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Classification and Regression Tree Analysis for Predicting Morphological Hand Types Based on Radiography Data

Análisis de Árbol de Clasificación y Regresión para Predecir Tipos Morfológicos de la Mano Basados en Datos Radiográficos

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SUMMARY: Analysis and systematization of the longitudinal dimensions of the phalanges of the index and ring fingers for the classification of morphological types of the hand using classification and regression trees (CART). X-rays of the hands of 50 men and 50 women (mean age 47.16 (10.1) years, range 23-65 years) were studied. Each hand, depending on the ratio of the length of the index and ring fingers, was classified into three types: radial (R, 2d>4d), indefinite (N, 2d=4d), ulnar (U, 2d>4d). Morphometry of radiographs included measurements of the lengths of the proximal (PP), middle (MP), and distal (DP) phalanges. The sex differences of the analyzed indicators are statistically significant. There were no significant bilateral differences between the phalanges of the II and IV fingers in length, regardless of sex ($p>0.05$). A set of rules for classifying the morphological types of the hand depending on the lengths of the phalanges of the index and ring fingers was created by constructing a binary decision tree. The CART method demonstrates the usefulness of this statistical procedure for developing a scientifically based prediction of the morphological type of the hand. The results of this study can be the basis of an algorithm for determining the morphological type of the hand depending on the length of the phalanges of the fingers.

KE**Y WORDS: Morphology; Phalanx; Hand; X-ray; Osteometry; Classification trees.**

INTRODUCTION

The ratio of the length of the index and ring fingers of the hand (2D:4D) is characterized by sexual dimorphism, while men, as a rule, have lower values (2D<4D) than women (2D>4D) (Breedlove, 2010; Manning & Fink, 2018; Richards *et al*., 2020). In 1935, M.V. Volotsky proposed a nomenclature of morphological types of hands: ulnar type (D2<D4), radial type (D2>D4), indefinite type (D2=D4) (Volotsky, 1935). Many works have been devoted to the study of the 2D:4D ratio, in which various measurement methods were used, including direct measurement of the length of the fingers of the hands (Manning & Taylor, 2001; Peters *et al*., 2002; Khairullin, 2011), indirect measurement of finger lengths in photographs or scans (Trivers *et al*., 2006) and radiographs of the hands (Vehmas *et al*., 2006; Robertson *et al*., 2008). However, none of the studies to date have presented algorithms or models for classifying morphological types of the hand based on the analysis of the longitudinal dimensions of the phalanges of the fingers. One of the methods of statistical analysis that allows you to predict whether observations or objects belong to a particular class of dependent categorical variable, depending on the corresponding values of one or more independent (predictor) variables, is the method of classification and regression trees (CART) (Breiman *et al*., 1984). CART is a data mining technique that seeks to construct an optimal decision tree based on partitioning a set of variables to accurately predict a dichotomous outcome (Speybroeck, 2012). The formation or splitting of the tree will continue until a stop criterion based on the overall purity of the tree is reached, when the subset can no longer be split, and at a location called the terminal subset, classification is performed. Statistical learning methods, such as classification and regression trees (CART), have become very popular tools for analyzing complex data that often arise in biomedical research (Calle & Sánchez-Espigares, 2007; Speybroeck).

The aim of this study was to analyze and systematize the longitudinal dimensions of the phalanges of the II and IV fingers for the classification of morphological types of the hand using CART.

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MATERIAL AND METHOD

The participants of this study were 50 men aged 23-63 years and 50 women aged 23-65 years permanently residing in the territory of the Middle Volga region. Individuals with known diseases and post-traumatic hand deformities were excluded from the study. The research was conducted in accordance with Russian legislation and the ethical rules of the Helsinki Declaration for Human research (2013). All the research procedures were agreed upon. The subjects signed an informed consent form. The entire project was approved by the Local Ethics Committee of Ulyanovsk State University (Ulyanovsk City of Russia).

