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Original Research Article

Upper Limb Osteometry of the Colombian Population: A Comparative Characterization of Scapula, Clavicle, Humerus, Radius and Ulna

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ABSTRACT

Background: In response to the lack of osteometry research in Colombia, this paper applies a pioneering methodology to the osteometry of the upper limbs and carries out a comparative evaluation of the results obtained with those from several studies conducted worldwide. Morphometric characterization is crucial to inform clinical interventions in areas ranging from orthopedic surgery to forensic anthropological research.

Methods: Fifteen samples of dry scapula, clavicle, humerus, radius and ulna were measured. Original parameters were used for this morphometry. Values of $p \leq 0.05$ were considered significant.

Results: Morphometry of the upper limb bones in the Colombian population is described. The mean weight of dry bones were: scapula 53.322 ± 16.717 grams; clavicle 21.545 ± 4.127 grams; humerus 104.913 ± 36.617 grams; radius 42.187 ± 9.785 grams; and ulna 46.159 ± 11.639 grams. Radius length was statistically significant: p=0.0259.

Conclusions: This is the first published paper reporting the osteometry and comparative analysis of the upper limb bones in Colombia. The morphometric data presented in this study contribute to the field of Colombian osteometrics and provide a reference for future interdisciplinary research.

KEY WORDS: Anatomy, Anthropometry, Arm Bones, Bones of Upper Extremity, Clavicle, Humerus, Osteology, Radius, Scapula, Ulna.

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INTRODUCTION

The upper limbs are vital for human biomechanics, enabling a wide range of specialized and sophisticated movements that mark our standing as a highly evolved species. Subject to constant mechanical stress, the upper limbs are susceptible to injury and are therefore of particular clinical interest [1].

Bone morphometry (osteometry) is a morphological approach for the precise measurements of bones, providing numerical dimensions to improve descriptions of specific bones and their markings. Applying morphometric techniques facilitates the study of biomechanics, providing supporting data for comparative anatomy and also data of clinical relevance in areas such as surgery or forensic medicine. Morphometric data can also be used to monitor changes in bone growth or development processes which may be impacted by contextual and environmental factors, as well as to estimate the genetic-quantitative parameters of individual bone shape and quantify changes in the evolutionary processes [2].

The aim of this paper was to consolidate data characterizing the upper limb morphometry of the Colombian population.

METHODS

Fifteen samples of each bone of the upper limb were measured. The first group of samples comprised seven right and eight left scapulae, and eight right and seven left clavicles. The second group contained seven right and eight left humeri, seven right and eight left radii, and nine right and six left ulnas. These samples were obtained from the Anatomy Laboratory of the Technological University of Pereira in Colombia.

Measurements were obtained using the following equipment: a measuring tape (Stanley Black & Decker, Inc., Seattle, USA) for perimeters; a digital caliper (Ubermann, Chile) for measuring breadth, length and spaces between markings; millimetric paper (Bico, Colombia) for measurements across areas flat enough to lie on the paper without affecting the result, such as the full length of bones; a digital scale (Goldtech, India) to obtain sample weights, and an iPhone 13 camera (Apple Inc., California, USA) to produce a photographic record. All data were collected on a Microsoft Excel® sheet (2205 edition). For shoulder girdle measurements, see Table 1 and Figures 1 and 2. For arm bone measurements, see Table 2 and Figures 3, 4 and 5.

