Int. J. Morphol.,
42(4):1005-1010, 2024.

Volumetric Analysis of Carpal Bones by Sex with 3D Slicer Software Program

Análisis Volumétrico de los Huesos del Carpo por Sexo con el Programa de Software 3D Slicer

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CELIK, N.G.; ERDEM, S. & KOCAK, M. Volumetric analysis of carpal bones by sex with 3D slicer software program. *Int. J. Morphol., 42(4)*:1005-1010, 2024.

SUMMARY: In this study, we aim to share the volumes of the carpal bone and the ratio of these volumes to the total volume of wrist bones from Computed Tomography (CT) images obtained from individuals of different ages and sex using 3D Slicer. Right wrist CT images of 0.625 mm slice thickness of 42 healthy individuals (21 female, 21 male) of both sexes were included in our study. Volume calculations were made by loading the images into 3D Slicer, an open-source software package. In this study, mean capitate volume was the largest in both sexes (male 3479.9±679.2; female 2207.1±272.1 mm^3), while pisiform had the smallest mean volume (male 810.0±141.2; female 566.6±97.7 mm^3). This order was ordered from largest to smallest as hamate, scaphoid, trapezium, lunate, triquetrum, trapezoid, and pisiform. According to this study, carpal bone volumes were larger in males than in females ($p<0.001$). The ratio of each carpal bone volume to the total carpal bone volume was calculated according to sex and it was found that there was no difference ($p>0.05$). In this study, it was seen that carpal bone volume differed according to sex. However, it was observed that the bone volumes of both sexes took up the same amount in the total bone volume. This information will be very useful in sex determination, 3D anatomical material creation, implant applications and reconstructive surgery.

KEY WORDS: Carpal bones; Computed tomography; Sex; Three-dimensional (3D) Imaging; Volume.

INTRODUCTION

Carpal bones are short bones located between the antebrachial and metacarpal bones. A wrist has eight bones, four proximal and four distal (Arıncı & Elhan, 2016). The hand and wrist are one of the most used parts of our body (Thomas *et al*., 1998). Considering the work of bones, tendons, vessels, nerves and joints, this region has a very complex structure (McCann *et al*., 2010; Eschweiler *et al*., 2022). This complex structure is very important for the functional and dynamic anatomy of the hand with the new developments in hand surgery (Eroglu *et al*., 2002). The anatomical structure of the region is also very important in musculoskeletal research, such as the formulation of effective treatment plans, sex determination, age determination, joint biomechanics, development of joint replacement methods and various joint diseases (McLean *et al*., 2009; Demirkıran *et al*., 2014; Foster *et al*., 2018).

Injuries and traumas to the wrist, which is a functional limb, are among the most common reasons for applying to emergency services (Thomas *et al*., 1998; Tekin *et al*., 2017). Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) can be used as diagnostic modalities in the evaluation of the region (Foster *et al*., 2018; Kraus *et al*., 2021). Contributing to the assessment of anatomical structures, CT provides information about bone volume and morphometric measurements (Crisco *et al*., 2005; Eshak *et al*., 2011). There are many studies examining the volume (Patterson *et al*., 1995; Canovas *et al*., 1997), length (Patterson *et al*., 1995; Mastrangelo *et al*., 2011), width and height (Mastrangelo *et al*., 2011) of the wrist bones with various methods according to sex. CT is the standard imaging technique for evaluating the region (Kraus *et al*., 2021).

It has been reported in previous studies that sex estimation was made from wrist bones (Sulzmann *et al*., 2008; Mastrangelo *et al*., 2011). Most studies are related to metacarpal bones (Falsetti, 1995; Barrio *et al*., 2006; Eshak *et al*., 2011). In addition, it was pointed out that bone

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Received: 2024-04-20 Accepted: 2024-04-23

structures are important for biological profiles in forensic medicine and archaeological sciences.

