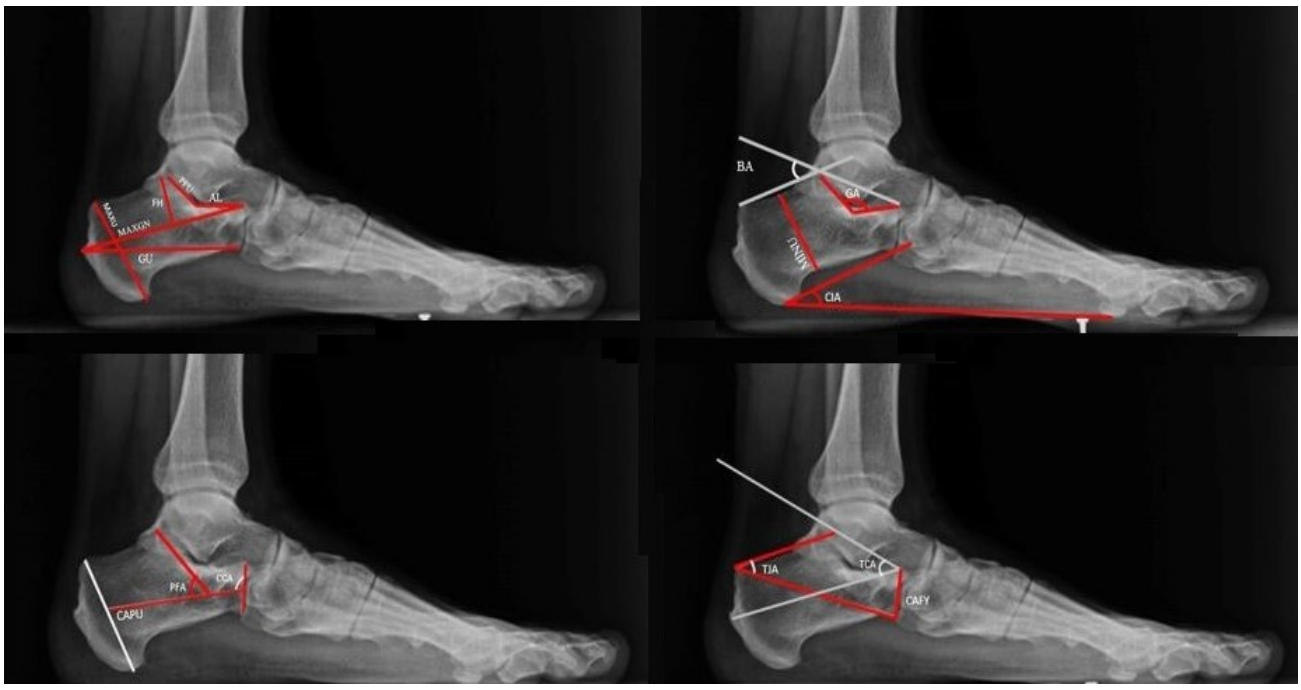

Figure 1. Demonstration of parameters

Measurement and Analysis Methodology

Images in Digital Imaging and Communications in Medicine (DICOM) format were transferred to Radiant DICOM Wiewer (64-bit version) and 16 parameters were measured using the measurement console of the programme. Parameters;

1) Maximum width (MAXGN),
2) Body length (GU),
3) Minimum calcaneus length (MINU),
4) Maximum calcaneus length (MAXU),
5) Calcaneus anterior facet height (CAFY),
6) Talocalcaneal angle (TCA),
7) Böhler angle (BA),
8) Gissane angle (GA),
9) Posterior facet angle (PFA),
10) Anteroposterior length of the calcaneus (CAPU),
11) Anterior angle of the cuboid facet of the calcaneus (CCA),
12) Facet height (FH),
13) Posterior facet length (PFU),
14) Processus anterior length (AL),
15) Calcaneus inclination angle (CIA),
16) Talo-tuber angle (TJA) (Figure 1) (7, 9, 15-17).

