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Sex Determination by the Machine Learning Algorithms Through Using Morphometric Measurements of the Carpal, Metacarpal, and Phalangeal Bones

Determinación del Sexo Mediante Algoritmos de Aprendizaje Automático Mediante el Uso de Mediciones Morfométricas de los Huesos del Carpo, el Metacarpo y las Falanges

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SUMMARY: In the study, it was aimed to predict sex from hand measurements using machine learning algorithms (MLA). Measurements were made on MR images of 60 men and 60 women. Determined parameters; hand length (HL), palm length (PL), hand width (HW), wrist width (EBG), metacarpal I length (MIL), metacarpal I width (MIW), metacarpal II length (MIIL), metacarpal II width (MIIW), metacarpal III length (MIIL), metacarpal III width (MIIIW), metacarpal IV length (MIVL), metacarpal IV width (MIVW), metacarpal V length (MVL), metacarpal V width (MVW), phalanx I length (PILL), measured as phalanx II length (PIIL), phalanx III length (PIIL), phalanx IV length (PIVL), phalanx V length (PVL). In addition, the hand index (HI) was calculated. Logistic Regression (LR), Random Forest (RF), Linear Discriminant Analysis (LDA), K-nearest neighbour (KNN) and Naive Bayes (NB) were used as MLAs. In the study, the KNN algorithm's Accuracy, SEN, F1 and Specificity ratios were determined as 88 %. In this study using MLA, it is understood that the highest accuracy belongs to the KNN algorithm. Except for the hand's MIIW, MIIIW, MIVW, MVW, HI variables, other variables were statistically significant in terms of sex difference.

KEY WORDS: Hand; Sex determination; Magnetic resonance imaging; Machine learning.

INTRODUCTION

Identification is an essential tool in such events resulting in high number of deaths, including wars and natural disasters, and is performed mostly by the use of characteristics like sex, height and race (Zeyfeoglu & Hancı, 2001). Of all, sex is considered as the most important data due to osseous dimorphism (Rohmani *et al*., 2021). In recent years, DNA analysis has become the most reliable method for sex determination; however, it requires forensic laboratories with high cost (Frutos, 2002; Curate *et al*., 2017; Rohmani *et al*., 2021; Toy *et al*., 2022). Machine learning algorithms (MLA), which is a sub-branch of artificial intelligence research being recently used in health sciences, allows to produce the best output from the data with less work force and cost (Senol *et al*., 2022; Toy *et al*., 2022).

Although pelvic and cranial bones are the most preferred skeletal elements in sex determination, other components of the skeleton such as femur, have also been reported giving high accuracy (Case & Ross, 2007; DeSilva *et al*., 2014; Bidmos *et al*., 2021). However, the literature performed on the bones of the foot and hand have suggested less accuracy (Abledu *et al*., 2015; Arshad *et al*., 2019; Dayarathne *et al*., 2021). On the other hand, since they provide population-specific data, and their smaller size compared to other long bones reduces the risk ratio limiting factors during the study, Furthermore, MLA method is believed to increase the accuracy ratio of the sex determination on the bones of food and hand (Barrio *et al*., 2006; Abledu *et al*., 2015; Arshad *et al*., 2019; Dayarathne *et al*., 2021; Senol *et al*., 2022). Hand with the unique biomechanic and design peculiarities including tendons and fasciae of the musculoskeletal system, nerve and vascular packages, canals and tunnels, has several important tasks such as grasping and perception. It is commonly affected in the course of various diseases and traumas. Upper limb injuries have indeed a rate of 31 % among all injuries and 1/3 of these result in functional loss of the hand (Bayraktar & Özsahin, 2018).

