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Sex prediction with morphometric measurements of first and fifth metatarsal and phalanx obtained from X-ray images by using machine learning algorithms

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Background: *The aim of this study is to predict sex with machine learning (ML) algorithms by making morphometric measurements on radiological images of the first and fifth metatarsal and phalanx bones.*

Materials and methods: *In this study, radiologic images of 263 individuals (135 female, 128 male) between the ages of 27 and 60 were analysed retrospectively. The images in digital imaging and communications in medicine (DICOM) format were transferred to personal workstation Radiant DICOM Viewer programme. Length and width measurements of the first and fifth metatarsal and foot phalanx bones were performed on the transferred images. In addition, the ratios of the total length of the first proximal and distal phalanx and length of the first metatarsal and total length of fifth proximal, middle, and distal phalanx and maximum length of fifth metatarsal were calculated.*

Results: *As a result of machine learning algorithms, highest accuracy, specificity, sensitivity, and Matthews correlation coefficient values were found as 0.85, 0.86, 0.85, and 0.71, respectively with decision tree algorithm. It was found that accuracy rates of other algorithms varied between 0.74 and 0.83.*

Conclusions: *As a result of our study, it was found that sex estimation was made with high accuracy rate by using machine learning algorithms on X-ray images of the first and fifth metatarsal and foot phalanx. We think that in cases when pelvis, cranium and long bones are harmed and examination is difficult, bones of the first and fifth metatarsal and foot phalanx can be used for sex estimation.*
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Key words: decision tree, machine learning algorithms, metatarsus, phalanx, radiography, sex prediction, X-ray

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INTRODUCTION

For years, sex has been one of the most important parameters used for identity determination. In medical and forensic cases, especially anthropometric measurements taken from the parts of an unidentified decomposed or decayed body are important in terms of predicting the height, sex and age of the individual [29]. These anthropometric measurements are frequently used in sex determination and data obtained as a result of studies are very useful especially in terms of identity determination of victims of large-scale disasters and deadly attacks [17].

In identity determination, sex determination draws attention as the first and most important point [11]. For sex determination, there are bones that have been studied many times and the reliability of which has been proven. Of these bones, cranium, pelvis, and long bones are the most examined ones. Both metrically and morphologically, pelvis is the best area in sex determination and it is reported to give correct results with a rate of 95–98% [4, 15, 31, 33]. It is followed by cranium and long bones [24, 35]. In cases when pelvis, cranium and long bones are harmed and examination is difficult, sex prediction is tried with less dimorphic parts of the human skeleton.

Today, although DNA technologies are considered as the method with highest reliability in sex determination, they also have disadvantages such as accessibility, taking time, need for qualified personnel and cost. Because of this, methods such as osteometry, which are easier to access, less costly, highly accurate, easily accessible, fast, and not requiring expertise have begun to be preferred in sex prediction [14, 27].

Machine learning (ML) is specialised data analysis method that automates model building with machines that learn to use certain algorithms [5]. ML algorithms are grouped in three as supervised learning, unsupervised learning and reinforcement learning. Supervised learning is the algorithm that models the relationship between input and output data [18]. Unsupervised learning is the ML algorithm which is based on observations and which allows to reveal the features of previously unknown data. Reinforcement learning is the algorithm matching the input data with desired output data [21]. Building a sex prediction model is based on solving a classification task and this classification is one of the most frequently performed exploratory tasks in ML algorithms. ML helps forensic teams, anatomists, and anthropologists in many aspects in areas such as crime prevention, individual identity analysis, forensic cyber security, forensic informatics and forensic criminology [2, 3]. Foot bones are among the bones frequently used in sex determination studies due to their presence in both forensic and archaeological contexts, their small and robust structures, being less exposed to taphonomic elements, their resistance to post-mortem changes and being protected by shoes [22, 25, 26]. Literature review shows that sex estimation studies on foot bones generally focus on the shape of the first metatarsal bone and transverse arch of foot in both gender [10].

The aim of this study was sex prediction with ML algorithms by making osteometric measurements on radiological images of the first and fifth metatarsal and phalanx bones.

MATERIALS AND METHODS

Population sample

The study was initiated with 2021/760 numbered decision of Karabuk University Non-Interventional Clinical Studies Ethics Committee. X-ray images of a total of 263 individuals (135 females, 128 males) between the ages of 27 and 60 were included in the study. The X-ray images were selected as randomised among the people admitted to the hospital with various problems in 2021. The exclusion criteria were determined as pathology, fracture, tumour and degeneration of the metatarsal bones.

