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Estimation of the Maximum Length of the Humerus from Its Segments' Lengths

Estimación de la Longitud Máxima del Húmero a Partir de las Longitudes de sus Segmentos

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SUMMARY: Long limb bones and fragmentary portions, such as the humerus, are commonly used and examined in forensic and archaeological investigations. This study aimed to estimate the maximum length of the humerus from the measurements of its segments' lengths in our population. The right and left humeri of 100 dry bones from unknown sexes were included in the study. A total of 28 different segments were obtained from 8 different anatomical landmarks named H0, H1, H2, H3, H4, H5, H6, and H7. The length of each segment was compared with the maximum length of the humerus (MHL). An independent t-test, Pearson's correlation, and linear and multiple regression analyses were performed and statistical significance was assigned to p values <0.05. The differences in the measurements of the right and left humeri were not statistically significant (p > 0.05). All of the humerus segments indicated a high correlation when compared with the maximum humerus length (p < 0.05). The H2-3 segment showed a weak correlation with MHL r = 0.173 (p > 0.05). This study demonstrated that the linear and multiple regression equations can be used to estimate the humerus length from its segments' lengths.

KEY WORDS: Humerus length; Segment length; Regression equation.

INTRODUCTION

For many years, anatomists, anthropologists, and forensic experts have taken a keen interest in the relationship between stature and different parts of the body (Ozaslan *et al*., 2003). The estimation of height from an unknown body, body parts, and skeletal remains is crucial and can hardly be ignored in forensic cases (Ozaslan *et al*.; Danborno *et al*., 2008; Borkar, 2014). In the absence of other bones such as those of the skull or pelvis, for example (even if only a part of the long bones of the extremity are present), the total length of the long bone is primarily calculated with the help of anatomical knowledge of these long bones, and then appropriate regression formulas are applied to estimate their lengths (Nath & Badkur, 2002). Collectively, the femur and tibia are the most suitable bones for this assessment (Nath & Badkur; Radoinova *et al*., 2002). However, when these bones are unavailable, it is possible to estimate the statue by the morphometric analysis of the humerus (Kate & Majumdar, 1976). Especially after catastrophic events, such as earthquakes, floods, tsunamis, plane crashes, train accidents, and terrorist attacks, it is often necessary to identify the victims from their fragmented remains (Ozaslan *et al*.; Danborno *et al*.). Therefore, in forensic examinations and anthropometric studies, the humerus has been a moderately studied bone. It plays an essential role in stature estimation and sex identification of the individual in medico-legal cases and anthropological studies (Radoinova *et al*.; Hamzehtofigh *et al*., 2019). Also, classical osteometric techniques have been used to appreciate the value of estimating the humerus length from its fragments (Mall *et al*., 2001; Radoinova *et al*.; Kate & Majumdar). This information is also of interest to anatomists in the academic field.

Various regression formulas have been used worldwide to determine the humerus length by different anthropometric measurements. In different population groups, intact long bone samples of the upper and lower extremities have been used to derive regression equations for the estimation of the limb and stature length (Beddoe, 1888; Pearson, 1899). The estimation of the humerus length from its segments' lengths has been conducted by various researchers in different countries. Each researcher has had his or her unique formula for calculating the humerus length from its segments, as the relationship between long bones to stature differs when factoring in sex, race, and side of the body among the populations (Ozaslan *et al*.; Wright &

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Vásquez, 2003; Salles *et al*., 2009; Premchand & Manjappa, 2014).

Estimating the humerus length is also helpful in medicolegal work. It is believed that morphometric information of the humerus segments is vital for clinicians in the treatment of proximal and distal fragment fractures of the humerus (Jupiter & Mehne, 1992; Green & Izzi, 2003).

Formulating regression formulas suitable for our population is necessary. This study aimed to derive regression equations that would provide a high degree of prediction for the establishment of the total length of the humerus from its segments in our population.