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MLA is divided into two groups as supervised learning (classification) and unsupervised learning (clustering). K-nearest neighbour (KNN) algorithm, a supervised learning algorithm, is the simplest classification algorithm. It performs learning on the entire data set determined in accordance with the distance to closest neighbours. Contrary to its name, Logistic Regression (LR) is mostly preferred in binary classifications. Due to less hyper parameter requirement, it saves both time and model learning cost. Unlike LR and KNN, Naive Bayes (NB) makes a classification based on the calculation of probability distribution. Linear Discriminant Analysis (LDA) algorithm aims to separate features from each other linearly. It classifies datasets of each group quite far from one another. Likewise, Random Forest (RF) algorithms makes classification by creating multiple decision trees, aiming to increase the quality of classification. Since MLA is a contemporary method having recently been applied frequently on the sex determination studies to increase the accuracy ratio of the sex determination on the bones this study was designed to evaluate the accuracy of sex determination using MR images of the right and left hand, thus acquiring distinctive data on Turkish population. The results will surely be an essential source of reference to support future studies.

MATERIAL AND METHOD

The study was conducted on the hand MR images of 120 individuals (60 females, 60 males), admitted to Bolu Abant Izzet Baysal University Training and Research Hospital for various reasons, and possessing no traumas of the hand and wrist. The study has ethically been approved by the Clinical Research Ethics Committee (Date: 11.10.2022, Decision No: 2022/269). The images were randomly selected from the PACS (Picture Archiving and Communication Systems) system of the hospital and transferred to personal workstation Radiant DICOM Viewer (Version 2021.2) program in DICOM (Digital Imaging and Communications in Medicine) format. MR images were taken with 1.5 T Signa Explorer MRI Scanner (GE Medical Systems, Milwaukee, Wisconsin, USA. The variables measured in the study were as follows; hand length (HL), palm length (PL), hand width (HW), wrist width (WW), metacarpal I length (MIL), metacarpal I width (MIW), metacarpal II length (MIIL), metacarpal II width (MIIW), metacarpal III length (MIIIL), metacarpal III width (MIIIW), metacarpal IV length (MIVL), metacarpal IV width (MIVW), metacarpal V length (MVL), metacarpal V width (MVW), phalanx I length (PIL), phalanx II length (PIIL), phalanx III length (PIIIL), phalanx IV length (PIVL), phalanx V length (PVL) and hand index (HI). The variables are shown in Figure 1. MLA's were performed using Python 3.10 (64 bit) software language and sckit-learn framework. The analyses were done by using a computer with Huawei matebook 13 ryzen 7 16 gb ram 512 ssd and windows 11 (64 bit) features. LR, RF, LDA, KNN, and NB were applied as MLA.