The obtained numerical data were analysed using ML algorithms. ML algorithms were performed using a personal computer with Monster Abra i5 operating system. Python 3.9 programming language and scikit-learn 1.1.1 framework were used for modelling. Modelling was performed with 20% of the data as test and 80% as training. Logistic regression (LR), linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), decision tree (DT), random forest (RF), extra tree classifier (ETC), Gaussian Naïve Bayes (GaussianNB), k-nearest neighbours (k-NN) algorithms were used as ML models. Accuracy (Acc), Specificity (Spe), Sensitivity (Sen), F1 score (F1) values were used for the performance of the models. In addition, the contribution of the parameters to the overall result was revealed with the SHapley Additive exPlanations (SHAP) analyser of the RF algorithm.

$$Acc = \frac{TP}{TP + FN + FP + TN}$$
$$Sen = \frac{TP}{TP + FN}$$
$$Spe = \frac{TN}{TN + FP}$$
$$F1 = 2\frac{Precision \times Recall}{Precision + Recall}$$

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

Statistical Analysis

Statistical analysis of the data was performed using Minitab 17 and SPSS 21 package programs and p<0.05 was considered statistically significant. Anderson Darling test was used as normality test. Mean±standard deviation was used for descriptive statistics of normally distributed data and median (min-max) values were used for non-normally distributed data. For comparison in terms of gender, Two Sample T test was used for normally distributed data and Mann Whitney-U test was used for non-normally distributed data. The relationship between the parameters and the degree of relationship were determined by Pearson correlation test for normally distributed data and Spearman rho correlation test for non-normally distributed data. Basic statistical analyses and ROC analysis were used to evaluate the contribution of parameters in terms of gender.

Results

In this study performed on foot X-Ray images of 200 female and 200 male subjects, it was found that all parameters except MAXGN, CAFY, PFA, TJA and age were not normally distributed. Descriptive statistics and gender comparisons of the normally distributed parameters are shown in Table 1. All parameters had higher values in males than females. Two Simple T test showed that MAXGN and CAFY parameters were significant in terms of gender (p<.005).

Table 1. Statistical analysis of normally distributed parameters by Two Simple T test

Parameters	Gender	Mean±standard deviation	p*
MAXGN	Male	83.94±5.00	**.000**
	Female	74.58±4.51	
CAFY	Male	26.90±2.06	**.000**
	Female	24.16±2.04	
PFA	Male	47.506±3.961	.256
	Female	47.011±4.707	
TJA	Male	39.342±3.354	.064
	Female	38.699±3.570	

(*MAXGN: Maximum width, CAFY: Calcaneus anterior facet height, PFA: Posterior facet angle, TJA: Talo-tuber angle)*

Descriptive statistics of non-normally distributed parameters are shown in Table 2. Mann Whitney U test showed that all non-normally distributed parameters except the CIA parameter were significant in terms of gender (p<.005).

According to Pearson correlation analysis, a moderate correlation was found between MAXGN and CAFY parameter (p<.005) (Table 3).

According to Spearman rho correlation analysis, a high correlation was found between MAXU and MINU and CAPU and GU parameters (p<.005) (Table 4).

Table 2. Statistical analysis of non-normally distributed data by Mann Whitney U test

Parameters	Gender	Median (minimum-maximum)	p**
GU	Male	79.35 (68.10-93.60)	**.000**
	Female	70.50 (60.00-85.40)	
MİNU	Male	41.25 (32.10-49.40)	**.000**
	Female	36.00 (29.80-44.70)	
MAXU	Male	48.25 (39.00-60.00)	**.000**
	Female	42.70 (33.80-52.10)	
TCA	Male	38.660 (26.000-50.200)	**.028**
	Female	37.850 (29.000-51.600)	
BA	Male	35.300 (25.000-47.700)	**.000**
	Female	39.300 (26.000-45.199)	
GA	Male	119.000 (109.500-132.400)	**.030**
	Female	118.050 (105.300-136.900)	
CAPU	Male	63.80 (50.70-78.40)	**.000**
	Female	58.30 (45.20-75.90)	
CCA	Male	100.000 (87.800-107.200)	**.000**
	Female	98.300 (86.200-114.200)	
FH	Male	28.30 (22.10-33.80)	**.000**
	Female	25.05 (20.70-31.40)	
PFU	Male	25.30 (18.10-32.20)	**.000**
	Female	22.70 (17.30-29.10)	
AL	Male	19.40 (14.80-26.30)	**.000**
	Female	17.85 (14.20-22.50)	
CIA	Male	45.043 (19.700-45.198)	.184
	Female	45.044 (22.000-45.198)	