Image protocol and processing

Images in the study were obtained by the digital single tube X-ray device at Karabuk University Training and Research Hospital. The images in digital imaging and communications in medicine (DICOM) format were transferred to personal workstation Radiant DICOM Viewer (Version: 2020.2) programme. Length and width measurements were made on the transferred images (Table 1, Figs. 1, 2). In addition, the ratios of the total length of the first proximal and distal phalanx and length of the first metatarsal and total length of fifth proximal, middle, and distal phalanx and maximum length of fifth metatarsal were calculated. Parameters were measured once by a specialist radiologist with at least 10 years of experience.

Statistical analysis

In descriptive statistics, Minitab 17 package programme was used for median, minimum and max-

Table 1. Length and width measurements

Measurement parameters	
Length	**Width**
Maximum length of metatarsal I	Medio-lateral width of the first metatarsal head
Maximum length of metatarsal V	Shaft width of metatarsal I
Length of proximal phalanx I	Width of metatarsal base I
Length of distal phalanx I	Medio-lateral width of the fifth metatarsal head
Length of middle phalanx V	Shaft width of metatarsal V
Length of proximal phalanx V	Width of metatarsal base V
Length of distal phalanx V	Width of proximal phalanx I
Total length of first proximal and distal phalanx	Width of distal phalanx I
Total length of fifth proximalis, middle and distalis phalanx	Width of proximal phalanx V
	Width of middle phalanx V
	Width of distal phalanx V

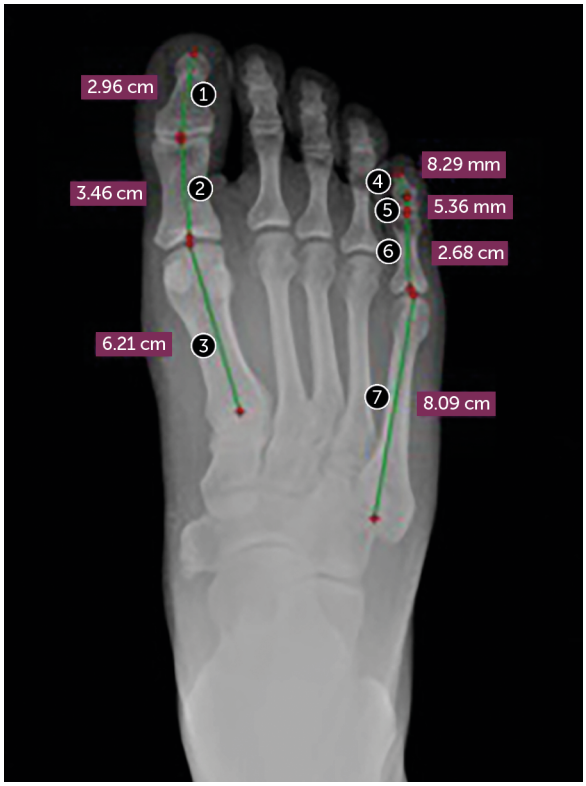

Figure 1. Length measurements of the first and fifth metatarsals and foot phalanx bones; 1 — length of the first distal phalanx; 2 — length of the first proximal phalanx; 3 — maximum length of the first metatarsal; 4 — length of the fifth distal phalanx; 5 — length of the fifth middle phalanx; 6 — length of the fifth distal phalanx; 7 — maximum length of the fifth metatarsal.