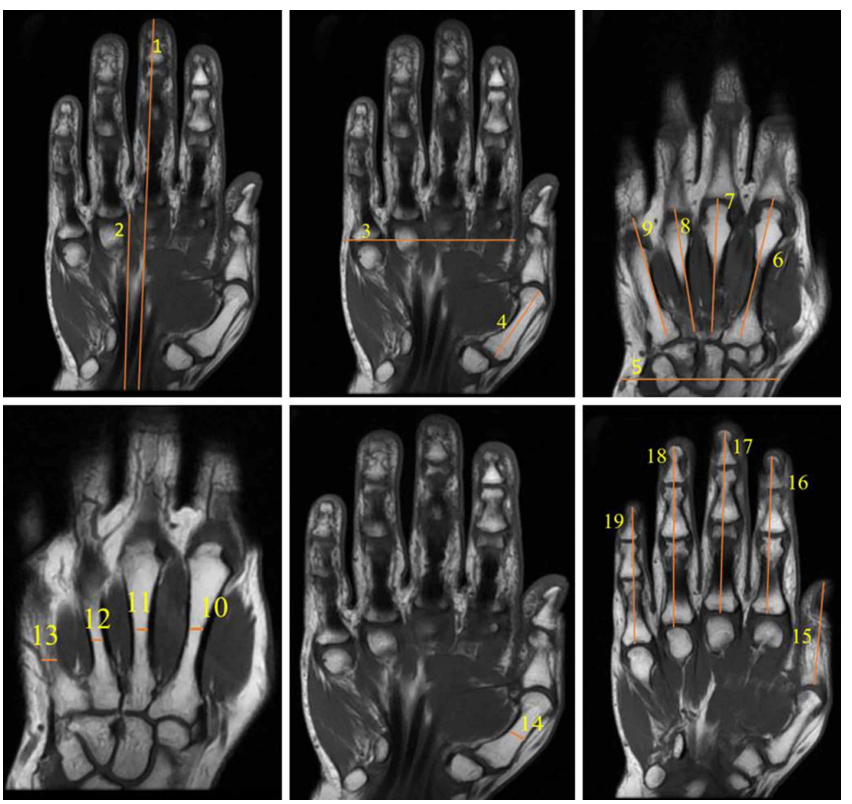

Fig. 1. 1- HL, 2- PL, 3- HW, 4- MIL, 5- WW, 6- MIIL, 7- MIIIL, 8- MIVL, 9, MVL, 10- MIIW, 11- MIIIW, 12- MIVW, 13- MVW, 14- MIW, 15- PIL, 16- PIIL, 17- PIIIL, 18- PIVL, 19- PVL. Abbreviations: HL: Hand length, PL: Palm length, HW: Hand width, WW: Wrist width. MIL: Metacarpal I length, MIW: Metacarpal I width, MIIL: Metacarpal II length, MIIW: Metacarpal II width, MIIL: Metacarpal III length, MIIW: Metacarpal III width, MIVL: Metacarpal IV length, MIVW: Metacarpal IV width, MVL: Metacarpal V length, MVW: Metacarpal V width, PIL: Phalanx

Evaluation criteria: Evaluation criteria are values calculated from confusion matrix (cm) table. Cm is a table consisting of results called true negative (TN), false negative (FN), false positive (FP), true positive (TP). In the present study, Accuracy (ACC), Sensitivity (SEN), F1 score (F1) and Specificity (SPE) were used as evaluation criteria.

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

$$SPE = \frac{TP}{TP+FP}$$

$$SEN = \frac{TP}{TP+FN}$$

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

Equation 1. Formulization of evaluation criteria

Statistical Analysis. Statistical analysis of the data was performed by using Minitab® 21.2 (64-bit) package program. Conformity of the variables to normal distribution was tested with Anderson darling test. Mean and standard deviation values were included for normally distributed (parametric) variables, while median, minimum and maximum values were included for variables which were not normally distributed (nonparametric). Sex comparisons were made with Two Simple T test for parametric variables and with Mann Whitney U test for nonparametric variables.

RESULTS

Table I shows the results of the statistical analyses. Median ages were found as 33 for men and 48 for women. No significant difference was found on the variables of MIIW, MIIIW, MIVW, MVW and HI between the sexes. Mean (m) and standard deviation (sd) values of the parametric variables, and median, minimum (min), and maximum (max) values of the nonparametric variables were included in the study. The ACC result was determined as KNN 0.88, which is the highest ACC value obtained. The ACC results of NB, LDA and RF algorithms were found as 0.79 while the result of LR algorithm was determined as 0.83. Table II shows the results of ACC, SPE, SEN and F1 algorithms. While NB algorithm predicted all of the 11 men correctly, it predicted 8 of 13 women correctly. The correct predictions by RF algorithm were 9 of 11 and 10 of 13 in men and women consequently. Likewise, LDA algorithm predicted 10 of 11 men and 9 of 13 women correctly. Furthermore, KNN algorithm having the highest ACC rate among the algorithms estimated 10 of 11 men and 11 of 13 women correctly. Finally, LR algorithm classified 10 of 11

Table I. The variables and p values.