Radiography of the right and left hands was performed in an anterior-posterior projection (the center of the X-ray radiation was directed at the third metacarpophalangeal joint), the X-ray source was located 90 cm from the object of study. Radiography was performed at an exposure time of 5 seconds and an exposure of 100 mA (Pavlovsky & Kobyliansky, 1999).

Each hand was classified according to the length of the index finger: longer (radial type, R), equal (indefinite type, N), or shorter than the ring finger (ulnar type, U), by visually comparing the ratio of the most separated points at the ends of the distal phalanges of the fingers relative to each other on the radiograph (Volotskoi, 1935).

Morphometry of digital images of radiographs was performed in the Hipax Private Health Disk Image Viewer program with an accuracy of 0.1 mm. The lengths of the proximal phalanges (PP), middle (MP), and distal (DP) phalanges of the II and IV fingers (the distance between the center of the articular area of the proximal epiphysis and the point furthest from it on the distal epiphysis of the phalanx) were measured, which are analogs of the corresponding indicators of direct osteometry adopted in anthropology (Alekseev, 1966) (Fig. 1).

All statistical calculations were performed using Statistica 13.3 (StatSoft, Palo Alto, California, USA). The quantitative data was checked for outliers (Grubbs test), followed by a sample distribution type check (Shapiro-Wilk test). For each indicator, the mean, standard deviation, and confidence interval were calculated. To build the classification algorithm, we used data mining methods from the Data Mining module. To identify the most important predictor indicators, the Function Selection and variable screening procedures were used. The classification of hand types based on the length of the finger phalanx indicators were performed using the Extended Classification Trees (C & RT) method, which allows you to implement data separation based on the limit value of one of the explanatory variables, so that the created subsets have a higher proportion of observations from the same group in order to create subsets consisting of observations belonging to only one group (misclassification costs – equal, goodness of fit – Gini measure, prior probalities – estimated, stopping rule – prune on misclassification error).

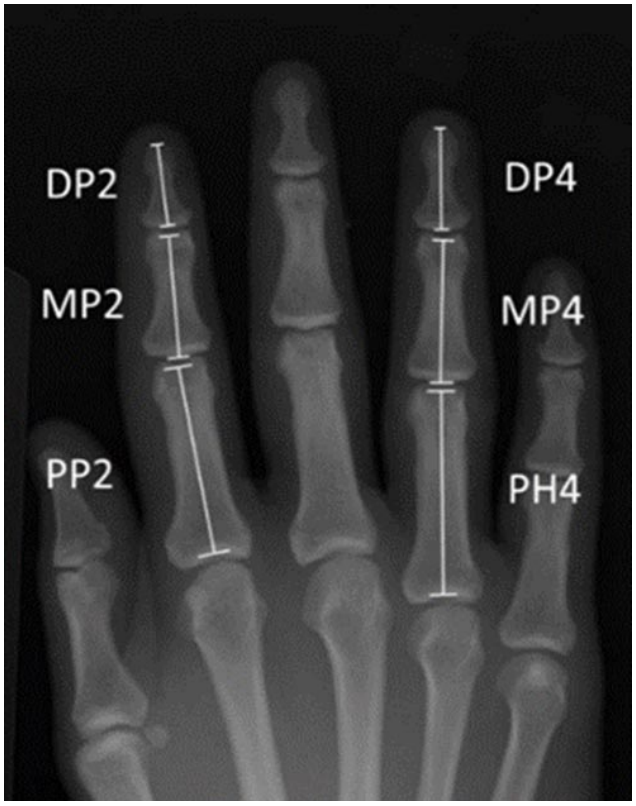

Fig. 1. X-ray image with measured parameters.

RESULTS

In the study sample, the average age of men was 46.08 (10.01) years (M (SD)), women 48.24 (10.01)) years. The age difference between men and women was not significant ($p=0.28$). The sex differences of the analyzed indicators, as expected, are pronounced and statistically significant ($t=6.7 \div 13.7$, $p<0.05$). No statistically significant bilateral differences were found between the phalanges of the second and fourth fingers in length, regardless of sex ($p>0.05$), so it was decided to combine the indicators of the right and left hands into one group. Descriptive statistics of the lengths of the phalanges of the fingers are presented in Table I.