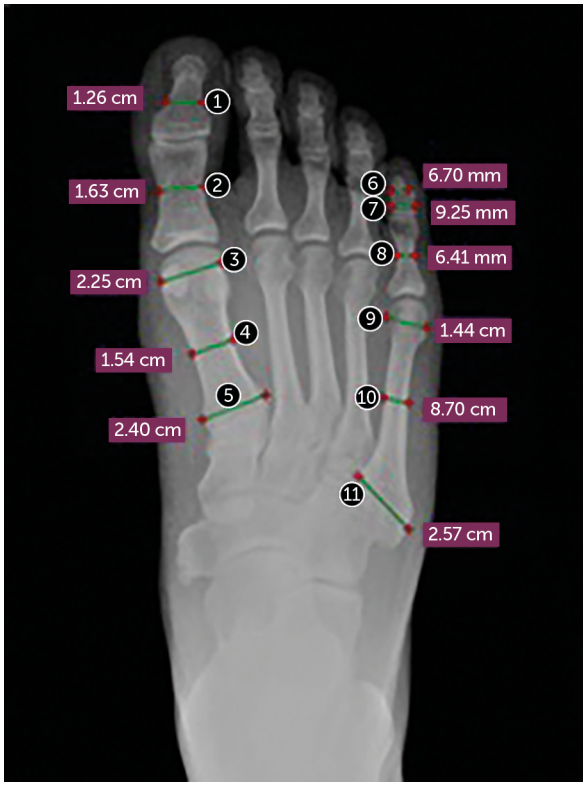

Figure 2. Width measurements of the first and fifth metatarsals and foot phalanx bones; 1 — width of the first distal phalanx; 2 — width of the first proximal phalanx; 3 — medio-lateral width of the first metatarsal head; 4 — width of the middle shaft first metatarsal; 5 — width of the first metatarsal base; 6 — width of the fifth distal phalanx; 7 — width of the fifth middle phalanx; 8 — width of the fifth proximal phalanx; 9 — medio-lateral width of the fifth metatarsal head; 10 — middle shaft width of the fifth metatarsal; 11 — width of the fifth metatarsal base.

Table 2. Median, minimum, and maximum values of the length measurements taken from radiological measurements of male and female

Parameters [cm]	Sex	Median [cm]	Minimum [cm]	Maximum [cm]
Maximum length of metatarsal I	Male	6.185	4.600	7.780
	Female	5.650	4.690	6.950
Maximum length of metatarsal V	Male	7.400	6.020	8.910
	Female	6.790	5.580	8.040
Length of proximal phalanx I	Male	3.230	2.490	3.980
	Female	2.930	1.760	3.530
Length of distal phalanx I	Male	2.715	2.040	3.430
	Female	2.470	1.920	2.950
Length of proximal phalanx V	Male	2.420	1.910	2.940
	Female	2.230	1.640	2.690
Length of middle phalanx V	Male	0.700	0.340	1.410
	Female	0.630	0.320	0.910
Length of distalis phalanx V	Male	0.915	0.310	1.320
	Female	0.830	0.480	1.130
Total length of first proximal and distal phalanx	Male	5.915	4.670	7.230
	Female	5.380	4.020	6.210
Total length of fifth proximal, middle and distal phalanx	Male	4.050	2.810	5.130
	Female	3.680	2.890	4.580
Total length of first proximal and distal phalanx/ /maximum length of metatarsal I	Male	1.050	1.900	1.290
	Female	1.050	1.890	1.480
Total length of fifth proximal, middle and distal phalanx/ /maximum length of metatarsal V	Male	1.820	1.470	2.230
	Female	1.820	1.550	2.210

imum values. Mann-Whitney U test was performed for age parameter.

Machine learning algorithms

For ML algorithms, Python programming language (Version 3.7.1) and scikit-learn framework (Version 0.20.0) was used as 80% training set and 20% test set [30]. Quadratic discriminant analysis, linear discriminant analysis, decision tree, random forest, extra tree classifier, logistic regression algorithms were used in our study.

Performance criteria

Accuracy (Acc), Matthews correlation coefficient (Mcc), specificity (Spe), sensitivity (Sen) values were included in the study.

RESULTS

Median, minimum (min) and maximum (max) values were included in descriptive statistics. Median, min, max values of the length measurements taken from radiological measurements of men and women are shown in Table 2, while median, min, max values of the width measurements are shown in Table 3. Median age of the women in the study was 44 years, while the median age of the men in the study was 49 years. No statistically significant difference was found according to Mann-Whitney-U test in terms of age according to sex groups ($p = 0.098$).

As a result of ML algorithm analysis, highest Acc, Spe, Sen, Mcc values were found as 0.85, 0.86, 0.85, and 0.71, respectively with decision tree algorithm. It was found that accuracy rates of other algorithms varied between 0.74 and 0.83 (Table 4).

As a result of our study, confusion matrix of decision tree algorithm with the highest Acc rate was included (Fig. 3).

DISCUSSION

The aim of this study was to predict sex with ML algorithms by making morphometric measurements on radiological images of the first and fifth metatarsal and phalanx bones of a total of 263 individuals (135 females, 128 males) between the ages of 27 and 60.