(GU: Body length, MINU: Minimum calcaneus length, MAXU: Maximum calcaneus length, TCA: Talocalcaneal angle, BA: Böhler angle, GA: Gissane angle, CAPU: Calcaneus anteroposterior length, CCA: Anterior angle of the cuboid facet of the calcaneus, FH: Facet height, PFU: Posterior facet length, AL: Proccesus anterior length, CIA: Calcaneus inclination angle)

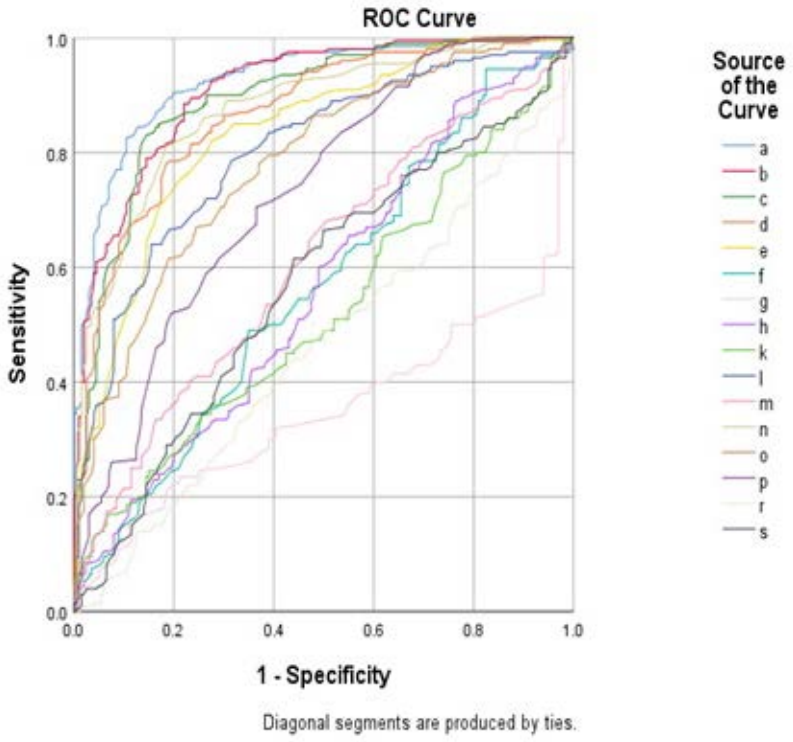

Figure 2. ROC curve (a: MAXGN, b: GU, c: MINU, d: MAXU, e: CAFY, f: TCA, g: BA, h: GA, k: PFA, l: CAPU, m: CCA, n: FH, o: PFU, p: AL, r: CIA, s: TJA)

Table 3. Pearson correlation test

Parameters	MAXGN	CAFY	PFA
CAFY	0.624 **0.000**		
PFA	0.031 0.541	-0.007 0.896	
TJA	-0.086 0.085	0.093 0.063	

(CAFY: Calcaneus anterior facet height, PFA: Posterior facet angle, TJA: Talo-tuber angle, MAXGN: Maximum width)

The effect of the parameters on the overall outcome was evaluated by ROC analysis and it was found that the MAXGN parameter made the highest contribution in terms of gender prediction (Figure 2, Table 5).

As a result of ML algorithms, the highest accuracy rate was 0.91 with QDA and GaussianNB algorithm (Table 6).

As a result of the ML algorithms, the highest accuracy rate was obtained in the QDA algorithm, which correctly prdicted all 44 male individuals and 29 of 36 female individuals in the test set, and in the GaussianNB algorithm, which correctly predicted 39 of 44 male individuals and 34 of 36 female individuals (Figure 3).

We evaluated the contribution of the parameters for gender prediction with the SHAP solver of the RF algorithm and found that the MAXGN parameter provided the highest contribution (Figure 4).

