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Sex Prediction of Hyoid Bone from Computed Tomography Images Using the DenseNet121 Deep Learning Model

Predicción del Sexo del Hueso Hioides a Partir de Imágenes de Tomografía Computarizada Utilizando el Modelo de Aprendizaje Profundo DenseNet121

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SUMMARY: The study aims to demonstrate the success of deep learning methods in sex prediction using hyoid bone. The images of people aged 15-94 years who underwent neck Computed Tomography (CT) were retrospectively scanned in the study. The neck CT images of the individuals were cleaned using the RadiAnt DICOM Viewer (version 2023.1) program, leaving only the hyoid bone. A total of 7 images in the anterior, posterior, superior, inferior, right, left, and right-anterior-upward directions were obtained from a patient's cut hyoid bone image. 2170 images were obtained from 310 hyoid bones of males, and 1820 images from 260 hyoid bones of females. 3990 images were completed to 5000 images by data enrichment. The dataset was divided into 80 % for training, 10 % for testing, and another 10 % for validation. It was compared with deep learning models DenseNet121, ResNet152, and VGG19. An accuracy rate of 87 % was achieved in the ResNet152 model and 80.2 % in the VGG19 model. The highest rate among the classified models was 89 % in the DenseNet121 model. This model had a specificity of 0.87, a sensitivity of 0.90, an F1 score of 0.89 in women, a specificity of 0.90, a sensitivity of 0.87, and an F1 score of 0.88 in men. It was observed that sex could be predicted from the hyoid bone using deep learning methods DenseNet121, ResNet152, and VGG19. Thus, a method that had not been tried on this bone before was used. This study also brings us one step closer to strengthening and perfecting the use of technologies, which will reduce the subjectivity of the methods and support the expert in the decision-making process of sex prediction.

KEY WORDS: Hyoid bone; Deep learning; Sex estimation; DenseNet121; ResNet152; VGG19.

INTRODUCTION

The hyoid bone is a horseshoe-shaped, solitary bone that connects with the cranium, mandible, and pharynx and has no joints with any other bone (Kim *et al.*, 2006). It is crucial in airway function in cases of swallowing, speech, and prevention of regurgitation. It also stabilises and supports the audio path. The hyoid bone changes its position relative to the vertebrae during normal growth and development. While it is at the level of the 2nd-3rd cervical vertebra in infancy, it descends to the 4th-5th cervical vertebra in adults (Lieberman *et al*., 2001; Cotter *et al*., 2015; Fisher *et al*., 2016).

In palaeoarchaeology, archaeology, anthropology, and forensic medicine, it is necessary to determine sex from burnt, deficient, or severely mutilated corpses or skeletal remains (Balseven-Odabasi *et al*., 2013; D'Anastasio *et al*., 2014). It is crucial to collect as much information as possible from sexually dimorphic elements. For such cases, the hyoid bone showing sexual dimorphism offers an alternative (Kindschuh *et al*., 2010; D'Anastasio *et al*., 2014).

Deep learning (DL) is a specialized method of artificial intelligence that can process information and learn by adjusting the weights at each synapse, it is based on multi-layered structures (algorithms) of artificial neurons and enables an intelligent task to be performed with high precision (Papadakis *et al*., 2019). DL is a specialized artificial intelligence method that can process information, learn by adjusting the weights at each synapse, is based on multi-layered structures (algorithms) of artificial neurons and enables an intelligent task to be performed with high precision.

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This approach has improved object detection and recognition significantly. Thus, multi-model deep learning architectures can substantially contribute to the advancement of medicine. DL has been used and improved the speed and efficiency of analyzing many medical imaging techniques such as X-ray, computed tomography (CT), and magnetic resonance imaging (MRI). In particular, Convolutional Neural Network (CNN) has recently shown superior performance over other machine learning methods in object detection and recognition applications from medical images, revealing clinical information and individual characteristics (Papadakis *et al*., 2019; Hassan *et al*., 2021; Kim *et al*., 2021b).

This study aimed to compare sex prediction from hyoid bone with DenseNet121, ResNet152, and VGG19 CNN architectural models. Since it is a study that predicts sex using deep learning, a new window will be opened in fields such as forensic medicine, archaeology, and anthropology.