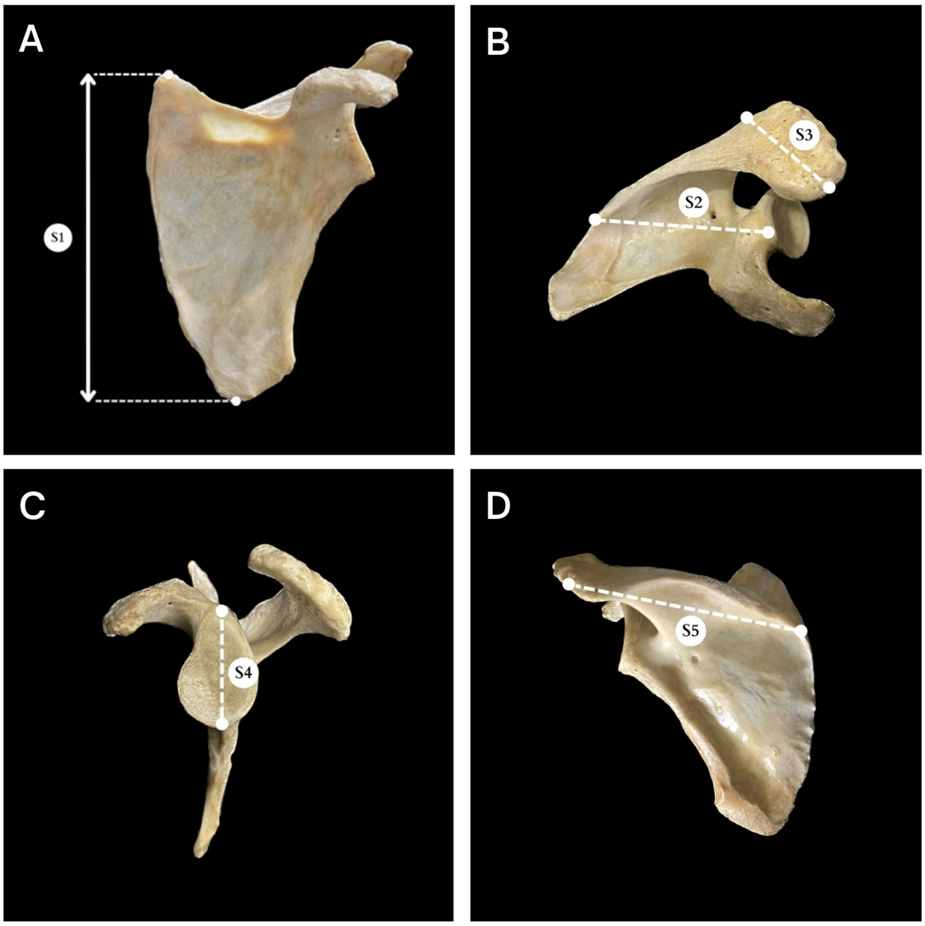

Fig. 1: Scapula morphometry for left bone. A: Ventral view. B: Superior view. C: Lateral view. D: Dorsal view. For abbreviations refer to Table 1.

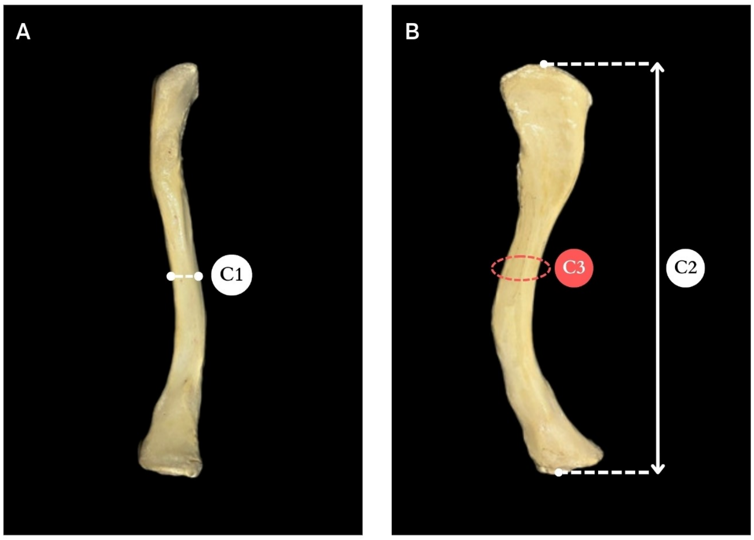

Fig. 2: Clavicle morphometry for left bone. A: Ventral view. B: Superior view. For abbreviations refer to Table 1.