Table I. The length of the phalanges of the index and ring fingers.

Sex	Parameters	n	M (SD), mm	95% CI, mm
Male	PP2	94	39,96 (2,33)	39,49÷40,44
	MP4	94	41,53 (2,08)	41,11÷41,96
	MP2	94	22,05 (1,57)	21,73÷22,38
	MP4	93	26,05 (1,54)	25,74÷26,37
	DP 2	94	16,96 (1,02)	16,75÷17,17
	DP 4	93	18,14 (1,05)	17,92÷18,35
Female	PP2	81	38,61 (2,38)	38,09÷39,14
	MP4	80	38,53 (2,53)	37,97÷39,1
	MP2	81	23,1 (2,37)	22,57÷23,62
	MP4	81	22,68 (2,74)	22,08÷23,29
	DP 2	81	16,2 (1,08)	15,96÷16,44
	DP 4	80	16,13 (1,35)	15,83÷16,43

According to the results of the analysis, the most significant indicators are the length of the phalanges of the ring fingers ($p<0.05$). The least important predictive factor is sex ($p<0.05$) (Fig. 2).

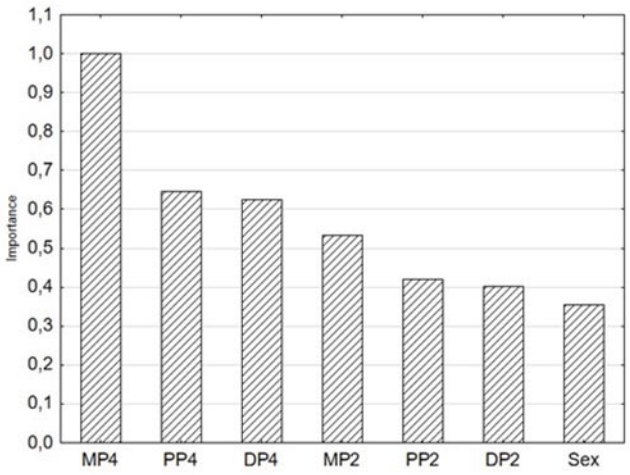

Fig. 2. Significance of prognostic factors ($p<0.05$).

Based on the results of the C&RT analysis, a set of classification rules is created by constructing a binary decision tree that splits the entire data set into disjoint subsets of homogeneous groups with a minimum number of classification errors (Fig. 3). The root of the tree was represented by the MP4 indicator, which dichotomously systematizes observations with subsequent vertices – DP2 and sex (Sex). Depending on the sex, the values of the indicators PP2, MP4, MP2 and DP4 refer the hand to one of three morphological types, forming 7 terminal vertices. The PP2 index forms terminal vertices with the possibility of classifying two morphological types of the hand.