MATERIAL AND METHOD

In this study, 100 dry humeri (35 right, 65 left) belonging to a modern population in the Department of Anatomy, Faculty of Medicine, Cukurova University, were included. Any deformities or damaged bones were excluded from the study. A total of 28 different segments were obtained from 8 different measurement points of the bones (Fig. 1). The measurement points were as follows: the most proximal point of the caput humeri (humerus head) (H0), the most proximal point of the tuberculum majus (greater tuberosity) (H1), the most protruding point of the tuberculum minus (lesser tuberosity) (H2), the most distal point of the circumference of the caput humeri (H3), the most distal point of the tuberositas deltoidea (deltoid tuberosity) (H4), the proximal margin (border) of the fossa olecrani (olecranon fossa) (H5), the distal margin (border) of the fossa olecrani (olecranon fossa) (H6), the most distal point of the trochlea humeri (H7).

Fig. 1. The measurement methods of different segments of the humerus (H0); most proximal point of the humeral head, (H1); most proximal point of the greater tuberosity, (H2); most proximal point of the lesser tuberosity, (H3); most distal point of the circumference of the caput humeri, (H4); most distal point of the tuberositas deltoidea, (H5); proximal margin of the fossa olecrani, (H6); distal margin of the fossa olecrani, (H7); most distal point of the trochlea humeri.

Table I. Descriptive statistics and bilateral differences in the right and left humerus bones.

Variable (mm)	Right (*n* = 35)			Left (*n* = 65)			t-value (bilateral difference)	
	Mean	SD	SEM	Mean	SD	SEM	T	P
MHL	307.48	22.65	3.83	309.75	19.39	2.40	-0.526	0.600
H01	8.51	2.06	0.34	8.27	2.36	0.29	0.512	0.610
H02	18.70	3.39	0.57	17.62	3.32	0.41	1.540	0.127
H03	37.63	4.03	0.68	37.70	2.98	0.37	-0.094	0.925
H04	164.54	14.36	2.42	164.83	12.67	1.57	-0.103	0.918
H05	271.14	20.11	3.40	273.27	17.93	2.22	-0.544	0.588
H06	294.31	21.44	3.62	296.90	18.65	2.31	-0.627	0.532
H12	10.07	2.72	0.46	9.28	2.70	0.33	1.389	0.168
H13	29.05	4.58	0.77	29.10	3.56	0.44	-0.059	0.953
H14	154.66	13.87	2.34	155.84	12.43	1.54	-0.436	0.664
H15	261.97	19.30	3.26	264.23	17.75	2.20	-0.590	0.557
H16	285.00	20.27	3.42	287.36	18.51	2.29	-0.586	0.559
H17	298.80	21.56	3.64	301.44	19.09	2.36	-0.631	0.529
H23	18.78	3.13	0.53	20.14	4.56	0.56	-1.563	0.121
H24	145.11	12.74	2.15	146.62	12.75	1.58	-0.568	0.571
H25	252.03	18.33	3.09	255.20	17.30	2.14	-0.854	0.395
H26	275.43	19.60	3.31	279.04	18.07	2.24	-0.927	0.356
H27	288.90	20.78	3.51	292.19	18.83	2.33	-0.804	0.423
H34	126.57	11.88	2.00	127.44	11.10	1.37	-0.365	0.716
H35	232.91	17.54	2.96	235.10	16.26	2.01	-0.624	0.534
H36	256.49	18.78	3.17	259.13	16.91	2.09	-0.717	0.475
H37	270.02	19.70	3.33	272.32	17.48	2.16	-0.601	0.549
H45	106.08	8.98	1.51	107.11	10.95	1.35	-0.477	0.634
H46	129.21	9.96	1.68	130.70	11.35	1.40	-0.655	0.514
H47	142.68	10.63	1.79	144.45	11.86	1.47	-0.734	0.465
H56	22.73	2.72	0.46	23.13	2.49	0.30	-0.738	0.462
H57	35.92	3.75	0.63	36.09	3.65	0.45	-0.218	0.828
H67	13.12	2.73	0.46	12.79	2.37	0.29	0.624	0.534

In addition to the humerus, we use a code in the form of a letter to refer to the segment lengths to represent the bone and the landmark numbers. For instance, "H0-1" represents the segment between landmarks H0 and H1 on the humerus. The equations we derived link the distances between these landmarks to the maximum length of each humerus, measured after standard definitions. To measure the total length of the humerus, we placed each bone on the osteometric board with the long axis of the diaphysis parallel to the length of the humerus. Then, all the segment lengths of the humerus were measured using a Vernier caliper that measured 0.01 (TTI Vernier caliper, 0–200 mm).