The cadaver study evaluated the length, circumference and volume of the scaphoid, capitate, lunate and trapezium bones. Thus, it has been reported that bone models that closely resemble cadaveric anatomy will be created via 3D printers (Lebowitz *et al*., 2021).

In recent years, with the development of technology, many software tools have entered our lives. These software tools can make objective measurements using medical images. 3D Slicer, one of the software we mentioned, is a free, open-access software tool that allows versatile visualisations and performs quantitative analysis (Fedorov *et al*., 2012).

Our aim in this study is to share the segmentation study of wrist CT images obtained from individuals of different ages and sex using 3D Slicer. In line with the results obtained from this study, it is aimed to create a data set to be used in developing course materials for institutions that provide clinical implant application, reconstructive surgery and anatomy education.

MATERIAL AND METHOD

Participants. CT images of 42 healthy individuals (21 female, 21 male) aged 18-64 years were included in the study. CT data were included in the images of individuals who did not have any chronic disease that could damage the wrist bone structure, who did not have wrist surgery, and who applied to the clinic only with a complaint of pain between 2017-2022. Right wrist images of all participants were included in the study.

Bolu Abant Izzet Baysal University Clinical Research Ethics Committee (Date: 08.03.2022, Approval Decision No: 2022/32) permission was obtained. It was conducted by the Helsinki Declaration of 1975, which was revised in 2013. The data of the participants were anonymised.

CT acquisition protocol and 3D image processing process. All CT examinations were obtained using a 128-slice (GE Revolution EVO, GE Medical System, USA) brand and model device. Displays at 120 kVp and 20 mAs current values, standard; section thickness, 0.625 mm. Sagittal-coronal reformats, and 3D images were obtained from these images.

This study was a retrospective analysis of hand-wrist CT scans of patients admitted to the radiology department. Patient images were exported in Digital Imaging and Communications in Medicine (DICOM) format. This transferred DICOM data was saved on a personal computer (64-bit, Intel Core i7, 16 GB RAM). 3D Slicer (https://www.slicer.org/, version 4.10.2), a free and open-source software program, was used for the volumetric analysis of the structures to be examined. Images uploaded to the 3D Slicer program were viewed in three planes (axial, coronal and sagittal). The segmentation process was carried out step by step by determining images suitable for analysis. The "Modules" list in the program was entered, and "Segment Editor" was selected from there. Tabs to represent structures have been added to the "Add" toolbar in the Segment Editor. In the first tab, bone structures were painted entirely with the "Threshold" tab (Threshold Range=370/2000 HU). Subsequently, the raw image of the wrist bones was visualized in three dimensions with the "Show 3D" tab. The " Islands " tool masked the bones to be segmented in different colours. As the last step, volume measurement reports were automatically received with the "Quantification" option from the "Modules" list (Fedorov *et al*., 2012) (Fig. 1).

The differences in the morphometry of the carpal bones according to the sexes were evaluated in two stages. First, the mean volumes of each wrist bone according to sex were calculated. Secondly, the ratios of each individual's carpal bone volume/total wrist bone volume were compared as a percentage.

Statistical Method. The data were evaluated in the statistical package program of IBM SPSS Statistics Standard Concurrent User V 26 (IBM Corp., Armonk, New York, USA). Descriptive statistics included the number of units (n) and mean ± standard deviation. The normal distribution of the data of numerical variables was evaluated with the Shapiro-Wilk normality test. The homogeneity of variances was assessed with Levene's test. In independent samples, volume mm^3 and percentage values of men and females were assessed by t-test. The Pearson correlation coefficient evaluated the relationships between age and volume values. A value of $p<0.05$ was considered statistically significant.