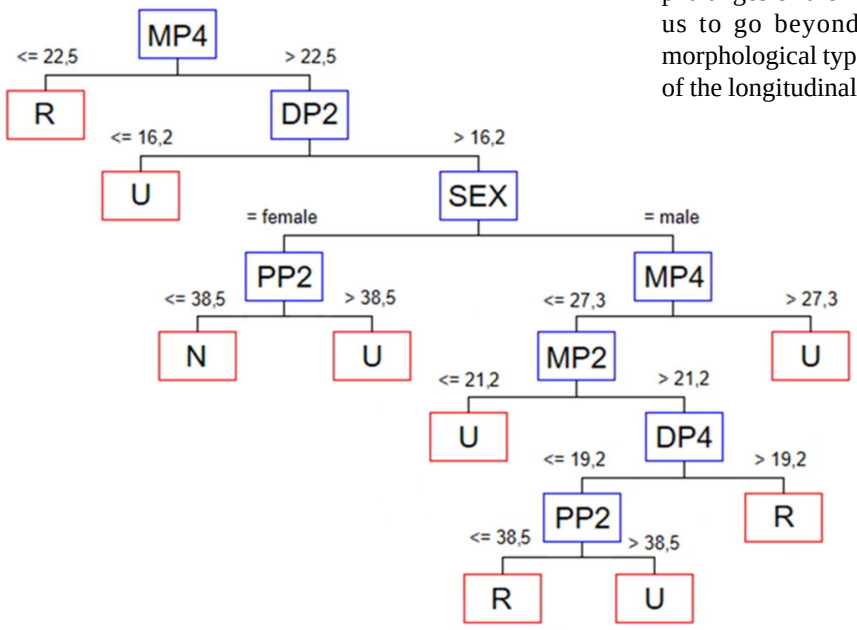

Fig. 3 Tree of classification of hands by morphological types

DISCUSSION

Currently, there is no single system for predicting the morphological type of the hand. The purpose of this study was to show the usefulness of multivariate CART procedures for classifying morphological objects. The results obtained by us significantly objectify the criteria for classifying the morphological types of the hand obtained by other researchers (George, 1930; Volotskoi; Blincoe; 1962; Peters *et al.*). The implementation of the algorithm with the inclusion in the analysis of indicators of the lengths of the phalanges of the index and ring fingers of the hand allows us to go beyond the stereotypes in determining the morphological type of the hand based solely on the analysis of the longitudinal dimensions of the index and ring fingers (Robertson *et al.*). The high prognostic significance revealed for the indicators of the phalanges of the ring fingers in comparison with the indicators of the phalanges of the index fingers confirms the data on the predominance of the gradient from the digiti minimi to the thumb in the process of patterning in the cranio-caudal direction at the stages of morphogenesis of the upper limbs (Tickle, 2006; Hiscock *et al.*, 2017). The low significance of sex as a prognostic factor is consistent with the data of some authors that the differences in the 2D:4D ratio between males and females are more dependent on the ethnicity of the skeletal material (Bakholdina *et al.*, 2016).

CONCLUSION

In conclusion, we note that from the data presented in this paper, the CART method demonstrates the usefulness of this statistical procedure for developing a scientifically based forecast of the morphological type of the hand. The results of this study can be the basis of an algorithm for determining the morphological type of the hand depending on the length of the phalanges of the index and ring fingers.

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RESUMEN: En este estudio se realizó un análisis y sistematización de las dimensiones longitudinales de las falanges de los dedos índice y anular para la clasificación de tipos morfológicos de la mano, mediante árboles de clasificación y regresión (CART). Se estudiaron radiografías de las manos de 50 hombres y 50 mujeres (edad media 47,16 (10,1) años, rango 23-65 años). Cada mano, según la proporción de la longitud de los dedos índice y anular, se clasificó en tres tipos: radial (R, 2d> 4d), indefinida (N, 2d = 4d), ulnar (U, 2d> 4d). La morfometría de las radiografías incluyó mediciones de las longitudes de las falanges proximal (FP), media (FM) y distal (FD). Las diferencias de sexo de los indicadores analizados fueron estadísticamente significativas. No hubo diferencias bilaterales significativas entre las falanges de los dedos II y IV en longitud, independientemente del sexo (p> 0,05). Se creó un conjunto de reglas para clasificar los tipos morfológicos de la mano en función de las longitudes de las falanges de los dedos índice y anular mediante la construcción de un árbol de decisión binario. El método CART demuestra la utilidad de este procedimiento estadístico para desarrollar una predicción con base científica del tipo morfológico de la mano. Los resultados de este estudio pueden ser la base de un algoritmo para determinar el tipo morfológico de la mano en función de la longitud de las falanges de los dedos.

PALABRAS CLAVE: Morfología; Falange; Mano; Osteometría; Radiografía; Árboles de clasificación.

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