Statistical Analysis. An independent t-test was used to identify bilateral differences. Pearson's correlation analyses were performed to determine the relationship between the maximum length of the humerus and its segmental measurements. Then, the linear and the multiple regression equations were derived to estimate the maximum length of the humerus. The statistical analysis was performed using SPSS software, version 21.0 (SPSS, Inc., Chicago, IL, USA).

RESULTS

The following results were obtained. The mean values of the right and left humerus bones and bilateral differences are shown in Table I.

The mean length of the humerus on the right side was 30.48 ± 2.26 cm, while it was 30.97 ± 1.93 cm on the left side. No statistically significant differences were observed between the right and left sides in all measurements, including the maximum humerus length ($p > 0.05$). The correlation between the maximum humerus length and humerus segments

Table II. Correlation between maximum humerus length and humerus segments.

PARAMETERS		H56	H46	H45	H36	H35	H34	H26	H25	H24	H23	H16	H15	H14	H13	H12	H67	H06	H57	H05	H47	H04	H37	H03	H27	H02	H17	H01	MHL
MHL	r	0.395**	0.741**	0.682**	0.976**	0.964**	0.795**	0.974**	0.958**	0.793**	0.173	0.976**	0.974**	0.820**	0.419**	0.236*	0.332**	0.992**	0.531**	0.983**	0.805**	0.858**	0.988**	0.680**	0.987**	0.417**	0.994**	0.331**	1
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.085	0.000	0.000	0.000	0.000	0.018	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	
H01	r	0.361**	0.187	0.099	0.299**	0.254*	0.296**	0.230*	0.187	0.185	-0.299**	0.238*	0.177	0.198*	-0.361**	-0.121	0.074	0.327**	0.307**	0.289**	0.168	0.361**	0.311**	0.253*	0.252*	0.580**	0.232*	1	
	P	0.000	0.062	0.325	0.003	0.011	0.003	0.021	0.063	0.065	0.003	0.017	0.079	0.049	0.000	0.230	0.463	0.001	0.002	0.004	0.094	0.000	0.002	0.011	0.011	0.000	0.020		
H17	r	0.369**	0.742**	0.689**	0.972**	0.964**	0.787**	0.977**	0.965**	0.798**	0.208*	0.979**	0.984**	0.824**	0.473**	0.260**	0.334**	0.986**	0.516**	0.980**	0.810**	0.845**	0.983**	0.674**	0.989**	0.370**	1		
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.000	0.000	0.000	0.000	0.009	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
H02	r	0.284**	0.280**	0.216*	0.347**	0.317**	0.273**	0.231*	0.199*	0.110	-0.546**	0.372**	0.319**	0.325**	-0.015	0.733**	0.141	0.394**	0.326**	0.368**	0.266**	0.398**	0.369**	0.415**	0.270**	1			
	P	0.004	0.005	0.031	0.000	0.001	0.006	0.021	0.047	0.274	0.000	0.000	0.001	0.001	0.882	0.000	0.163	0.000	0.001	0.000	0.007	0.000	0.000	0.000	0.006				
H27	r	0.372**	0.740**	0.687**	0.973**	0.964**	0.790**	0.991**	0.979**	0.818**	0.277**	0.969**	0.976**	0.808**	0.445**	0.123	0.325**	0.982**	0.508**	0.977**	0.810**	0.837**	0.982**	0.651**	1				
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.222	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
H03	r	0.279**	0.378**	0.329**	0.553**	0.537**	0.490**	0.629**	0.609**	0.588**	0.457**	0.647**	0.648**	0.629**	0.743**	0.301**	0.287**	0.664**	0.420**	0.657**	0.439**	0.661**	0.574**	1					
	P	0.005	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.000	0.000	0.000	0.000	0.000	0.000						
H37	r	0.379**	0.755**	0.702**	0.990**	0.981**	0.804**	0.974**	0.961**	0.779**	0.150	0.965**	0.969**	0.795**	0.343**	0.194	0.336**	0.984**	0.511**	0.979**	0.821**	0.828**	1						
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.137	0.000	0.000	0.000	0.000	0.053	0.001	0.000	0.000	0.000	0.000	0.000							
H04	r	0.362**	0.331**	0.256*	0.815**	0.800**	0.936**	0.821**	0.803**	0.926**	0.167	0.835**	0.817**	0.962**	0.381**	0.191	0.321**	0.844**	0.487**	0.834**	0.392**	1							
	P	0.000	0.001	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.096	0.000	0.000	0.000	0.000	0.056	0.001	0.000	0.000	0.000	0.000								