Table 3. Median, minimum, and maximum values of the width measurements taken from radiological measurements of male and female

Parameters [cm]	Sex	Median [cm]	Minimum [cm]	Maximum [cm]
Medio-lateral width of first metatarsal head	Male	2.380	1.790	3.040
	Female	2.140	1.680	2.690
Width of metatarsal corpus I	Male	1.650	1.150	2.010
	Female	1.430	1.120	1.860
Width of metatarsal base I	Male	2.450	1.820	3.160
	Female	2.150	1.680	2.840
Medio-lateral width of metatarsal head V	Male	1.480	0.970	2.110
	Female	1.430	0.940	1.810
Width of metatarsal corpus V	Male	0.940	0.730	1.250
	Female	0.910	0.610	1.210
Width of metatarsal base V	Male	2.560	1.940	3.280
	Female	2.320	1.820	2.870
Width of proximal phalanx I	Male	1.570	1.140	1.950
	Female	1.360	0.940	1.780
Width of distal phalanx I	Male	1.200	0.850	1.640
	Female	1.060	0.790	1.330
Width of proximal phalanx V	Male	0.580	0.370	0.780
	Female	0.510	0.380	0.700
Width of middle phalanx V	Male	0.855	0.470	1.180
	Female	0.790	0.480	1.040
Width of distal phalanx V	Male	0.520	0.350	0.830
	Female	0.470	0.330	0.700

Table 4. Machine learning algorithms performance values

Algorithms	Accuracy	Specificity	Sensitivity	Mcc
QDA	0.83	0.83	0.83	0.69
LDA	0.81	0.81	0.81	0.62
DT	**0.85**	**0.86**	**0.85**	**0.71**
RF	0.83	0.85	0.83	0.68
ETC	0.74	0.75	0.74	0.48
LR	0.81	0.82	0.81	0.62

QDA — quadratic discriminant analysis; LDA — linear discriminant analysis; DT — decision tree; RF — random forest; ETC — extra tree classifier; LR — logistic regression; Mcc — Matthews correlation coefficient

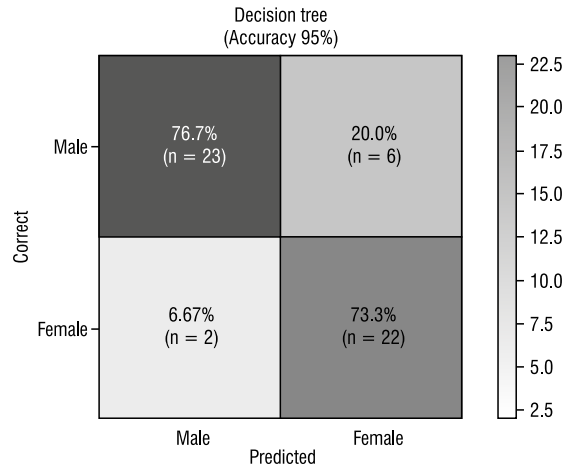

Figure 3. Confusion matrix of decision tree algorithm.

As a result of ML algorithm analysis, highest Acc, Spe, Sen, Mcc values were found as 0.85, 0.86, 0.85 and 0.71, respectively with decision tree algorithm. It was found that accuracy rates of other algorithms varied between 0.74 and 0.83.

When the literature is reviewed, it can be seen that hip bone and cranial bones are the first preferred bones in sex determination. This is because some parts of the pelvis and cranial bones show sex specific morphological differences [13, 34, 37]. In cases when these bones are not present, it can be seen that femur [8], tibia and fibula [12], patella [27], sternum [28], humerus [19], ulna and radius [16], foot and hand bones [36] have also been tried in sex prediction.

Akhlaghi et al. [1] measured the length, width, length-width ratio (L/W) and length-width (L×W)

of right foot metatarsal bones of 184 individuals by using radiographic images. In the study, as a result of logistic regression analysis, it was found that L×W value of the first metatarsal bone and L×W values of all metatarsal bones had the highest accuracy (86% and 85%) in sex prediction. It was found that first metatarsal width and mean width of all metatarsal bones had an accuracy ratio of 82% and 84%, respectively. In our study, they were found to have an accuracy ratio of 74% and 85% as a result of ML analysis. In line with these results, the study conducted by Akhlaghi et al. [1] and our study are similar.