RESULTS

The mean age of the participants was 35.1±13.2 (range 18-56 years) in females and 32.3±12.0 in males (range 19-64), respectively. There was no statistical difference between the ages of males and females ($p>0.483$). Table I shows that the total carpal, scaphoid, lunate, triquetrum, pisiform, trapezium, trapezoid, capitate and hamate bone volume in mm^3 is statistically higher in males than in females ($p<0.05$). The differences between males and females volume percentage (%) values were not statistically significant ($p>0.05$). It was the largest bone capitate of both sexes and subsequently formed the hamate, scaphoid, trapezium, lunate, triquetrum, trapezoid, and pisiform bones, respectively.

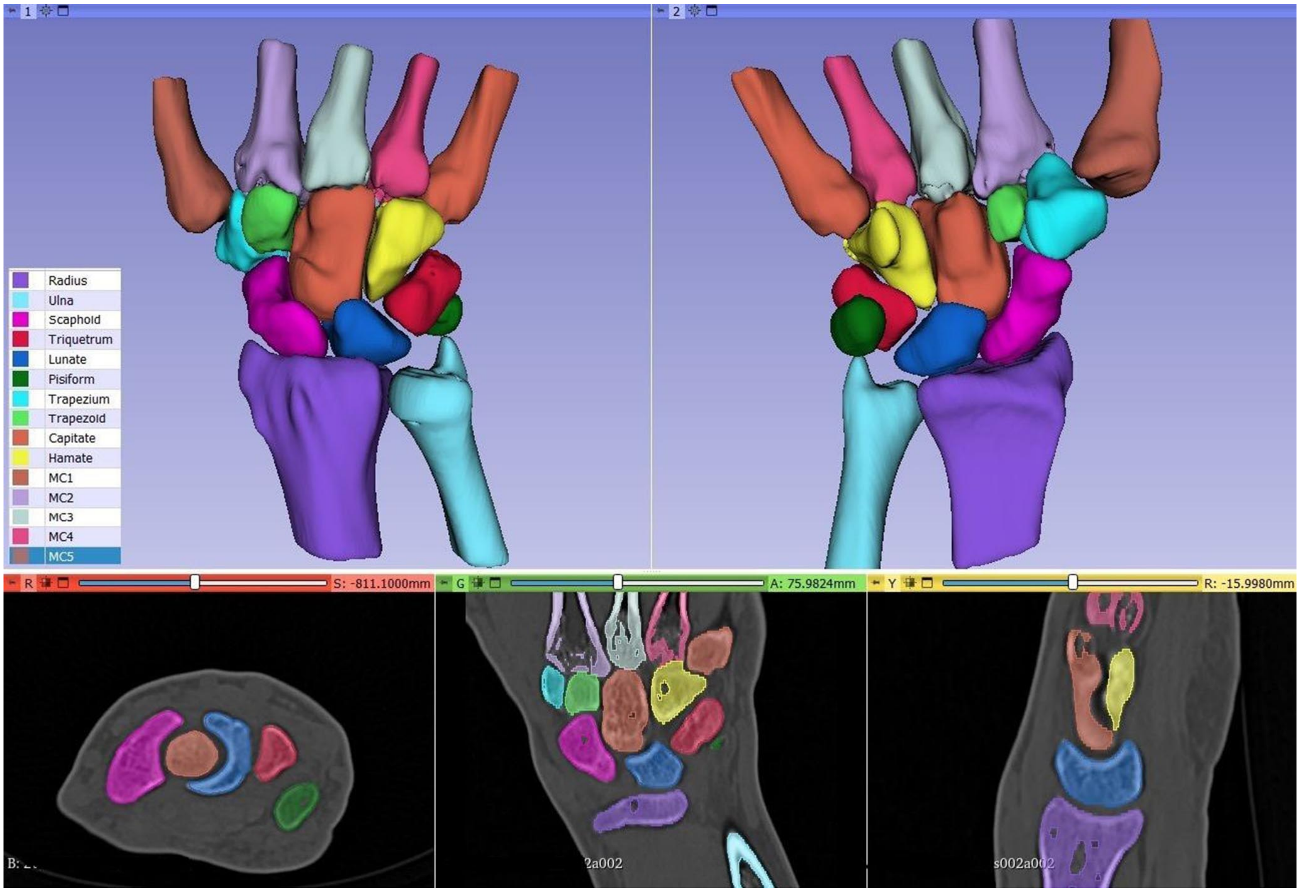

Fig. 1. Segmentation of carpal bones.