H47	r	0.295**	0.943**	0.921**	0.815**	0.811**	0.358**	0.805**	0.797**	0.371**	0.120	0.787**	0.807**	0.364**	0.296**	0.185	0.234*	0.806**	0.399**	0.802**	1								
	P	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.236	0.000	0.000	0.000	0.003	0.066	0.019	0.000	0.000	0.000									
H05	r	0.285**	0.757**	0.729**	0.982**	0.987**	0.789**	0.980**	0.980**	0.784**	0.226*	0.974**	0.991**	0.808**	0.431**	0.208*	0.257**	0.991**	0.384**	1									
	P	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.000	0.000	0.000	0.000	0.038	0.010	0.000	0.000										
H57	r	0.727**	0.245*	0.075	0.433**	0.343**	0.438**	0.430**	0.340**	0.425**	0.043	0.434**	0.364**	0.414**	0.192	0.169	0.658**	0.465**	1										
	P	0.000	0.014	0.457	0.000	0.000	0.000	0.000	0.001	0.000	0.669	0.000	0.000	0.000	0.056	0.094	0.000	0.000											
H06	r	0.405**	0.767**	0.707**	0.988**	0.974**	0.789**	0.984**	0.968**	0.784**	0.196	0.982**	0.979**	0.808**	0.412**	0.212*	0.243*	1											
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.051	0.000	0.000	0.000	0.000	0.034	0.015												
H67	r	0.075	0.043	0.040	0.232*	0.232*	0.298**	0.228*	0.217*	0.271**	0.225*	0.238*	0.240*	0.332**	0.244*	0.109	1												
	P	0.459	0.673	0.691	0.020	0.020	0.003	0.023	0.030	0.006	0.024	0.017	0.016	0.001	0.014	0.280													
H12	r	0.076	0.176	0.165	0.178	0.174	0.103	0.094	0.088	-0.006	0.404**	0.254*	0.240*	0.224*	0.290**	1													
	P	0.452	0.079	0.101	0.077	0.084	0.309	0.353	0.383	0.950	0.000	0.011	0.016	0.025	0.003														
H13	r	0.037	0.241*	0.250*	0.332**	0.343**	0.276**	0.442**	0.449**	0.418**	0.656**	0.451**	0.481**	0.455**	1														
	P	0.713	0.016	0.012	0.001	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000															
H14	r	0.290**	0.325**	0.267**	0.786**	0.780**	0.883**	0.797**	0.787**	0.885**	0.223*	0.829**	0.807**	1															
	P	0.003	0.001	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.000	0.000																
H15	r	0.248*	0.755**	0.734**	0.971**	0.982**	0.774**	0.980**	0.986**	0.790**	0.237*	0.974**	1																
	P	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.000																	
H16	r	0.400**	0.782**	0.724**	0.976**	0.962**	0.741**	0.971**	0.956**	0.748**	0.191	1																	
	P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.056																		
H23	r	-0.028	0.060	0.090	0.159	0.170	0.168	0.302**	0.310**	0.341**	1																		
	P	0.780	0.556	0.372	0.114	0.090	0.095	0.002	0.002	0.001																			
H24	r	0.249*	0.247*	0.197*	0.762**	0.766**	0.954**	0.815**	0.813**	1																			
	P	0.012	0.013	0.050	0.000	0.000	0.000	0.000	0.000																				
H25	r	0.243*	0.745**	0.726**	0.967**	0.978**	0.777**	0.990**	1																				
	P	0.015	0.000	0.000	0.000	0.000	0.000	0.000																					
H26	r	0.364**	0.757**	0.707**	0.980**	0.974**	0.785**	1																					
	P	0.000	0.000	0.000	0.000	0.000	0.000																						
H34	r	0.275**	0.240*	0.187	0.787**	0.785**	1																						
	P	0.006	0.016	0.063	0.000	0.000																							
H35	r	0.253*	0.768**	0.749**	0.989**	1																							
	P	0.011	0.000	0.000	0.000																								
H36	r	0.390**	0.783**	0.730**	1																								
	P	0.000	0.000	0.000																									
H45	r	0.100	0.969**	1																									
	P	0.322	0.000																										
H46	r	0.335**	1																										
	P	0.001																											
H56	r	1																											
	P																												

**. Correlation is significant at the 0.01 level (2-tailed).*. Correlation is significant at the 0.05 level (2-tailed).

Table III. Linear regression equations and Pearson's correlation coefficients for the estimation of MHL (mm) from humerus segments.