Variables	Sex	n	Values	p value
Age	M	60	33.00 (21.00-65.00)c	0.001a
	F	60	48.00 (20.00-66.00)c	
HL	M	60	187.15 (162.50-229.20)c	0.001a
	F	60	174.75 (160.60-195.90)c	
PL	M	60	102.49±9.28d	0.001b
	F	60	93.96±7.72d	
HW	M	60	83.90 (72.90-96.80)c	0.001a
	F	60	77.95 (45.10-88.40)c	
WW	M	60	61.20 (48.30-77.60)c	0.002a
	F	60	57.40 (43.10-68.40)c	
MIL	M	60	44.55 (39.10-66.80)c	0.001a
	F	60	42.75 (33.30-63.60)c	
MIW	M	60	6.58±1.46d	0.019b
	F	60	5.98±1.25d	
MIIL	M	60	63.72±4.04d	0.001b
	F	60	60.44±3.63d	
MIIW	M	60	4.61±1.10d	0.159b
	F	60	4.96±1.60d	
MIIIL	M	60	62.29±4.08d	0.001b
	F	60	58.39±4.00d	
MIIIW	M	60	4.40 (2.90-8.50)c	0.719a
	F	60	4.4 0 (1.90-8.10)c	
MIVL	M	60	56.21±3.43d	0.001b
	F	60	52.54±3.88d	
MIVW	M	60	4.05 (2.00-7.50)c	0.585a
	F	60	4.5 0 (2.10-8.50)c	
MVL	M	60	51.10±2.93d	0.001b
	F	60	47.83±3.20d	
MVW	M	60	4.45 (2.60-7.60)c	0.475a
	F	60	4.60 (2.10-8.10)c	
PIL	M	60	59.20 (47.60-70.70)c	0.001a
	F	60	53.90 (45.20-64.20)c	
PIIL	M	60	80.60 (55.00-96.90)c	0.009a
	F	60	78.30 (60.30-96.30)c	
PIIIL	M	60	90.45 (60.90-106.10)c	0.003a
	F	60	86.15 (66.80-108.90)c	
PIVL	M	60	87.55 (60.30-101.60)c	0.001a
	F	60	83.20 (57.10-99.40)c	
PVL	E	60	68.35 (48.90-83.90)c	0.001a
	K	60	63.80 (45.80-81.00)c	
HI	M	60	44.74 (38.83-54.33)c	0.771a
	F	60	44.79 (25.69-49.84)c	

Table I. Abbreviations: HL: Hand length, PL: Palm length, HW: Hand width, WW: Wrist width. MIL: Metacarpal I length, MIW: Metacarpal I width, MIIL: Metacarpal II length, MIIW: Metacarpal II width, MIIL: Metacarpal III length, MIIW: Metacarpal III width, MIVL: Metacarpal IV length, MIVW: Metacarpal IV width, MVL: Metacarpal V length, MVW: Metacarpal V width, PIL: Phalanx I length, PIIL: Phalanx II length, PIIIL: Phalanx III length, PIVL: Phalanx IV length, PVL: Phalanx V length, HI: Hand index, M: Male, F: Female, a: p value as a result of Mann Whitney U test b: p value as a result of Two simple t test, c: Median (min-max), d: n±sd.