In literature review, as a result of the discriminant analysis performed on the patella and metatarsal bones of 160 individuals, the accuracy of the measurements from metatarsal bones was found to be between 85% and 100%. Therefore, metatarsal bones were found to be more reliable and valid than patella [25].

In another study conducted on metatarsal and phalanx, sex prediction was aimed by measuring the length of phalanx first and fifth toes and first and fifth metatarsal bones by using artificial neural network technique. The model was found to have Acc of 0.95, Spe of 0.97, Sen of 0.95 and Mcc of 0.92 [38]. In our study, the highest Acc, Spe, Sen, Mcc values were found as 0.85, 0.86, 0.85, and 0.71, respectively, with decision tree algorithm. It was found that accuracy rates of other algorithms varied between 0.74 and 0.83. The differences in the results may be resulting from differences in method.

As a result of the study that aimed to predict sex with osteometric methods, Mountrakis et al. [26] reported that metatarsal bones showed significant sexual dimorphism and the Acc of discriminant function equations for sex prediction was between 80% and 90%. In another study, the lengths of the metatarsal bones of 100 individuals were measured by using Vernier calliper. The measurements were evaluated by using discriminant function and logistic regression analysis and as a result of the evaluation, various combinations of metatarsal bones have been shown to give high mean Acc (between 79% and 84%) for sex prediction [6]. In a study conducted with dry metacarpal and metatarsal bones by using digital calliper for sex prediction, as a result of discriminant functions it was found that the accuracy of metacarpal bones varied between 79% and 85%, while the Acc of metatarsal bones varied between 77% and 83% [36]. In our study, as a result of ML algorithms, Acc was found to be between 74% and 85% with quadratic discriminant analysis, linear discriminant analysis, decision tree, random forest, extra tree classifier, logistic regression algorithms. In line with these results, in addition to other sex prediction techniques, it was shown that metatarsal bones could be used for sex prediction and the results of our study were found to be in parallel with the literature.

Although the methods used for sex prediction in length measurements performed on dry metatarsal bones and foot phalanx bones are different, it has been found that length measurements show significant difference between genders. As a result of the analysis of these studies, a mean accuracy range varying between 70% and 84% has been shown and it has been found that the results are in parallel with the results of our study [6, 7, 9, 32]. All metatarsal bones show sex based biomechanical differences. In a study which examined the length and width measurements of metatarsal bones by using three-dimensional foot scanning data, women were found to have smaller rates [23]. In studies conducted on different populations, foot length and width have been shown to differ in women and men [20].

Limitations of the study

The limitations of our study are the difficulty in taking the images of metatarsal and foot phalanx bones due to their small structure, small sample size, the fact that foot morphology may be affected by ethnic origin, the study was conducted only on a specific population and superposition disadvantage since X-ray is a two-dimensional imaging technique.

CONCLUSIONS

In this study, mean first metatarsal and fifth metatarsal values of men were found to be higher than mean values of women and this result was found to be in parallel with other studies conducted. As a result of our study, X-ray images of the first and fifth metatarsal and phalanx can be used for sex determination by using ML algorithms.

Conflict of interest: None declared

REFERENCES

1. Akhlaghi M, Bakhtavar K, Bakhshandeh H, et al. Sex determination based on radiographic examination of metatarsal bones in Iranian population. Int J Med Toxicol Forensic Med. 2017; 7(4): 203–208, doi: 10.22037/ijmtfm.v7i4(Autumn).17059.