Right			Left			Both		
Regression equations	±SEE	R^2	Regression equations	±SEE	R^2	Regression equations	±SEE	R^2
MHL = 253.575 + 6.33 × H01	18.78	0.333**	MHL = 295.612 + 1.709 × H01	19.11	0.044	MHL = 283.845 + 3.005 × H01	19.450	0.110*
MHL = 229.006 + 4.196 × H02	17.90	0.394**	MHL = 278.071 + 1.798 × H02	18.59	0.095*	MHL = 263.261 + 2.538 × H02	18.733	0.174**
MHL = 146.975 + 4.265 × H03	14.95	0.577**	MHL = 158.591 + 4.010 × H03	15.37	0.381**	MHL = 153.048 + 4.138 × H03	15.112	0.462**
MHL = 67.990 + 1.456 × H04	8.84	0.852**	MHL = 104.689 + 1.244 × H04	11.37	0.662**	MHL = 89.776 + 1.331 × H04	10.593	0.736**
MHL = 5.228 + 1.115 × H05	3.27	0.980**	MHL = 20.687 + 1.058 × H05	4.05	0.957**	MHL = 14.476 + 1.081 × H05	3.805	0.966**
MHL = _0.764 + 1.047 × H06	3.06	0.982**	MHL = 3.496 + 1.032 × H06	2.45	0.984**	MHL = 1.893 + 1.037 × H06	2.662	0.984**
MHL = 279.132 + 2.814 × H12	21.63	0.115*	MHL = 297.222 + 1.350 × H12	19.19	0.035	MHL = 292.021 + 1.772 × H12	20.034	0.056*
MHL = 237.127 + 2.421 × H13	20.05	0.240*	MHL = 252.187 + 1.978 × H13	18.20	0.132*	MHL = 245.352 + 2.187 × H13	18.719	0.176**
MHL = 83.825 + 1.446 × H14	10.68	0.784**	MHL = 121.356 + 1.209 × H14	12.35	0.601**	MHL = 106.193 + 1.305 × H14	11.785	0.672**
MHL = 4.065 + 1.158 × H15	3.72	0.974**	MHL = 30.778 + 1.056 × H15	5.00	0.934**	MHL = 20.498 + 1.095 × H15	4.648	0.949**
MHL = _8.342 + 1.108 × H16	2.97	0.983**	MHL = 18.774 + 1.013 × H16	5.01	0.934**	MHL = 8.243 + 1.049 × H16	4.469	0.953**
MHL = _5.403 + 1.047 ×H17	1.92	0.993**	MHL = 5.912 + 1.008 × H17	2.38	0.985	MHL = 1.497 + 1.023 × H17	2.257	0.988**
MHL = 269.364 + 2.029 × H23	22.07	0.076	MHL = 298.982 + 0.535 × H23	19.39	0.016	MHL = 292.155 + 0.854 × H23	20.302	0.030
MHL = 79.155 + 1.573 × H24	10.69	0.784**	MHL = 144.951 + 1.124 × H24	13.16	0.546**	MHL = 121.874 + 1.281 × H24	12.549	0.629**
MHL = 4.262 + 1.203 × H25	5.24	0.948**	MHL = 38.178 + 1.064 × H25	6.11	0.902**	MHL = 26.125 + 1.113 × H25	5.921	0.918**
MHL = _4.106 + 1.131 × H26	4,68	0.959**	MHL = 18.587 + 1.043 × H26	4,55	0.946**	MHL = 10.812 + 1.073 × H26	4.686	0.949**
MHL = _4.818 + 1.081 × H27	2.95	0.983**	MHL = 13.331 + 1.014 × H27	3.36	0.970**	MHL = 6.769 + 1.038 × H27	3.304	0.974**
MHL = 96.939 + 1.663 × H34	11.24	0.761**	MHL = 144.286 + 1.298 _ H17	13.06	0.553**	MHL = 126.137 + 1.438 × H34	12.517	0.632**
MHL = 17.468 + 1.245 × H35	6.09	0.930**	MHL = 39.382 + 1.150 × H35	5.17	0.930**	MHL = 31.086 + 1.186 × H35	5.505	0.929**
MHL = 5.613 + 1.177 × H36	5.06	0.952**	MHL = 19.543 + 1.120 × H36	4.17	0.954**	MHL = 14.343 + 1.141 × H36	4.498	0.953**
MHL = 0.564 + 1.137 × H37	3.44	0.978**	MHL = 11.427 + 1.095 × H37	3.03	0.976**	MHL = 7.140 + 1.112 × H37	3.177	0.976**
MHL = 109.732 + 1.864 × H45	15.48	0.547**	MHL = 183.495 + 1.179 × H45	14.58	0.443**	MHL = 163.637 + 1.361 × H45	15.077	0.465**
MHL = 72.205 + 1.821 × H46	13.78	0.641**	MHL = 149.259 + 1.228 × H46	13.59	0.516**	MHL = 126.619 + 1.401 × H46	13.831	0.549**
MHL = 46.372 + 1.830 × H47	11.77	0.738**	MHL = 124.627 + 1.282 × H47	12.13	0.615**	MHL = 101.144 + 1.445 × H47	12.232	0.648**
MHL = 214.878 + 4.074 × H56	20.04	0.240*	MHL = 251.037 + 2.538 × H56	18.47	0.106*	MHL = 236.551 + 3.149 × H56	18.940	0.156**
MHL = 162.861 + 4.026 × H57	17.12	0.445**	MHL = 224.546 + 2.361 × H57	17.50	0.198**	MHL = 202.155 + 2.964 × H57	17.459	0.282**
MHL = 261.264 + 3.523 × H67	20.81	0.181*	MHL = 281.219 + 2.230 × H67	18.80	0.075*	MHL = 273.773 + 2.726 × H67	19.442	0.110*