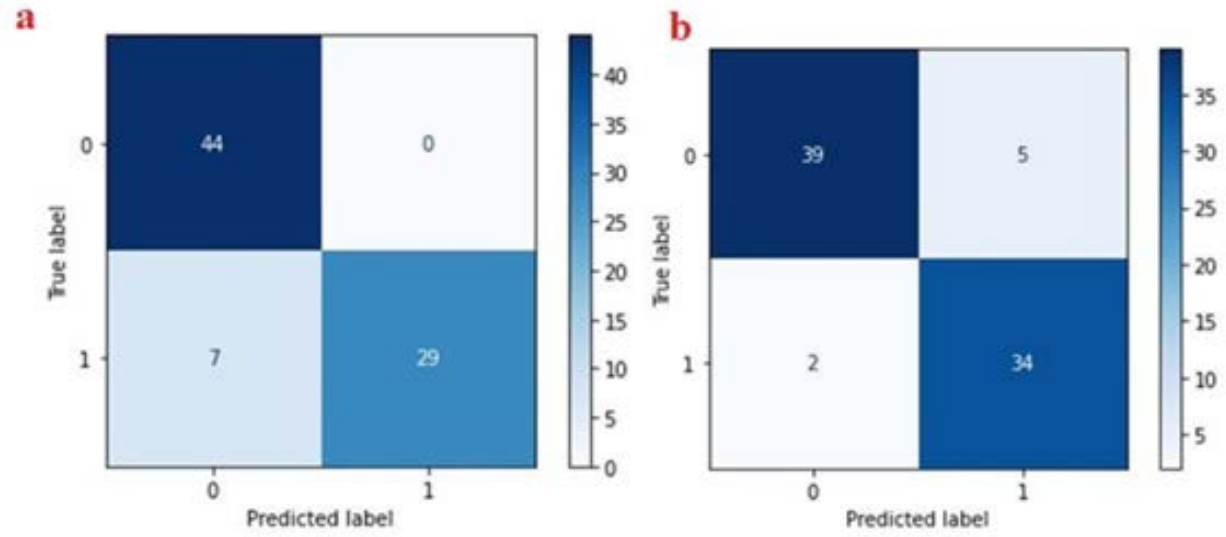

Figure 3. Confusion matrix table of the algorithms with the highest performance (a: QDA, b: GaussianNB)

Table 4. Spearman rho correlation analysis

Parameters		GU	MİNU	MAXY	TCA	BA	GA	CAPU	CCA	FH	PFU	AL
MİNU		0.662 0.000										
MAXU		0.677 0.000	0.869 0.000									
TCA		0.021 0.676	0.087 0.083	0.097 0.052								
BA		-0.176 0.000	-0.194 0.000	-0.176 0.000	-0.003 0.953							
GA		0.137 0.006	0.129 0.010	0.085 0.091	0.033 0.514	-0.031 0.532						
CAPU		0.774 0.000	0.457 0.000	0.436 0.000	-0.015 0.766	-0.094 0.061	0.067 0.181					
CCA		0.051 0.310	0.154 0.002	0.156 0.002	0.026 0.599	-0.071 0.158	0.080 0.110	0.058 0.246				
FH		0.616 0.000	0.642 0.000	0.626 0.000	0.126 0.012	-0.202 0.000	0.084 0.093	0.478 0.000	0.155 0.002			
PFU		0.457 0.000	0.446 0.000	0.434 0.000	0.028 0.573	-0.094 0.060	0.017 0.729	0.429 0.000	0.155 0.021	0.507 0.000		
AL		0.481 0.000	0.336 0.000	0.367 0.000	0.065 0.198	-0.120 0.017	0.024 0.631	0.439 0.000	0.176 0.000	0.324 0.000	0.254 0.000	
CIA		-0.029 0.559	-0.006 0.907	-0.008 0.869	-0.048 0.336	0.015 0.770	0.008 0.871	0.007 0.893	-0.002 0.970	-0.025 0.616	-0.063 0.210	-0.021 0.681