MATERIAL AND METHOD

Image Population: The study included images of individuals aged 15-94 years who underwent CT angiography between 2020 and 2023. Any trauma or disinformation in the hyoid bone was not excluded from the study. These included 570 CT images in which the os hyoideum was wholly visualized. The study was approved by the Non-Interventional Local Ethics Committee (Decision No: 1224/2023).

RadiAnt DICOM Viewer (2023.1) program was used to open all images. It was made in 3D with the 3D Volume Rendering button. Using the Scalpel tool in the opened window, the image was cleaned by cutting the other structures until only the hyoid bone remained (Fig. 1). The images were then exported using the Snipping Tool in image (.jpeg) format. The images were first filed by sex and then by direction. The names and ages of the patients were entered into Microsoft Excel.

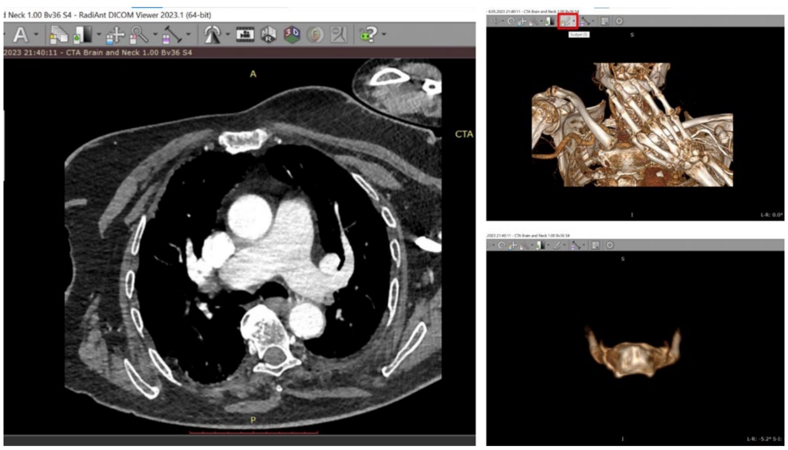

Fig. 1. Opening the image in the RadiAnt program, making it 3-dimensional, cutting the other structures with a scalpel, and leaving only the hyoid bone.

3990 images were obtained from 7 directions: anterior, posterior, superior, inferior, right, left, and right-anterior-upward. In the image folder of males, 310 images were taken from 7 directions, and 2170 images were obtained. In women, 260 images were taken from 7 directions, and 1820 images were obtained. The images taken from seven directions were completed to 2500 with the data enrichment method (Figs. 2 and 3). Horizontal flip, 20 % rotation, 20 % width shift, 20 % height shift, 20 % height shift, and zoom were performed for data enrichment. 80 % of the data set was divided into training set, 10 % validation, and 10 % test set (Table I).

Fig. 2. Original images.

Table I. Division of images into training, validation, and test sets.

	Total data	Training set (80 %)	Validation set (10 %)	Test set (10 %)
Original data set	2170+1820=3390	-	-	-
Augmented data set	5000	4000	500	500

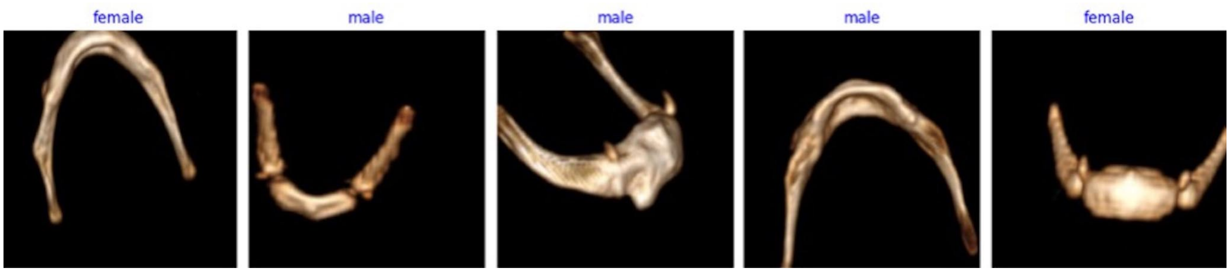

Fig. 3. Augmented images.

Statistical Methods: Minitab 17 program was used for age analysis of the population included in the study. Compliance with normal distribution was evaluated by the Anderson-Darling test. Since age was not normally distributed, the Mann-Whitney U test was used. $p<0.05$ was considered statistically significant.