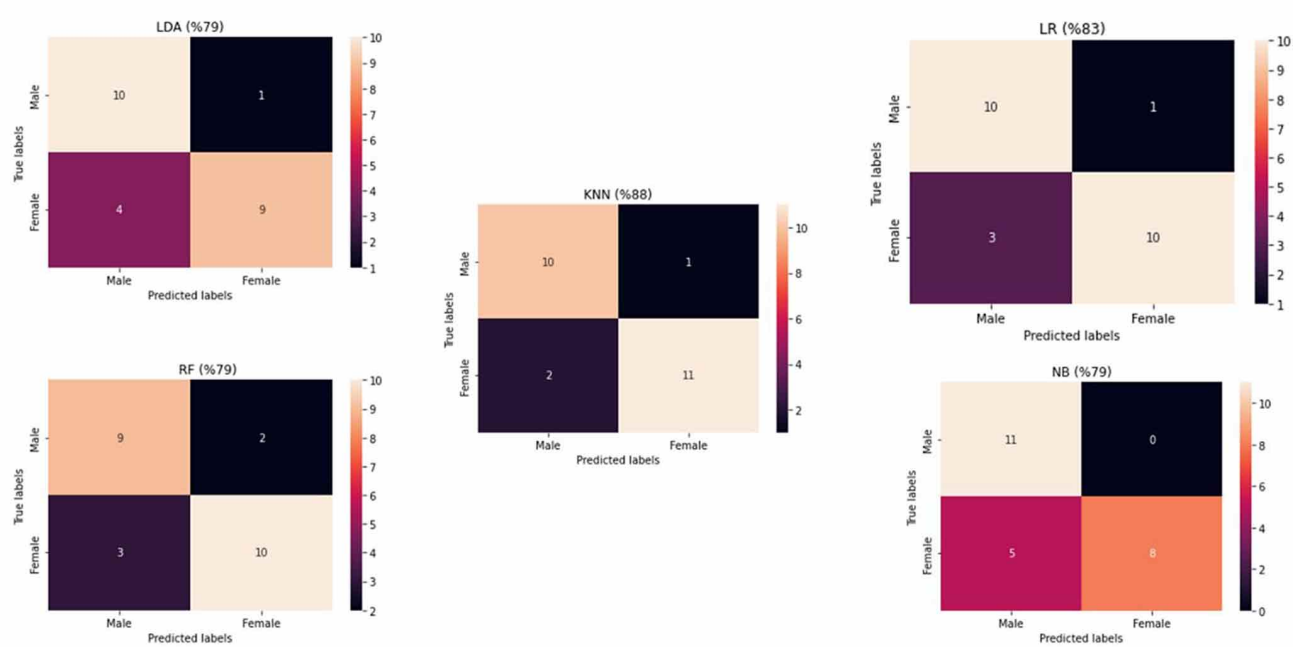

Fig. 2. Confusion matrix tables of MLA results. Abbreviations: LDA: Linear discriminant analysis, KNN: K-nearest neighbour, LR: Logistic Regression, RF: Random forest, NB: Naive Bayes, MLA: Machine learning alghoritms.

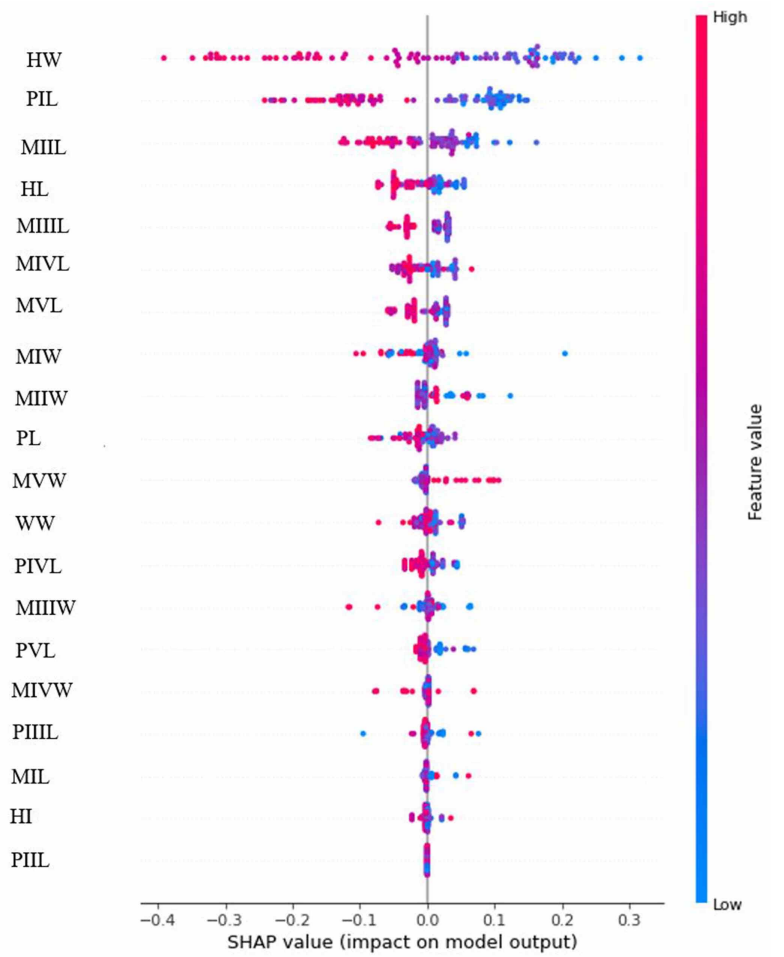

Table II. ACC, SPE, SEN, F1 values of MLA results.