(MINU: Minimum calcaneus length, MAXU: Maximum calcaneus length, TCA: Talocalcaneal angle, BA: Böhler angle, GA: Gissane angle, CAPU: Anteroposterior length of calcaneus, CCA: Anterior angle of the cuboid facet of the calcaneus, FH: Facet height, PFU: Posterior facet length, AL: Processus anterior length, CIA: Calcaneus inclination angle, GU: Body length)

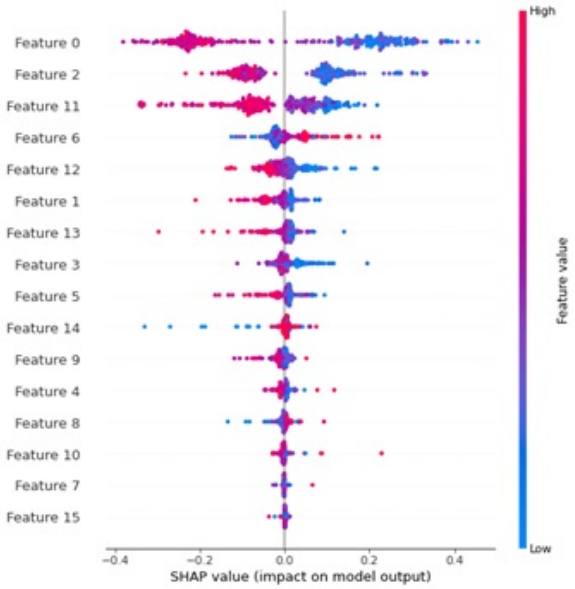

Figure 4. SHAP decoder of the RF algorithm

(Feature 0: MAXGN: Maximum width, 1: GU: Body length, 2: MINU: Minimum calcaneus length, 3: MAXU: Maximum calcaneus length, 4: CAFY: Calcaneus anterior facet height, 5: TCA: Talocalcaneal angle, 6: BA: Böhler angle, 7: GA: Gissane angle, 8: PFA: Posterior facet angle, 9: CAPU: Anteroposterior length of the calcaneus, 10: CCA: Anterior angle of the cuboid facet of the calcaneus, 11: FH: Facet height, 12: PFU: Posterior facet length, 13: AL: Processus anterior length, 14: CIA: Calcaneus inclination angle)

Table 5. ROC analysis performance values

(MAXGN: Maximum body length, GU: Body length, MINU: Minimum calcaneus length, MAXU: Maximum calcaneus length, CAFY: Calcaneus anterior facet height, TCA: Talocalcaneal angle, BA: Böhler angle, GA: Gissane angle, PFA: Posterior facet angle, CAPU: Anteroposterior length of the calcaneus, CCA: Anterior angle of the cuboid facet of the calcaneus, FH: Facet height, PFU: Posterior facet length, AL: Processus anterior length, CIA: Calcaneus inclination angle, TJA: Talo-tuber angle, Sen: Sensitivity, Spe: Specificity)

Parameters	AUC (95%)	Cutt off	p	Sen	Spe
MAXGN	0.927 (0.902-0.952)	7.895	**0.000**	85	85
GU	0.910 (0.882-0.938)	7.465	**0.000**	81.5	81.5
MİNU	0.893 (0.861-0.924)	3.805	**0.000**	83.5	84
MAXU	0.870 (0.836-0.904)	4.535	**0.000**	78.5	79
CAFY	0.832 (0.792-0.871)	2.555	**0.000**	76.5	77
TCA	0.563 (0.507-0.619)	38.25	**0.028**	54.5	55
BA	0.352 (0.296-0.408)	36.55	**0.000**	40	39.5
GA	0.563 (0.507-0.619)	118.35	**0.030**	52.5	52.5
PFA	0.522 (0.465-0.579)	47.45	0.441	49	48
CAPU	0.801 (0.758-0.844)	6.095	**0.000**	72	72
CCA	0.608 (0.553-0.663)	98.85	**0.000**	57	58
FH	0.875 (0.841-0.909)	2.685	**0.000**	81	81.5
PFU	0.780 (0.735-0.824)	2.395	**0.000**	70.5	70.5
AL	0.728 (0.680-0.777)	1.865	**0.000**	64.5	67
CIA	0.462 (0.405-0.518)	45.04	0.185	49	49
TJA	0.570 (0.513-0.626)	38.95	**0.016**	58	57