Table I. Volume and percentage values of carpal bones by sex.

Parameters	Sex		Test Statistics	
	Male *n*=21	Female *n*=21	*t* value	*p* value
Age	32.3±12.0	35.1±13.2	0.708	0.483
Total Carpal Volume [mm³]	16913.4±3295.0	10823.4±1216.8	**7.945**	**<0.001**
Total Carpal Volume [%]	100.0±0.0	100.00±0.0	-	-
Scaphoid Volume [mm³]	2597.6±568.7	1581.1±228.8	**7.598**	**<0.001**
Scaphoid Volume [%]	15.30±0.95	14.78±0.94	1.788	0.081
Lunate Volume [mm³]	1954.0±435.4	1290.5±198.1	**6.355**	**<0.001**
Lunate Volume [%]	11.52±0.75	11.88±0.72	1.596	0.118
Triquetrum Volume [mm³]	1586.8±333.1	1051.9±139.8	**6.784**	**<0.001**
Triquetrum Volume [%]	9.39±0.68	9.72±0.64	1.612	0.115
Pisiform Volume [mm³]	810.0±141.2	566.6±97.7	**6.492**	**<0.001**
Pisiform Volume [%]	4.92±0.72	5.27±0.73	1.555	0.128
Trapezium Volume [mm³]	2239.3±550.4	1417.9±206.6	**6.401**	**<0.001**
Trapezium Volume [%]	13.12±1.01	13.08±0.99	0.150	0.882
Trapezoid Volume [mm³]	1388.6±270.3	868.4±110.4	**8.163**	**<0.001**
Trapezoid Volume [%]	8.22±0.49	8.04±0.65	0.994	0.326
Capitate Volume [mm³]	3479.9±679.2	2207.1±272.1	**7.972**	**<0.001**
Capitate Volume [%]	20.61±1.33	20.40±1.32	0.512	0.611
Hamate Volume [mm³]	2855.3±537.4	1820.2±177.6	**8.380**	**<0.001**
Hamate Volume [%]	17.02±1.03	16.86±0.81	0.543	0.590

Data are given as mean±standard deviation, t: independent samples t test.

Table II shows a statistically significant weak negative correlation between age and capitate volume (%) in the whole group (r=-0.317; p=0.041). A statistically moderate positive correlation was found between age and trapezium volume (mm^3) and trapezium volume (%) in females (r=0.490; p=0.024 and r=0.505; p=0.019). A statistically moderate negative correlation was found between age and capitate volume (%) in females (r=-0.454; p=0.039). Other correlation coefficients in Table II were not statistically significant (p>0.05).

Table II. Correlations between age and volumes.

Parameters	All		Male		Female	
	r	*p*	*r*	*p*	*r*	*p*
Total Carpal Volume [mm^3]	-0.006	0.969	0.077	0.740	0.320	0.158
Total Carpal Volume [%]	-	-	-	-	-	-
Scaphoid Volume [mm^3]	-0.007	0.963	0.109	0.637	0.197	0.392
Scaphoid Volume [%]	0.151	0.341	0.177	0.442	0.201	0.383
Lunate Volume [mm^3]	-0.029	0.853	-0.001	0.996	0.232	0.311
Lunate Volume [%]	-0.088	0.579	-0.283	0.214	0.035	0.882
Triquetrum Volume [mm^3]	0.019	0.906	0.106	0.646	0.286	0.209
Triquetrum Volume [%]	0.072	0.652	0.084	0.718	0.010	0.967
Pisiform Volume [mm^3]	0.048	0.761	0.051	0.827	0.372	0.097
Pisiform Volume [%]	0.049	0.756	-0.118	0.611	0.151	0.513
Trapezium Volume [mm^3]	0.029	0.854	0.044	0.848	**0.490***	**0.024**
Trapezium Volume [%]	0.251	0.108	-0.011	0.962	**0.505***	**0.019**
Trapezoid Volume [mm^3]	0.016	0.922	0.181	0.431	0.203	0.376
Trapezoid Volume [%]	0.034	0.829	0.339	0.133	-0.142	0.538
Capitate Volume [mm^3]	-0.065	0.681	0.031	0.895	0.058	0.802
Capitate Volume [%]	**-0.317***	**0.041**	-0.158	0.494	**-0.454***	**0.039**
Hamate Volume [mm^3]	-0.011	0.946	0.101	0.664	0.283	0.213
Hamate Volume [%]	-0.072	0.651	0.055	0.812	-0.201	0.382