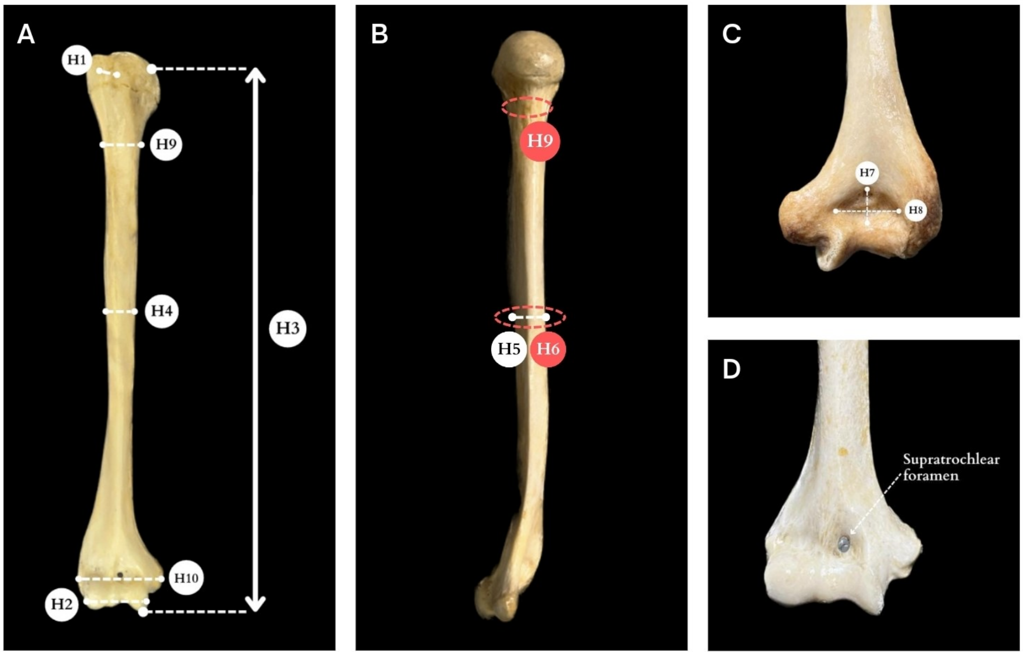

Fig. 3: Humerus morphometry for right bone. A: Ventral view. B: Lateral view. C: Dorsal view of the distal epiphysis. D: Ventral view of the distal epiphysis. For abbreviations refer to Table 2

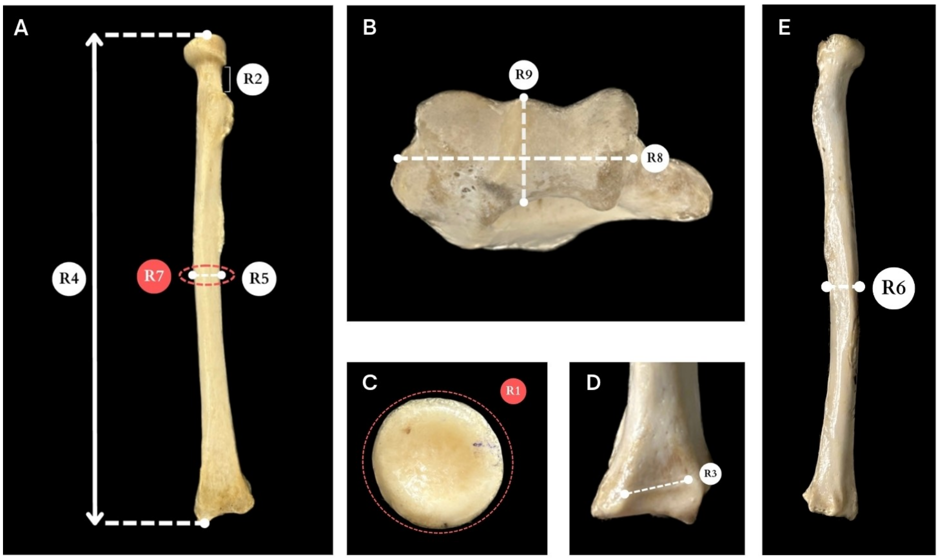

Fig. 4: Radius morphometry for right bone. A: Ventral view. B: Inferior view of the distal epiphysis. C: Superior view of the proximal epiphysis. D: Ventral view of the distal epiphysis. E: Dorsal view. For abbreviations refer to Table 2.

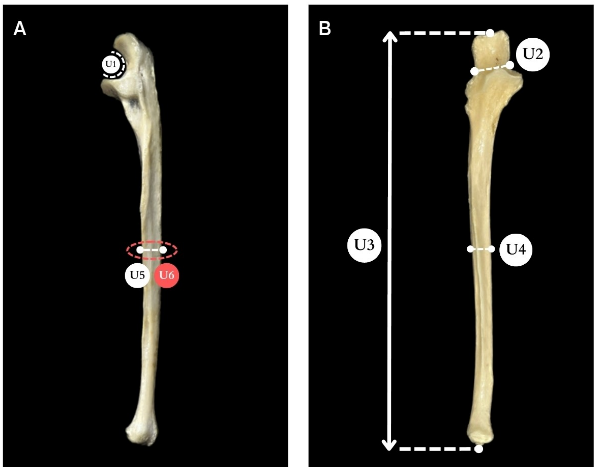

Fig. 5: Ulna morphometry for the right bone. A: Lateral view. B: Ventral view. For abbreviations refer to Table2.