Table 6. Performance results of machine learning algorithms

Algorithms	Acc	Spe	Sen	F1
QDA	91	93	90	91
GaussianNB	91	91	92	91
RF	90	90	90	90
ETC	90	90	90	90
DT	89	89	89	89
LR	89	89	89	89
k-NN (k=5)	86	86	86	86

(QDA: Quadratic discriminant analysis, GaussianNB: Gaussian Naive Bayes classification, RF: Random forest, ETC: Extra-tree classification, DT: Decision tree, LR: Logistic regression, k-NN: K-Nearest neighbors regression, Acc: Accuracy, Spe: Specificity, Sen: Sensitivity)

Discussion

As a result of our study, an accuracy of up to 0.91 was obtained in gender estimation from calcaneus with ML algorithms, which is a current methodology. In addition, the MAXGN parameter was found to have the highest contribution to gender estimation.

When mass deaths occur in events such as accidents, natural disasters and war, identification is important for forensic medicine. In these cases, factors such as disruption of body integrity and decomposition make identification difficult. Another beneficial effect of identification in mass deaths is the importance of returning them to their families. The morphometry of bones provides information about the origin of individuals, as well as the cause of death, gender, height and age. In identification, gender must first be determined. Establishing gender reduces the likelihood of biological elements of identity. Sex estimation is vital in forensic anthropology applications to obtain critical information such as identification, age and ethnicity estimates (3, 18, 19).

To date, sexual dimorphism of the calcaneus has been studied in various populations such as Italy, Greece, South Africa and Colombia. In these studies, no sex difference was observed between races (20-23). In the literature, it was seen that there were studies conducted on X-Ray in the Turkish population. Torun and Çay found that calcaneal inclination angle was associated with foot morphology in both sexes in their study (15). In another evaluation in terms of gender, it was shown that there were significant differences in medial arch angle, lateral arch angle and foot length measurements in adults (16). As a result of our study, we obtained the highest accuracy rate of 0.91 among ML algorithms in terms of gender prediction from QDA and GaussianNB algorithms.

BA is an angle used as an important parameter in medicine performed on the calcaneus. This angle plays an important role in the evaluation of calcaneus fractures. BA was introduced by Dr. Lorenz Bohler in 1931 and he gave its value between 30°-35° in his paper (24). Seyahi et al. In their study for the Turkish population, they found BA to be 20°-46° (p=0.198), but they did not find any difference between genders in BA (25). In our study, BA was found between 25°-47° and was 35±10 in males and 39±7 in females. We found that this parameter ranked 4th in determining gender among the parameters we used.

GA is as important as BA in healing after surgical procedure applied to calcaneus fractures (26). Seyahi et al. 2009, they did not find a significant result between genders (p=0.177) (25). In this study, it was found between 105°-136° in both male and female gender. This value was 118±13° in women and 119±10° in men. In the SHAP analysis, this parameter ranked 14th in determining gender. When the studies conducted for sex prediction of the MAXGN parameter were examined, it was observed that this length was evaluated too much. Çekdemir et al. 2021, which aimed to estimate gender from calcaneus, measured the MAXGN value as 85.65±5.16 mm in males and 76.74±4.21 mm in females. They found statistically significant differences between both sexes with these values (p<0.001) (17). Riepert et al. In their 1995 study on sex estimation from calcaneus in a Central European population, they measured the MAXGN value and found no significant difference between males and females (27). In our study, a value of 74.58±4.51 mm was found in women and 83.94±5 mm in men. The highest usefulness and accuracy in terms of both ML and cross-gender algorithms was achieved with the MAXGN measure. Çekdemir et al. 2021, in their study on gender estimation from calcaneus of 489 individuals, found the CAFY parameter as 28.83±2.13 mm in males and 25.45±1.99 mm in females and reported a significant difference between genders (p<0.001) (17). In our study, the results were 26.90±2.06 mm for males and 24.16±0.204 mm for females. In our study, an accuracy of 86-91% was found according to the ML algorithm, and this parameter ranks 12th in determining gender.