r: Pearson correlation coefficient.

DISCUSSION

The hand has a complex structure combines biomechanical and fine tactile senses (Patterson *et al*. 1995; Maw *et al*., 2016). Wrist bones are the most used bone group in daily life and the most common injuries and traumas in the hospital environment. There are studies on hand morphometry in the current literature. However, very few studies evaluate the volume measurements of the wrist bones. In this direction, we aimed to analyse the ratios of carpal bone volumes to each other and to total wrist bone volume by using a three-dimensional software tool in our study, according to sex/age variables. We think our study can pioneer volume measurements of wrist bones with the 3D Slicer software tool using CT images.

Crisco *et al*. (2005), in a study with 54 healthy participants (28 females, 26 males) aged 18-30 years, reported that the volume of all wrist bones was significantly smaller in females than in males. Similarly, in our study, the volume values of females were smaller than males. The capitate in both studies had the largest volume, and the pisiform bone had the smallest volume. Others were listed as hamate, scaphoid, trapezium, lunate, triquetrum, trapezoid, and pisiform bones, from largest to smallest. Crisco *et al*. (2005), showed that the volume values in both sexes were slightly higher than in our study in all bones except the triquetrum. We think that this may be due to the number of samples, differences in methodology or the size and thickness of the triquetrum, and the effect of the ulnocarpal ligamentous complex in joint biomechanics. The same study reported that carpal bone sizes are smaller in females than males, but carpal bones in females and males occupy a similar proportion of the total carpal bone volume. These findings are in entire agreement with our study. In our results, the differences between males' and females' volume (%) values were not statistically significant.

Didi *et al*. (2016), compared the right-left carpal bones from CT images in 52 healthy individuals (29 females, 23 males) aged 18-41 years and compared them according to sex. It has been reported that carpal bone volumes are significantly higher in males according to sex. It was reported that there was no statistically significant difference between right and left wrist bone volumes (p>0.05). The findings are consistent with our study. It was determined that the mean pisiform bone volume was almost twice as large as our results in males only. We think that this may be related to the height or ethnicity of the participants.

Patterson *et al*. (1995), measured the volume of 35 adult wrist bones (21 cadavers, 14 live individuals) aged 17-89 years by CT. It has been reported that there is no difference between the wrist bone volumes of cadaver specimens and live participants. When evaluated according to sex, it was stated that the volume values of males were larger. It was stated that there was no significant difference in right and left wrist bone volumes. According to the volume sizes, the capitate bone has the largest volume, and it has been reported that the order is hamate, scaphoid, trapezium, lunate, triquetrum, trapezoid and pisiform. Similarly, it is consistent with our study.

In another study, the volume of 55 dry hamate bones, whose images were obtained by the Micro-CT method and rendered in 3D with a software program, was calculated. It was observed to be lower than the hamate volumes in vivo (Ocak *et al*., 2022). This result may be related to the fact that the sex and age categories were unknown in the study, and the dry bone volume was lower than that of the living body.