2. Ariu D, Giacinto G, Roli F. 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, doi: 10.1145/2046684.2046700.
3. Awais M, Naeem F, Rasool N, et al. Identification of sex from footprint dimensions using machine learning: a study on population of Punjab in Pakistan. Egypt J Forensic Sci. 2018; 8(1): 72, doi: 10.1186/s41935-018-0106-2.
4. Best KC, Garvin HM, Cabo LL. An investigation into the relationship between human cranial and pelvic sexual dimorphism. J Forensic Sci. 2018; 63(4): 990–1000, doi: 10.1111/1556-4029.13669, indexed in Pubmed: 29044526.
5. Bhardwaj R, Nambiar A, Dutta D. A study of machine learning in healthcare. 2017 IEEE 41st Annual Computer Software and Applications Conference (COMPSAC). 2017; 2: 236–241, doi: 10.1109/compsac.2017.164.
6. Bidmos MA, Adebesin AA, Mazengenya P, et al. Estimation of sex from metatarsals using discriminant function and logistic regression analyses. Australian J Forensic Sci. 2020; 53(5): 543–556, doi: 10.1080/00450618.2019.1711180.
7. Case DT, Ross AH. Sex determination from hand and foot bone lengths. J Forensic Sci. 2007; 52(2): 264–270, doi: 10.1111/j.1556-4029.2006.00365.x, indexed in Pubmed: 17316220.
8. Colman KL, Janssen MCL, Stull KE, et al. Dutch population specific sex estimation formulae using the proximal femur. Forensic Sci Int. 2018; 286: 268.e1–268.e8, doi: 10.1016/j.forsciint.2017.12.029, indexed in Pubmed: 29548547.
9. Cordeiro C, Muñoz-Barús JI, Wasterlain S, et al. Predicting adult stature from metatarsal length in a Portuguese population. Forensic Sci Int. 2009; 193(1-3): 131.e1–131.e4, doi: 10.1016/j.forsciint.2009.09.017, indexed in Pubmed: 19854594.
10. Domínguez-Maldonado G, Munuera-Martinez PV, Castillo-López JM, et al. Normal values of metatarsal parabola arch in male and female feet. Sci World J. 2014; 2014: 505736, doi: 10.1155/2014/505736, indexed in Pubmed: 24688397.
11. Eshak GA, Ahmed HM, Abdel Gawad EAM. Gender determination from hand bones length and volume using multidetector computed tomography: a study in Egyptian people. J Forensic Leg Med. 2011; 18(6): 246–252, doi: 10.1016/j.jflm.2011.04.005, indexed in Pubmed: 21771554.
12. Fasemore MD, Bidmos MA, Mokoena P, et al. Dimensions around the nutrient foramina of the tibia and fibula in the estimation of sex. Forensic Sci Int. 2018; 287: 222.e1–222.e7, doi: 10.1016/j.forsciint.2018.03.015, indexed in Pubmed: 29678345.
13. Funayama M, Aoki Y, Kudo T, et al. Sex determination of the human skull based upon line drawing from roentgen cephalograms. Tohoku J Exp Med. 1986; 149(4): 407–416, doi: 10.1620/tjem.149.407, indexed in Pubmed: 3775765.
14. Giurazza F, Schena E, Del Vescovo R, et al. Sex determination from scapular length measurements by CT scans images in a Caucasian population. Annu Int Conf IEEE Eng Med Biol Soc. 2013; 2013: 1632–1635, doi: 10.1109/EMBC.2013.6609829, indexed in Pubmed: 24110016.
15. Iscan MY, Steyn M. The human skeleton in forensic medicine. Charles C Thomas Publisher, Springfield, IL 2013.
16. Issa S, Khanfour A, Kharoshah M. A model for stature estimation and sex prediction using percutaneous ulnar and radial lengths in autopsied adult Egyptians. Egypt J Forensic Sci. 2016; 6(2): 84–89, doi: 10.1016/j.ejfs.2016.05.013.
17. Kanchan T, Krishan K, Sharma A, et al. A study of correlation of hand and foot dimensions for personal identification in mass disasters. Forensic Sci Int. 2010; 199(1-3): 112.e1–112.e6, doi: 10.1016/j.forsciint.2010.03.002, indexed in Pubmed: 20382487.
18. Karslı ÖB. Makine Öğrenme Algoritmaları ile Karaciğer Hastalığının Teşhisi. Turkish Studies-Information Technologies and Applied Sciences. 2020; 15(1): 75–83, doi: 10.29228/turkishstudies.39612.
19. Khan MA, Gul H, Mansor Nizami S. Determination of gender from various measurements of the humerus. Cureus. 2020; 12(1): e6598, doi: 10.7759/cureus.6598, indexed in Pubmed: 32064180.
20. Kim W, Kim YM, Yun MH. Estimation of stature from hand and foot dimensions in a Korean population. J Forensic Leg Med. 2018; 55: 87–92, doi: 10.1016/j.jflm.2018.02.011, indexed in Pubmed: 29474990.
21. Krems RV. Bayesian machine learning for quantum molecular dynamics. Phys Chem Chem Phys. 2019; 21(25): 13392–13410, doi: 10.1039/c9cp01883b, indexed in Pubmed: 31165115.
22. Krishan K. Determination of stature from foot and its segments in a north Indian population. Am J Forensic Med Pathol. 2008; 29(4): 297–303, doi: 10.1097/PAF.0b013e3181847dd3, indexed in Pubmed: 19259013.
23. Lee YC, Wang MJ. Taiwanese adult foot shape classification using 3D scanning data. Ergonomics. 2015; 58(3): 513–523, doi: 10.1080/00140139.2014.974683, indexed in Pubmed: 25361465.
24. MacLaughlin SM, Oldale KN. Vertebral body diameters and sex prediction. Ann Hum Biol. 1992; 19(3): 285–292, doi: 10.1080/03014469200002152, indexed in Pubmed: 1616286.
25. Moneim WMA, Hady RHA, Maaboud RMA, et al. Identification of sex depending on radiological examination of foot and patella. Am J Forensic Med Pathol. 2008; 29(2): 136–140, doi: 10.1097/PAF.0b013e318173f048, indexed in Pubmed: 18520480.
26. Mountrakis C, Eliopoulos C, Koilias CG, et al. Sex determination using metatarsal osteometrics from the Athens collection. Forensic Sci Int. 2010; 200(1-3): 178.e1–178.e7, doi: 10.1016/j.forsciint.2010.03.041, indexed in Pubmed: 20430546.
27. Oner S, Turan M, Oner Z. Estimation of gender by using decision tree, a machine learning algorithm, with patellar measurements obtained from MDCT images. Med Rec. 2021; 3(1): 1–9, doi: 10.37990/medr.843451.
28. Oner Z, Turan MK, Oner S, et al. Sex estimation using sternum part lenghts by means of artificial neural networks. Forensic Sci Int. 2019; 301: 6–11, doi: 10.1016/j.forsciint.2019.05.011, indexed in Pubmed: 31128410.
29. Ozden H, Balci Y, Demirüstü C, et al. Stature and sex estimate using foot and shoe dimensions. Forensic Sci Int. 2005; 147(2-3): 181–184, doi: 10.1016/j.forsciint.2004.09.072, indexed in Pubmed: 15567624.
30. Pedregosa F, Varoquaux G, Gramfort A, et al. Scikit-learn: machine learning in python. J Mach Learn Res. 2011; 12: 2825–2830, doi: 10.48550/arXiv.1201.0490.