Deep Learning Methods: In the study, DL models were trained using a GPU-assisted system in the Google Cloud environment. The training was performed on a 2.20 GHz Intel Xeon CPU with a Tesla T4 GPU and 16 GB of RAM. The study used Keras 2.3.1 and TensorFlow 1.4 libraries and Phyton 3 programming language. Sex prediction rates from images of the hyoid bone were calculated using DenseNet121, ResNet152, and VGG19 methods.

a) DenseNet121: The DenseNet design is a pre-trained transfer learning method that builds on ResNet by introducing dense connections where each layer is connected to all layers (Kathamuthu *et al*., 2023; Pillai *et al*., 2023). In DenseNet, each layer is fully connected to the previous one (Hasan *et al*., 2023). A feed-forward network provides the highest data flow by establishing short connections between network levels (Pappula *et al*., 2023). It is a feed-forward network that provides the highest data flow by establishing short connections between network levels.

b) ResNet152: ResNet, short for Residual Network, is designed to enable the activation of hundreds of thousands of convolutional layers (Roy *et al*., 2021). It has the property of residual connections and carries information at many resolutions simultaneously. It is a neural network consisting of 152 layers. It can learn the characteristics of low-quality images at multiple levels of detail by projecting information from numerous resolutions over the network (Dhodapkar *et al*., 2022). When ResNet is used, the problems of slope loss and bursting are solved by increasing the number of network layers (Hanis *et al*., 2023).

c) VGG19: Image classification is one of the most widely used deep CNN models. It is designed to consist of augmented CNN layers with a few cores to achieve more accurate results for image processing tasks (Kathamuthu *et al*., 2023). It is a 19-layer version of the VGG network with 3 fully connected, 16 convolutional, 1 softmax, and 5 max pool layers (Mohbey *et al*., 2022). This version is among the most powerful of the VGG architecture (Subasi *et al*., 2022).

RESULTS

A total of 570 people, 260 women and 310 men, were included in the study. The mean age of women was 46.21±17.92 years, and that of men was 42.32±17.39. Men's and women's ages were not normally distributed ($p<0.05$). The median age was 46 (16-94) for women and 40 (15-87) for men, and the difference was statistically significant favoring women.

DenseNet121: DenseNet121, out of 500 data in the test set, an accuracy of 89 % was achieved for sex prediction with 55 errors (Table II). The accuracy rate, missing data, and confusion matrix in the test and training sets are shown in Figure 4.

ResNet152: When the ResNet152 architectural model was used for sex prediction, an 87 % accuracy rate was found, with 65 errors out of 500 data in the test set (Table II). The accuracy rate and missing data in the test set are shown in Figure 5.

VGG19: The VGG19 architecture model showed 80.2 % accuracy in sex prediction with 99 errors out of 500 data in the test set (Table II). The accuracy rate and missing data in the test set are shown in Figure 6.

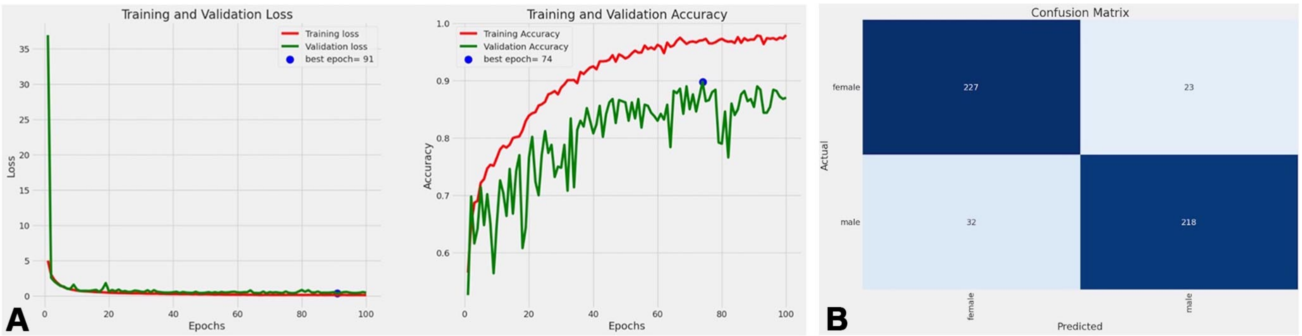

Fig. 4. A) DenseNet121 architecture model missing data and accuracy rate in training and validation set. B) Confusion matrix in the test set in the DenseNet121 architectural model.