RESULTS

The dry bone mean weights were: scapula 53.322 ± 16.717 grams; clavicle 21.545 ± 4.127 grams; humerus 104.913 ± 36.617 grams; radius 42.187 ± 9.785 grams, and ulna 46.159 ± 11.639 grams. The descriptive statistics for the measurements are shown in Table 3. R4 was statistically significant *p*=0.0259. Prevalence of the supratrochlear foramen for the humerus was 20%.

Table 1: Shoulder girdle bone morphometry and marking conventions.

Bone	Measurement	Description
Scapula	S1	Scapula length; from its cranial angle to its caudal angle
	S2	Scapula breadth; from its medial angle to the supraglenoid tubercle
	S3	Acromion length; from cranial angle of the scapula to the acromial angle
	S4	Glenoid cavity length; from the supraglenoid tubercle to the infraglenoid tubercle
	S5	Spine length; from the medial angle of the scapula to acromion width center point
Clavicle	C1	Clavicle breadth; from the cranial border to the caudal border
	C2	Clavicle length; from its acromial end to the sternal border. Measured in an superior view
	C3	Clavicle perimeter; measured at the middle of the shaft

Table 2: Upper extremity bone morphometry and marking conventions.

Bone	Measurement	Description
Humerus	H1	Humerus tubercle; distance from greater tubercle to lesser tubercle, ventral view
	H2	Humerus condyle; distance from medial condyle to lateral condyle, ventral view
	H3	Humerus length; from central point of the head to the most caudal projection of the inferior epiphysis, ventral view
	H4	Humerus shaft breadth; measured from the middle axis from medial to lateral
	H5	Humerus shaft breadth; measured from the middle axis, from dorsal to ventral
	H6	Humerus shaft perimeter; measured at the middle of the axis
	H7	Coronoid fossa length
	H8	Coronoid fossa breadth
	H9	Neck diameter
	H10	Humerus epicondyle; distance from medial epicondyle to lateral epicondyle, ventral view
Radius	R1	Radius head perimeter
	R2	Radius tuberosity; distance from the inferior border of the head to the superior border of the radial tuberosity
	R3	Ulnar notch breadth;, anterior to posterior, most distal points used
	R4	Radius length; from the head of the bone to the styloid process in ventral view
	R5	Radial shaft breadth; from its most medial to its most lateral points
	R6	Radial shaft breadth; from its most dorsal to its most ventral point
	R7	Radial shaft perimeter
	R8	Radial articular facet breadth; measured from medial to lateral
	R9	Radial articular facet length; measured from anterior to posterior
Ulna	U1	Trochlear notch length
	U2	Trochlear notch breadth; in its middle portion
	U3	Ulna length; from the most cranial part of the olecranon to the most caudal point of the styloid process
	U4	Ulnar shaft breadth; from medial to lateral
	U5	Ulnar shaft breadth; from dorsal to ventral
	U6	Ulnar shaft perimeter

Table 3: Morphometry results.

Measurement	*Mean ± SD in millimeters*	
	Right side	Left side
S2	106.21 ± 8.31	103.55 ± 05.56
S3	4.735 ± 0.533	4.443 ± 0.413
S4	3.598 ± 0.251	3.798 ± 0.263
S5	12.575 ± 0.98	12.571 ± 0.890
C1	11.824 ± 1.098	11.371 ± 1.745
C3	37.042 ± 0.707	36.111 ± 4.605
H1	6.38 ± 1.41	6.252 ± 0.87
H2	42.681 ± 4.491	40.581 ± 3.499
H4	20.993 ± 1.838	18.965 ± 3.09
H5	19.566 ± 2.814	19.559 ± 1.249
H6	66.333 ± 4.439	59.667 ± 7.972
H7	17.712 ± 1.76	17.045 ± 1.508
H8	23.708 ± 1.511	24.283 ± 2.31
H9	77.286 ± 8.835	70.946 ± 10.665
H10	61.38 ± 7.274	57.432 ± 5.045
R1	68.905 ± 7.507	65.908 ± 7.971
R2	12.653 ± 2.038	11.857 ± 2.182
R3	15.392 ± 1.643	13.783 V 2.014
R5	15.169 ± 1.622	15.094 ± 2.498
R6	12.273 ± 1.447	12.15 ± 0.86
R7	43.952 ± 3.498	42.958 ± 4.617
R8	27.575 ± 1.749	27.228 ± 1.215
R9	16.05 ± 1.484	16.166 ± 1.191
U1	34.926 ± 2.952	32.167 ± 1.835
U2	19.884 ± 1.468	19.405 ± 1.292
U4	12.986 ± 0.975	14.183 ± 1.553
U5	15.743 ± 1.367	14.566 ± 1.669
U6	46.889 ± 4.052	46.5 ± 4.665