Algorithm	ACC	SPE	SEN	F1
KNN	0.88	0.88	0.88	0.88
NB	0.79	0.86	0.79	0.79
LDA	0.79	0.81	0.79	0.79
LR	0.83	0.84	0.83	0.83
RF	0.79	0.79	0.79	0.79

Abbreviations: KNN: K-nearest neighbour, NB: Naive Bayes, LDA: Linear discriminant analysis, LR: Logistic Regression, RF: Random forest, ACC: Accuracy, SPE: Specificity, SEN: Sensitivity, F1: F1 score.

Fig. 3. SHAP analyser. Abbreviations: HL: Hand length, PL: Palm length, HW: Hand width, WW: Wrist width. MIL: Metacarpal I length, MIW: Metacarpal I width, MIIL: Metacarpal II length, MIIW: Metacarpal II width, MIIL: Metacarpal III length, MIIW: Metacarpal III width, MIVL: Metacarpal IV length, MIVW: Metacarpal IV width, MVL: Metacarpal V length, MVW: Metacarpal V width, PIL: Phalanx I length, PIIL: Phalanx II length, PIIIL: Phalanx III length, PIVL: Phalanx IV length, PVL: Phalanx V length, HI: Hand index.

men and 10 of 13 women correctly. The algorithm results are shown in Figure 2. HW parameter had the highest effect with regard to the results of SHAP analyser created to determine the effect degree of variables (Fig. 3).

DISCUSSION

This study has focused on sex determination by the ML through the usage of the parameters obtained from the images of the carpal, metacarpal, and hand phalangeal bones. The results have indicated statistically significant differences between the sexes on the values of the HL, PL, HW, WW, MIL, MIW, MIIL, MIIIL, MIVL, MVL, PIL, PIIL, PIIIL, PIVL, and PVL ($p \leq 0.05$). Of the MLs tested, 0.88 Acc, 0.88 Spe, 0.88 Sen, and 0.88 F1 values were found as a result of the KNN algorithm. Acc ratios of other MLs were found to be 0.88. It was found that 10 of 11 males and 11 of 13 females were predicted correctly as a result of the KNN algorithm matrix.

Sex determination is one of the most essential features to know when constructing a biological profile, because accurate identification and completion of the biological profile start with accurate result. It is not challenging for the researcher if a complete skeleton is present but biological profiling becomes difficult in the presence of missing skeletal fragments. Several studies have been attempting to determine sex by using different body features such as foot shape, footprint ratio, hand, foot and shoe dimensions, the femoral head, the patella, long bones of the arm, the cranium, and the pelvis. As to our knowledge, limited number of studies have been conducted on the determination of sex from foot and hand dimensions at particular (Agnihotri *et al*., 2005; Fawzy & Kamal, 2010; El Morsi & Al Hawary, 2013; Senol *et al*., 2022). A literature review has shown the hand and foot dimensions in males to be statistically larger than in females (Kanchan *et al*., 2010). In another study conducted on metacarpals and metatarsals in the Mexican population (Torres *et al*., 2020), the accuracy ratio has been found between 79.5 % to 85.3 %, by measuring the length of the anteroposterior base, anteroposterior head, transverse base, transverse head and maximum length using an electronic digital caliper, and the second metacarpal was the most dimorphic of the sample. Another research (El Morsi & Al Hawary, 2013) conducted on the sex determination in Egyptian population through using the X-ray images of the metacarpals and phalanges has reached the correct classification as an Acc ratio of 88 %-94 % by using both hands while calculating that as 88 % for the right hand and 88 %-90 % for the left hand alone. This research has predicted 47 of 50 males and 44 of 50 females correctly via the multivariate logistic regression. Similarly, among the results of our study, the length parameter of the second metacarpal has been found to be significant between sexes.