Riepert et al. reported the MINU parameter as 42.3±3.1 mm in men and 37.8±2.9 mm in women in their gender study on radiography (27). These data are similar to our data. Agoada conducted a study on X-Ray and cadaver in 2018 and measured the MAXU parameter as 50.50±5.68 mm on X-Ray and 49.75±4.31 mm on cadaver (28). This parameter ranked 9th in determining gender in our study. Kumar et al. found a value of 47.38±5.07 mm in men and 47.15±5.54 mm in women in their study and the findings were found to be insignificant similar to our study (p=0.882) (29).

In this retrospective study, it can be considered as a limitation that the body mass index of the patients, the type of footwear used, the calcaneus was not evaluated in three dimensions, and pediatric and octogenerian individuals were not included in the study.

When the literature is examined, to our knowledge, there is no study on gender estimation from calcaneus using ML algorithms. In this respect, we believe that our study will make great contributions to the literature.

Acknowledgements

I would like to thank all the authors for their contributions.

Ethical Approval: *The study was performed with the decision of İzmir Bakırçay University Non-Interventional Local Ethics Committee dated 31.05.2023 and numbered 1064. The study was a retrospective study, conducted through the image archive and personal confidentiality was observed.*

Author Contributions:
Concept: İ.N.K., Z.Ö., Y.S., S.Ö.
Literature Review: İ.N.K.
Design : İ.N.K., Z.Ö., Y.S.
Data acquisition: İ.N.K., Z.Ö., S.Ö.

Analysis and interpretation: İ.N.K., Z.Ö., S.Ö.
Writing manuscript: İ.N.K., Z.Ö., Y.S., S.Ö.
Critical revision of manuscript: Z.Ö.
Conflict of Interest: *The authors have no conflicts of interest to declare.*
Financial Disclosure: *Authors declared no financial support.*