Table 4: Mean bone lengths: Comparative study results.

	Mean ± SD in millimeters	
Bone length	Right side	Left side
Scapula		
Present study - S1	153.25 ± 1.522	143.24 ± 1.048
Elijah et al. 2021 [8]	148.9 ± 1.36	148.3 ± 1.12
Mendes et al. 2021 [6]	171.3 ± 22.64	172.6 ± 23.68
Gharehdaghi et al. 2018 [7]	151.3 ± 8.1	153.9 ± 7.9
Aigbogun et al. 2017 [4]	144.54 ± 11.84	143.24 ± 15.24
Akhtar et al. 2016 [5]	135.70 ± 14.32	134.29 ± 14.14
El- Din et al. 2015 [3]	151.05 ± 8.42	151.20 ± 9.47
Clavicle		
Present study - C2	153.792 ± 4.95	151.468 ± 9.347
Fontana et al. 2020 [14]	143.7 ± 10.7*	
Patted et al. 2020 [13]	142.5*	
Gharehdaghi et al. 2018 [7]	148.6 ± 6.6	150.9 ± 7.6
Sehrawat et al. 2016 [10]		
Male	148.52 ± 8.88	151.87 ± 8.98
Female	135.22 ± 8.27	138.22 ± 8.30
Lee et al. 2014 [11]		
Male	151.5±9.4*	
Female	138.2±10.5*	
Walters et al. 2010 [12]	151.6	148.2
Humerus		
Present study - H3	311.429 ± 24.385	297.292 ± 27.581
Gharehdaghi et al. 2018 [7]	321.7 ± 14.7	318.2 ± 17.8
Ogedengbe et al. 2017 [18]	320.81 ± 1.79	294.63 ± 1.55
Lee et al. 2014 [11]	302.7 ± 16.7	277.9 ± 15.1
Desai et al. 2012 [16]	292.3 ± 22.9	289.45 ± 21.8
Radius		
Present study - R4	263.19 ± 17.026	244.333 ± 11.902
Ngidi et al. 2023 [19]	249.8 ± 17.9*	
Curate et al. 2021 [21]		
Male	237.39 ± 0.764	213.37 + 0.716
Female	234.83 ± 0.765	210.62± 0.725
Suraj et al. 2019 [25]	243.5 ± 172.2	236.2 ± 168.9
Gharehdaghi et al. 2018 [7]	244.6 ± 10.8	244.2 ± 12.2
Lee et al. 2014 [11]	231.1 ± 14.6	207.5 ± 12.3
Ulna		
Present study - U3	259.556 ± 18.277	243.056 ± 7.884
Gharehdaghi et al. 2018 [7]	264.4 ± 10.8	262.1 ± 11.7
Prasad et al. 2016 [23]		
Male	275.2 ± 13.3	272.6 ± 13.5
Female	217.5 ± 9.2	216.8 ± 8.7
Lee et al. 2014 [11]	247.7 ± 13.4	225.9 ± 14.2

*Authors do not specify laterality for this value

DISCUSSION

Due to the absence of any published morphometric studies of the shoulder girdle and the long bones of the upper limbs in the Colombian population, this paper was written with the purpose of producing the first characterization of these bones as well as providing reference data for comparative anatomy and for health professionals in a range of clinical settings.

The intricate shape and dimensions of the scapula and its acromion are of particular importance in understanding the pathomechanics of rotator cuff injuries. Moreover, its morphology is an important tool in shoulder pathology diagnosis, such as total arthroplastyand recurrent dislocation [3].