Discriminant function analysis has been one of the most widely used methods in forensic sciences for the determination of sex. With the application of MLs just as used in the present study trained as 80 % training and 20 % test set has increased the prediction reliability of the study, making it more advantageous when compared with discriminant analysis. Previously, the bones of the hand, especially the metacarpal bones, were addressed for sex estimation with varying results in terms of accuracy (Ozden *et al*., 2005; Manolis *et al*., 2009; Eshak *et al*., 2011). This variation was attributed to many factors including racial or population variances. A study from the Greek origin, Athens collection, mentioned that the acc of metacarpal bones in was ranged from 72.3 %-88.9 %, while a study conducted Egyptian population, stated that the acc of metacarpal bones ranged from 71.4 % to 92.9 % and the acc of phalanges were ranged from 50 % to 83 % (Manolis *et al*., 2009; Eshak *et al*., 2011). In another research in the Spanish population in which sex was estimated from the metacarpals with univariant discriminant function, the correct sex classification rank progressed from 81 %, for right (R) metacarpals IV and V, to 91 %, for left (L) metacarpal II (Barrio *et al*., 2006). In our study, all the parameters were evaluated in combination, not separately, which might be the limitation of the study, and MIL, MIW, MIIL, MIIIL, MIVL, MVL parameters were statistically significant ($p<0.05$). This study was designed to assess the accuracy of sex determination from the carpals, metacarpals and hand phalanges of hands using MRI with MLs.

Consequently, the most important results of the study, HW parameter had the highest effect with regard to the sex determination and the ACC result was determined as KNN 0.88, which is the highest ACC value obtained. KNN algorithm having the highest ACC rate among the algorithms estimated 10 of 11 men and 11 of 13 women correctly. Working in small datasets, not knowing which hand is the dominant, and not working in different populations are the other limitations of our study.

TASKIN SENOL, G.; KÜRTÜL, I.; RAY, A. & AHMETOGLU, G. Determinación del sexo mediante algoritmos de aprendizaje automático mediante el uso de mediciones morfométricas de los huesos del carpo, el metacarpo y las falanges. *Int. J. Morphol., 41(4)*:1267-1272, 2023.

RESUMEN: En el estudio, el objetivo era predecir el sexo a partir de mediciones manuales utilizando algoritmos de aprendizaje automático (MLA). Las mediciones se realizaron en imáge-

nes de RM de 60 hombres y 60 mujeres. Parámetros determinados; longitud de la mano (HL), longitud de la palma (PL), ancho de la mano (HW), ancho de la muñeca (EBG), longitud del metacarpiano I (MIL), ancho del metacarpiano I (MIW), longitud del metacarpiano II (MIIL), ancho del metacarpiano II (MIIW), longitud del metacarpiano III (MIIL), ancho del metacarpiano III (MIIIW), longitud del metacarpiano IV (MIVL), ancho del metacarpiano IV (MIVW), longitud del metacarpiano V (MVL), ancho del metacarpiano V (MVW), longitud de la falange I (PILL), medido como longitud de la falange II (PIIL), longitud de la falange III (PIIL), longitud de la falange IV (PIVL), longitud de la falange V (PVL). Además, se calculó el índice de la mano (HI). Regresión logística (LR), Random Forest (RF), Análisis discriminante lineal (LDA), K-vecino más cercano (KNN) y Naive Bayes (NB) se utilizaron como MLA. En el estudio, las proporciones de precisión, SEN, F1 y especificidad del algoritmo KNN se determinaron en un 88 %. En este estudio que utiliza MLA, se entiende que la mayor precisión pertenece al algoritmo KNN. Excepto por las variables MIIW, MIIIW, MIVW, MVW, HI de la mano, otras variables fueron estadísticamente significativas en términos de diferencia de sexo.

PALABRAS CLAVE: Mano; determinación de sexo; Imagen de resonancia magnética; Aprendizaje automático.

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