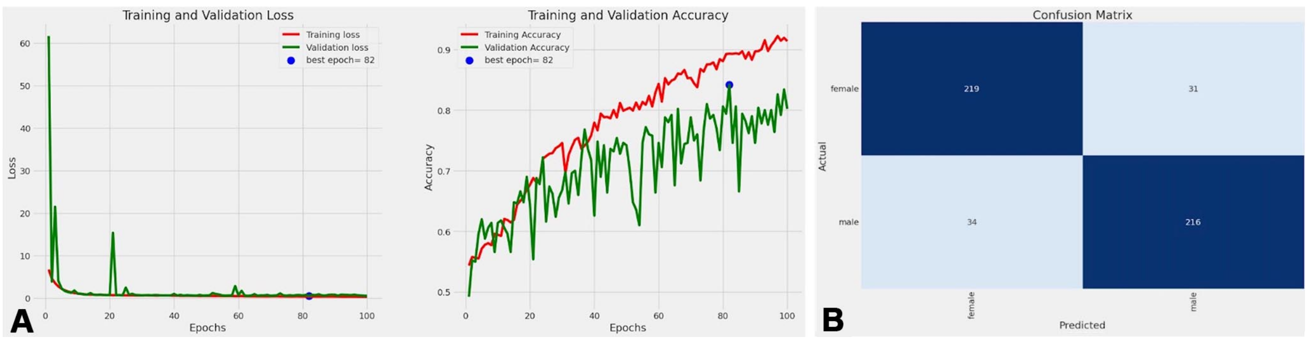

Fig. 5. A) Missing data and accuracy rate in training and validation set in the ResNet152 architecture model. B) Confusion matrix in the test set of the ResNet152 architectural model.

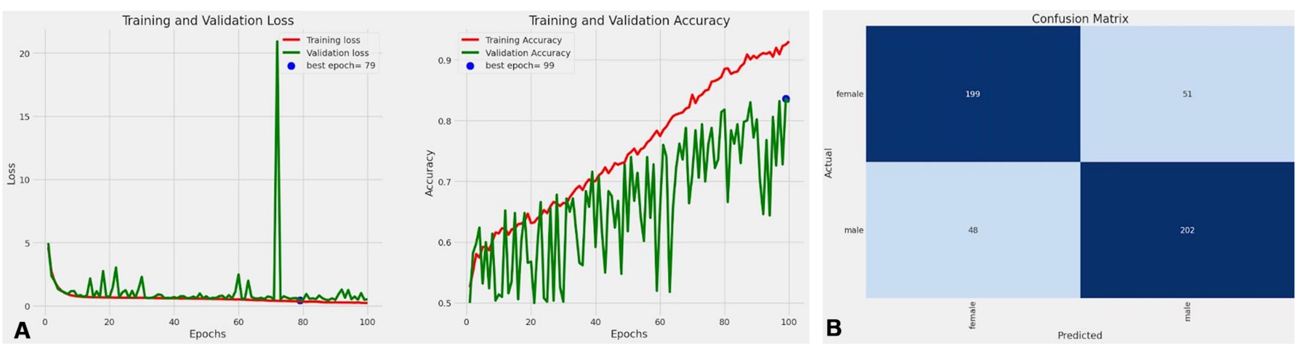

Fig. 6. A) VGG19 architecture model missing data and accuracy rates in training and validation sets. B) Confusion matrix in the test set of the VGG19 architectural model.

Table II. Performance measurements of the architectural models used.

Architectural Models		Specificity (Spe)	Sensitivity (Sen)	F1 Scor	Accuracy Rate
DenseNet121	Female	0.876	0.908	0.891	0.890
	Male	0.904	0.872	0.888	
	Macro avg	0.890	0.890	0.890	
	Weighted avg	0.890	0.890	0.890	
ResNet152	Female	0.865	0.876	0.870	0.870
	Male	0.874	0.864	0.869	
	Macro avg	0.870	0.870	0.870	
	Weighted avg	0.870	0.870	0.870	
VGG19	Female	0.805	0.796	0.800	0.802
	Male	0.798	0.808	0.803	
	Macro avg	0.802	0.802	0.802	
	Weighted avg	0.802	0.802	0.802	

DISCUSSION

The estimation of the sex is the first step in the forensic investigation. Sex is estimated by taking samples from structures showing sexual dimorphism in dismembered bodies (Bakici *et al*., 2021). It would be a convenience to use the hyoid bone for sex determination from the remaining intact bones of the mutilated corpses by providing an alternative (Balseven-Odabasi *et al*., 2013). In this study, with 5000 hyoid bone images (.jpeg), an accuracy rate of 87 % in the ResNet152 model, 80.2 % in the VGG19 model and 89 % in the highest DenseNet121 model were achieved.