Regarding its morphometry, scapula length (S1) in the Colombian population was similar to that reported in Nigerian data [4] and data from the right scapulae in the Indian population [5]. The remaining populations reported in the literature have longer scapula length measurements (see Table 4). Scapula breadth (S2) results are similar to those obtained in studies conducted in Brazil, Iran and Egypt, with 100.8±0.86 mm, 107.1±5.7 mm and 107.43±8.07 mm, respectively for right scapulae, and 103.5±0.90 mm, 107.2±10.4 mm and 107.01±9.00 mm respectively for left scapulae [3,6,7]. Colombian measurements were higher than the data reported in India which were 97.97±9.07 mm for the right scapulae and 97.02±0.30 mm for left scapulae [5]. Acromion length (S3) was shortest in Nigeria which reported 3.94±0.41 for the right scapulae and 3.88±0.41 for the left [8], in contrast to our findings in the Colombian population which were higher by almost a centimeter (see Table 3). Nonetheless, the proportion of right - left side variation remained similar, (1.015 in Nigeria and 1.06 in Colombia) with the right acromion found to be the longest in both populations. Measurement results for glenoid cavity length (S4) were similar to data from two Nigerian studies, Brazil, India and Egypt, with 33.8±3.0 mm and 37.71±4.24 mm, 36.85±0.36 mm, 36.22±3.58 mm and 38.88±2.63, respectively for right scapulae, and 34.9±3.5 mm and 36.22±3.58 mm, 36.32±0.34 mm, 35.52±3.12 mm and 39.01±2.49 mm respectively for the left [3-6,8]. Spine length (S5) values were similar to those reported for the Nigerian population, namely, which were 12.63±1.40 mm for the right spines and 12.91±1.09 for the left spines [8].

The clavicle is a key structure for upper body mobility, enabling the optimal execution of a number of essential upper extremity movements by ensuring sufficient distance is maintained from the thorax, as well as protecting the chest by dispersing any force transmitted from direct contact [9].

Its anatomic peculiarities have been examined in depth for forensic anthropological identifications and the design of fixative devices used to join clavicle fractures [10]. For the morphometry of the clavicle, it was found that the Colombian values for clavicle length (C2) were close to the highest in all the comparative literature reviewed, exceeding those of the Iranian, Korean and South African populations, and equal to those of the Indian samples analyzed by Patted et al [7,11-13]. They were only surpassed in the left clavicle by the male Indian sample from Sehrawat's study [10] (see Table 4). Bilateral results for clavicle breadth (C1) in our study were lower than the Indian male values reported by Sehrawat et al., but were higher than those of Indian females from the same study: while Sehrawat's female sample results were 10.17±1.32 mm for the right clavicles and 10.18±1.11 mm for the left, the male sample results reported were 12.30±1.53 mm and 12.00±1.25 mm for the right and left, respectively [10]. Average C1 values from the Colombian population were also lower in comparison to the values reported by Fontana et al., obtained from the measurement of clavicles from Japan, Austria, Germany, Belgium and the USA, with an average of 13.7±1.8 mm for the combined population [14] (see Table 3).

In comparisons of clavicle perimeter (C3), it is again noticed that the bilateral measurements corresponding to the Colombian population were lower than those from the male Indian sample obtained by Sehrawat et al. and the male Korean population, but higher than the female values reported in these same two studies. In contrast, the male Indian samples analyzed by Sehrawat et al. were reported as 38.52±3.28 mm for the right clavicles and 37.24±3.38 mm for the left, while the female results were 32.66±2.57 mm and 31.76±2.70 mm for the right and left clavicles, respectively [10]. In addition, the Colombian C3 average was 36.607±3.323 mm, compared to the Korean male average of 39.0±0.4 mm and the Korean female 34.0±0.4 mm (see Table 3).