Sulzmann *et al*. (2008), measured each wrist bone from different areas. It was stated that these bones showed sexual dimorphism in most of the measurements, while the pisiform bone showed the least sexual dimorphism. According to Mastrangelo *et al*. (2011), 136 individuals (78 males, 58 females) made measurements varying between 4 and 9 on each carpal bone in their study. According to these measurement results, it has been reported that all carpal bones show sexual dimorphism. Our study by Mastrangelo *et al*. (2011), is consistent, Sulzmann *et al*. (2008), are partially consistent with the study.

Carpal bones are also used in forensic medicine and anthropology to determine personal data such as sex, age, and ethnicity (Mastrangelo *et al*. 2011; Demirkıran *et al*., 2014).

We think that more comprehensive studies should be done according to age and sex parameters by using up-to-date software programs on carpal bones. We believe that knowing the morphology of this region well will be important in determining ethnicity, age and sex both in hand surgery and in the fields of Forensic Sciences and Anthropology.

CONCLUSION

Three-dimensional studies of volumetric analysis of carpal bones are very limited. Our study examined the morphometry of healthy individuals' carpal bone structures according to age and sex. The volume values of males were greater than that of females. However, it has been determined that males and females carpal bones occupy a similar proportion of the total carpal bone volume.

We think that the measurements of the carpal bones will be very useful in developing course materials in implant applications, reconstructive surgery and anatomy education in medicine. In addition, in this study, the volume fraction method was used to evaluate the dimensions of the carpal bones by sex and a different approach was tried to be presented. We think that this study will make an important contribution to the literature.

Ethical approval. Bolu Abant Izzet Baysal University Clinical Research Ethics Committee gave ethical approval (Date: 08.03.2022, Approval Decision No: 2022/32).

ACKNOWLEDGEMENTS. We thank Prof. Ferhan Elmali for the statistical analysis.

CELIK, N.G.; ERDEM, S. & KOCAK, M. Análisis volumétrico de los huesos del carpo por sexo con el programa de software 3D slicer. *Int. J. Morphol., 42(4)*:1005-1010, 2024.

RESUMEN: Nuestro objetivo fue determinar los volúmenes de los huesos del carpo y la relación entre estos volúmenes y el volumen total de estos huesos a partir de imágenes de TC obtenidas de individuos de diferentes edades y sexos utilizando 3D Slicer. En el estudio se incluyeron imágenes de TC del carpo de la mano derecha de los participantes en el estudio, con un grosor de corte de 0,625 mm, en 42 individuos sanos (21 mujeres, 21 hombres) de ambos sexos. Los cálculos de volumen se realizaron cargando las imágenes en 3D Slicer, un paquete de software de código abierto. El volumen medio del hueso capitado fue el mayor en ambos sexos (hombre 3479,9 ± 679,2; mujer 2207,1 ± 272,1 mm^3), mientras que el hueso pisiforme tuvo el volumen medio más pequeño (hombre 810,0 ± 141,2; mujer 566,6 ± 97,7 mm^3). De mayor a menor el volumen de los otros huesos fue: hamato, escafoides, trapecio, lunato, piramidal, trapezoide y pisiforme. Según este estudio, los volúmenes óseos del carpo eran mayores en hombres que en mujeres ($p<0,001$). La relación entre el volumen de cada hueso del carpo y el volumen total de los huesos del carpo se calculó según el sexo y se encontró que no hubo diferencias significativas ($p>0,05$). En este estudio se observó que el volumen de los huesos del carpo difería según el sexo. Sin embargo, se observó que los volúmenes óseos de ambos sexos ocuparon la misma cantidad del volumen óseo total. Esta información será de gran utilidad en la determinación del sexo, creación de material anatómico 3D, aplicaciones de implantes y cirugía reconstructiva.

PALABRAS CLAVE: Huesos del carpo; Tomografía computarizada; Sexo; Imágenes tridimensionales (3D); Volumen.

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