References

1. Krishan K, Chatterjee PM, Kanchan T, Kaur S, Baryah N, Singh R. A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. Forensic science international. 2016;261:165. e1-. e8.
2. Singh R, Mishra SR, Passey J, Kumar P, Singh S, Sinha P, et al. Sexual dimorphism in adult human mandible of North Indian origin. Forensic medicine and anatomy research. 2015;3(03):82.
3. Zeyfeoğlu Y, Hancı İH. İnsanlarda kimlik tespiti. Türk Tabipleri Birliği Sürekli Tıp Eğitimi Dergisi. 2001;375:4659-62.
4. Case DT, Ross AH. Sex determination from hand and foot bone lengths. Journal of forensic sciences. 2007;52(2):264-70.
5. Issa SY, Khanfour AA, Kharoshah M. A model for stature estimation and sex prediction using percutaneous ulnar and radial lengths in autopsied adult Egyptians. Egyptian journal of forensic sciences. 2016;6(2):84-9.
6. Marlow EJ, Pastor RF. Sex determination using the second cervical vertebra—a test of the method. Journal of forensic sciences. 2011;56(1):165-9.
7. Acar A. Yoncatepe toplumunda Calcaneus ve Talus kemiklerinden cinsiyet ve boy tahmini. Antropoloji. 2014(28):109-22.
8. Curate F, Umbelino C, Perinha A, Nogueira C, Silva AM, Cunha E. Sex determination from the femur in Portuguese populations with classical and machine-learning classifiers. Journal of Forensic and Legal Medicine. 2017;52:75-81.
9. Ekizoglu O, Inci E, Palabiyik FB, Can IO, Er A, Bozdag M, et al. Sex estimation in a contemporary Turkish population based on CT scans of the calcaneus. Forensic science international. 2017;279:310. e1-. e6.
10. Giurazza F, Schena E, Del Vescovo R, Cazzato R, Mortato L, Saccomandi P, et al., editors. Sex estimation from scapular measurement by CT scans evaluations in a Caucasian population. Engineering in Medicine and Biology Society (EMBC), 2013 35th Annual International Conference of the IEEE; 2013: IEEEX.
11. Bhardwaj R, Nambiar AR, Dutta D, editors. A study of machine learning in healthcare. 2017 IEEE 41st annual computer software and applications conference (COMPSAC); 2017: IEEE.
12. Ariu D, Giacinto G, Roli F, editors. Machine learning in computer forensics (and the lessons learned from machine learning in computer security). Proceedings of the 4th ACM workshop on Security and artificial intelligence; 2011.
13. Awais M, Naeem F, Rasool N, Mahmood S. Identification of sex from footprint dimensions using machine learning: a study on population of Punjab in Pakistan. Egyptian Journal of Forensic Sciences. 2018;8:1-9.
14. Erkartal HŞ, Tatlı M, Secgin Y, Toy S, Duman BS. Gender estimation with parameters obtained from the upper dental arcade by using machine learning algorithms and artificial neural networks. European Journal of Therapeutics. 2023;29(3):352-8.
15. Torun Bİ, Çay N. Ayak Arkus Açısı ve Ayak Uzunluğu Arasındaki İlişki. Kafkas Journal of Medical Sciences. 2018;8(3):172-7.
16. Doğruyol G, Çimen M. Medial ve lateral ark açıları ile ayak uzunluğunun yaş, cinsiyet ve taraf farklılığı açısından radyolojik olarak incelenmesi. Turkish Journal of Science and Health. 2020;2(1):76-83.
17. Cekdemir YE, Mutlu U, Karaman G, Balci A. Evaluation of computed tomography images of calcaneus for estimation of sex. La radiologia medica. 2021;126(8):1064-73.
18. Ahmed KF, Wang G, Silander J, Wilson AM, Allen JM, Horton R, et al. Statistical downscaling and bias correction of climate model outputs for climate change impact assessment in the US northeast. Global and Planetary Change. 2013;100:320-32.
19. Senol D, Secgin Y, Duman BS, Toy S, Oner Z. Sex and age estimation with machine learning algorithms with parameters obtained from cone beam computed tomography images of maxillary first molar and canine teeth. Egyptian Journal of Forensic Sciences. 2023;13(1):27.
20. Introna Jr F, Di Vella G, Pietro Campobasso C, Dragone M. Sex determination by discriminant analysis of calcanei measurements. Journal of Forensic Sciences. 1997;42(4):725-8.
21. Peckmann TR, Orr K, Meek S, Manolis SK. Sex determination from the calcaneus in a 20th century Greek population using discriminant function analysis. Science & Justice. 2015;55(6):377-82.
22. Bidmos MA, Asala SA. Discriminant function sexing of the calcaneus of the South African whites. Journal of forensic sciences. 2003;48(6):JFS2003104.
23. Moore MK, DiGangi EA, Ruíz FPN, Davila OJH, Medina CS. Metric sex estimation from the postcranial skeleton for the Colombian population. Forensic science international. 2016;262:286. e1-. e8.
24. Böhler L. Diagnosis, pathology, and treatment of fractures of the os calcis. JBJS. 1931;13(1):75-89.
25. Seyahi A, Uludag S, Koyuncu L, Atalar A, Demirhan M. The calcaneal angles in the Turkish population. Acta orthopaedica et traumatologica turcica. 2009;43(5):406-11.
26. Jiao L, Li H, Liao T, Han Z, Wu H, Jiang L. Impact of percutaneous poking reduction combined with minimally invasive plate internal fixation on foot function and complications of patients with Sanders type II and III calcaneal fractures. American Journal of Translational Research. 2021;13(5):5329.
27. Riepert T, Drechsler T, Schild H, Nafe B, Mattern R. Estimation of sex on the basis of radiographs of the calcaneus. Forensic science international. 1996;77(3):133-40.
28. Agoada D. The relationship between linear osteological and radiographic measurements of the human calcaneus and talus. The Anatomical Record. 2018;301(1):21-33.
29. Kumar A, Rastogi S, Haider Y, Kumar S, Chauhan S, Passey J. Morphometric variations of the lateral surface of calcaneus: Can standard plate sizes fit all? Journal of Clinical Orthopaedics and Trauma. 2021;13:156-62.