The humerus is the longest and strongest bone of the upper extremity, a crucial component for human movement and survival [15]. This bone is subjected to great functional stress and fractures [16], factors that are influenced by the specific morphometric particularities of each population. Osteometric data are essential to achieving satisfactory outcomes both in bone repair and reconstructive orthopedic cases [17]. For this bone morphometry, humerus length (H3) was found to show similar patterns across the studies reviewed. H3 was slightly higher for right humeri in India and Iran [7,16]. similar to the humeri of the Colombian population examined in the present paper. Furthermore, Korean and South African data [11,18] reports the exact same mean difference in length of 8.9% between male and female humeri, with the male bones found to be longer (see Table 4). Humerus condyle (H2) in the Korean population was reported as 42.2±2.8 for males and 38.0±2.4 for females [11]. However, average measurements in our Colombian population for H2 as well as for the right and left humeri were within the data ranges obtained for Korea, so it's possible to conclude there are morphometric similarities between both populations. Humerus epicondyle (H10) in the Iranian population was 61.8±3.6 for right humeri and 61.5±3 for left humeri, showing a slight difference with the results obtained in Colombians in which the right-left humeri difference was higher [7]. For the South African population, H10 was reported as 61.36±0.50 for males and 54.40±0.40 for females. For the study conducted in Korea, H10 measurements were 59.3±4.3 for males and 54.5±3.3 for females. South African and Korean studies reported similar differences in male-female H10 values of approximately 10% higher for men in both populations [11,18] (see Table 3). The study on South African samples taking similar morphometric measurements reported the following data points: humeral shaft breadth (H4) was 20.89±0.25 for males and 17.96±0.19 for females; humeral shaft perimeter (H6) was 62.95±0.53 for males and 58.99±0.54 for females [18]. H2, H4 and H6 measurements were classified into right and left humeri in this present study on the Colombian population, making direct comparisons with the South African data more difficult. However, the average data from both studies were found to be similar.

Accurate morphometric knowledge of the radius is essential for orthopedic surgeons and for anatomical and biomechanical precision in the construction of radial prostheses [19]. An in-depth understanding of this bone is also needed for the treatment of subluxation of the annular ligament, the most common pediatric injury, and for other specific fractures such as Smith, Colles and Barton [20].

The present study results for the right radius length (R4) were found to be the highest reported among all the comparative literature reviewed. Left radii results, however, were similar to the South African and Iranian populations [7,19], but higher than those reported for the Portuguese, Korean and Indian populations [11,19,21] (see Table 4). Radius tuberosity (R2) results were similar to those of the Indian population reported as 13.2±2.2 mm for the right ulnas and 12.6±2.7 mm for the left [19]. Radius head perimeter (R1) results for the right ulnas were similar to those reported in the South African population with a mean of 70.8±5.2 mm, and radial shaft breadth (R5 and R6) with 14.8±1.7 mm and 11.8±1.4 mm respectively. However, radial articular facet breadth (R8) was lower than that reported in our Colombian study, with 32.4±2.9 mm [19] (see Table 3).

The radius and ulna form a ring structure in the forearm connected by ligaments and the interosseous membrane. Both bones can suffer from various fractures and fracture-dislocations and, like any other joint in the body, can be affected by osteoarthritis in the elbow joint [22]. Ulna length is often used to estimate body height [23]. As for its morphometry, the left ulna length (U3) in the results of the Colombian population are lower than those reported in the Iranian and Indian populations, but higher than those from the Korean and Indian female populations [7,11,23] (see Table 4).

No academic papers were found which included data for the remaining morphometric measurements shown in Table 3 and thus no comparisons could be made. No weight comparisons were possible between our data and those of other studies due to the absence of this information for the scapula, humerus, radius and ulna. The authors recognize that there was a limitation in the number of bones used in the sample for this study.

CONCLUSION

The present study successfully characterized the osteometry of fifteen samples of each of the following bones: scapula, clavicle, humerus, radius, and ulna, all of which were obtained from the Anatomy Laboratory of the

Technological University of Pereira in Colombia, through the application of morphometric parameters. It is the first published study presenting the osteometry of the upper extremities in a Colombian population together with a comparative analysis of similar osteometry results from studies conducted in other countries. The morphometric data obtained in this study can serve as a reference to support future research in the fields of orthopedic surgery, radiology, forensic science, anthropometry, biomechanics, and clinical and basic anatomy research.

Conflicts of Interests

The author(s) declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

Effective scientific and intellectual participation in the study: JVG, AFL, DBG. **Technical procedures:** JVG, AFL, DBG. **Data acquisition:** JVG, AFL, DBG. **Data interpretation:** JVG, AFL, DBG. **Preparation and draft of the manuscript:** JVG, AFL, DBG. **Critical review and final approval:** JVG, AFL, DBG. **Guiding professor:** DBG. **Statistical analysis:** DBG.

ETHICS STATEMENT

The authors state that every effort was made to follow all local and international guidelines and laws that pertain to the ethical use of human cadaveric donors in anatomical research [24].

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