31. Pellico LG, Camacho FF. Biometry of the anterior border of the human hip bone: normal values and their use in sex determination. J Anat. 1992; 181(Pt 3): 417, indexed in Pubmed: 1304579.
32. Robling AG, Ubelaker DH. Sex estimation from the metatarsals. J Forensic Sci. 1997; 42(6): 1062–1069, indexed in Pubmed: 9397547.
33. Rogers TL. Determining the sex of human remains through cranial morphology. J Forensic Sci. 2005; 50(3): 1–8, doi: 10.1520/jfs2003385, indexed in Pubmed: 15932077.
34. Secgin Y, Oner Z, Turan M, et al. Gender prediction with parameters obtained from pelvis computed tomography images and decision tree algorithm. Med Sci | Int Med J. 2021; 10(2): 356–361, doi: 10.5455/medscience.2020.11.235.
35. Spradley MK, Jantz RL. Sex estimation in forensic anthropology: skull versus postcranial elements. J Forensic Sci. 2011; 56(2): 289–296, doi: 10.1111/j.1556-4029.2010.01635.x, indexed in Pubmed: 21210801.
36. Torres G, Garmendia AM, Sánchez-Mejorada G, et al. Estimation of gender from metacarpals and metatarsals in a Mexican population. Span J Leg Med. 2020; 46(1): 12–19, doi: 10.1016/j.remle.2018.09.004.
37. Toy S, Secgin Y, Oner Z, et al. A study on sex estimation by using machine learning algorithms with parameters obtained from computerized tomography images of the cranium. Sci Rep. 2022; 12(1): 4278, doi: 10.1038/s41598-022-07415-w, indexed in Pubmed: 35277536.
38. Turan MK, Oner Z, Secgin Y, et al. A trial on artificial neural networks in predicting sex through bone length measurements on the first and fifth phalanges and metatarsals. Comput Biol Med. 2019; 115: 103490, doi: 10.1016/j.compbiomed.2019.103490, indexed in Pubmed: 31606585.