Using bone morphology to determine sex is observer-dependent and thus may be affected by subjective bias. When metric measurements are used, observer subjectivity is much less and more objective than in morphological studies (Soltani *et al*., 2017). DL can automate biological profile prediction methods in forensic sciences and reduce subjectivity (Logar *et al*., 2016; Venema *et al*., 2023). In addition, automation will make things even more accessible.

Generally, studies in the literature have only investigated morphometric (Mukhopadhyay, 2012; D'Anastasio *et al*., 2014) and morphological features of the hyoid (Kindschuh *et al*., 2010; Balseven-Odabasi *et al*., 2013; Urbanová *et al*., 2013; Loth *et al*., 2015). In this study, no morphological classification and morphometric measurements were performed. It is the first study to use image-based DL methods to predict sex in the hyoid bone using images from neck CT scans.

In a study in which 33 measurements were made on hyoid bone photographs of 88 cadavers from the Turkish population, 78.1 % of females and 92.5 % of males were correctly classified (Balseven-Odabasi *et al*., 2013). Kim *et al*. (2006) reported an accuracy rate of 88.5 % for males and 87.9 % for females in a sex estimation study performed by removing the hyoid bones of 85 Korean cadavers using 34 measurements from the photograph. This study converted radiological images of the hyoid bone into 3D. The resulting images were then placed on the appropriate plane and saved as an image. It was run on the models in the images. The highest sex prediction rate was 89 % accuracy using DenseNet121. We believe that the differences in the accuracy rates obtained in the above-mentioned studies and the present study are due to geographical differences.

In another study, sex prediction rates of 82-85 % were reported by measuring 398 hyoid bones in the Robert J. Terry Anatomical Collection Washington (Kindschuh *et al*., 2010). In a study of the hyoid bone of 50 adult individuals from the Indian Bengal population, 90 % were correctly classified according to sex (Mukhopadhyay, 2012). The overall accuracy of the sex estimation results obtained by measurements on 134 hyoid bones of the white population was found to be between 89-93 % (Logar *et al*., 2016). In sex estimation from the hyoid bone in 280 CT images in the Japanese population, the highest rates were 93.3-94.6 % (Torimitsu *et al*., 2018). In the present study, the sex prediction rate of the ResNet152 model was 87 %. We think the reason for the different accuracy rates between the studies is the diverse populations.

The accuracy rate was found to be between 75-88 % in a sex estimation study using the discriminant function analysis method using 64 adult hyoid bones from the medieval period (D'Anastasio *et al*., 2014). In a study of 349 adult Iranian cadavers, it was reported that the sex prediction rate was 97.4 % as a result of logistic regression analysis (Soltani *et al*., 2017). In the study of sex estimation from 293 unfused hyoid bones belonging to the Indian population, stepwise discriminant analysis resulted in an accuracy rate of 75.1 %, and machine learning algorithms resulted in an accuracy rate of 80-83 % (Tyagi *et al*., 2021). A study comparing machine learning algorithms and deep learning using 135 ilium bone photographs of infants reported that DL performed 10 % better sex prediction (Ortega *et al*., 2021). This study observed that the VGG19 model correctly predicted sex at a rate of 80.2 %. We believe that the differences in accuracy rates are due to the method used.

Atas (2022) found a sex prediction rate of 97.25 % using 24,000 panoramic X-ray images with the DenseNet121 model. Xue *et al*. (2018) reported 99 % accuracy in the cervical set and 98 % in the lumbar set in their sex prediction study using DenseNet on 9667 cervical spine and 7428 lumbar spine X-ray images. Kim *et al*. (2021a) used the ResNet152 model to classify the sex of patients with 4160 paranasal sinus X-ray images and reported an accuracy rate of 98 %. In another sex prediction study, the accuracy rate was 92.11 % with the ResNet152 model from 523,051 face photographs (Ito *et al*., 2018). Using 224,316 chest X-ray images in the VGG-19 model, they reported a sex prediction accuracy rate of 94 % (Li *et al*., 2022). In this study, using 5000 hyoid bone images, the highest sex prediction rate was 89 % with DenseNet121, 87 % with ResNet152, and 80.2 % with the VGG19 model. We believe, these accuracy rate differences are related to the number of images used in the studies.

In the case of overfitting, the DL model can not adapt to new data because it is very well trained on the training data. Data replication is a common and powerful way to overcome these situations (Cao *et al*., 2022). Data replication was performed to allow for generalization and overcome the overfitting risk (Agbo-Ajala & Viriri, 2020; Cao *et al*., 2022). In this study, data replication was performed for the same reasons.

The present study was conducted with 5000 data. Compared to the deep learning studies in the literature, this amount of data can be considered a limitation of our study. We believe that higher rates can be achieved by increasing the number of data in future studies and that this study using DL models with hyoid bone will contribute to the literature.

CONCLUSION

DenseNet121, ResNet152, and VGG19 CNN architectural models were used for sex prediction in hyoid bone. Among the classified models, the highest rate of 89 % was detected in the DenseNet121 architecture model. Thus, it provides the advantage of reaching the result of sex estimation in a shorter time since only photography is taken and no measurement is made. It is the first study in the literature to predict sex in hyoid bone using DL architectures. In this study, the models were run with 7 images of each individual. Therefore, when a hyoid bone is found, we think taking a photograph from one of the 7 angles is sufficient. This work will bring us one step closer to strengthening and perfecting the use of technologies, which in the future will not only reduce the subjectivity of the methods but also support the expert in the decision-making process of sex prediction.

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BAKICI, R. S.; CAKMAK, M.; ONER, Z. & ONER, S. Predicción del sexo del hueso hioides a partir de imágenes de tomografía computarizada utilizando el modelo de aprendizaje profundo. DenseNet121. *Int. J. Morphol., 42(3)*:826-832, 2024.

RESUMEN: El estudio tuvo como objetivo demostrar el éxito de los métodos de aprendizaje profundo en la predicción del sexo utilizando el hueso hioides. En el estudio se escanearon retrospectivamente las imágenes de personas de entre 15 y 94 años que se sometieron a una tomografía computarizada (TC) de cuello. Las imágenes de TC del cuello de los individuos se limpiaron utilizando el programa RadiAnt DICOM Viewer (versión 2023.1), dejando solo el hueso hioides. Se obtuvieron un total de 7 imágenes en las direcciones anterior, posterior, superior, inferior, derecha, izquierda y derecha-anterior-superior a partir de una imagen seccionada del hueso hioides de un paciente. Se obtuvieron 2170 imágenes de 310 huesos hioides de hombres y 1820 imágenes de 260 huesos hioides de mujeres. Se completaron 3990 imágenes a 5000 imágenes mediante enriquecimiento de datos. El conjunto de datos se dividió en un 80 % para entrenamiento, un 10 % para pruebas y otro 10 % para validación. Se comparó con los modelos de aprendizaje profundo DenseNet121, ResNet152 y VGG19. Se logró una tasa de precisión del 87 % en el modelo ResNet152 y del 80,2 % en el modelo VGG19. La tasa más alta entre los modelos clasificados fue del 89 % en el modelo DenseNet121. Este modelo tenía una especificidad de 0,87, una sensibilidad de 0,90, una puntuación F1 de 0,89 en mujeres, una especificidad de 0,90, una sensibilidad de 0,87 y una puntuación F1 de 0,88 en hombres. Se observó que se podía predecir el sexo a partir del hueso hioides utilizando los métodos de aprendizaje profundo DenseNet121, ResNet152 y VGG19. De esta manera, se utilizó un método que no se había probado antes en este hueso. Este estudio también nos acerca un paso más al fortalecimiento y perfeccionamiento del uso de tecnologías, que reducirán la subjetividad de los métodos y apoyarán al experto en el proceso de toma de decisiones de predicción del sexo.

PALABRAS CLAVE: Hueso hioides; Aprendizaje profundo; Estimación del sexo; DenseNet121; ResNet152; VGG19.

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