**. Correlation is significant at the 0.01 level (two-tailed). *. Correlation is significant at the 0.05 level (two-tailed).

was examined (Table II). The humerus segments showed significant positive correlations with the total length of the humerus ($p < 0.05$). However, the H2-3 segment was statistically insignificant ($p > 0.05$). Linear regression equations were used to estimate the maximum humerus length from the segments (Table III). In the regression equations, the standard estimation error ranged between 2.25 and 20.302 mm. The lowest standard estimation error was identified in the H17 segment (SEE = 2.257). Multiple regression equations obtained for the estimate of MHL from humerus segments are shown in Table IV.

DISCUSSION

Knowing the length of long bones is a tool for estimating an individual's height. This knowledge plays an important role in the identification of missing persons in forensic research (Ozaslan *et al.*; Borkar). The humerus is the longest, largest, and strongest bone of the upper extremity (Williams, 1989). In the absence of other suitable long bones, such as the femur and tibia, stature can be estimated by using the humerus. Therefore, it is essential to define the humerus length from its segmental measurements (Udhaya *et al.*, 2011). The importance of the total humerus length in determining the specific characteristics of a population has been reported in many studies. Regression analyses are used to estimate the relationship between variables, such as the maximum

Table IV. Multiple (stepwise) regression equations for the estimation of MHL (mm) from humerus segments.

egression equations	±SEE	R	R^2	P-value
IHL = 32.096 + (1.251 _ H34) + (1.103 H45)	5.629	0.962	0.925	0.000
IHL = 13.988 + (1.173 _ H34) + (1.087 _ H45) + (1.294 _ H56)	4.638	0.975	0.949	0.000
IHL = 12.876 + (1.049 _ H24) + (1.097 _H46)	4.805	0.973	0.946	0.000
IHL = 1.745 + (1.231 _ H03) + (1.010 _ H36)	2.872	0.990	0.981	0.000
IHL = 6.302 + (1.211 _ H02) + (1.035 _ H24) + (0.996 _ H46)	2.742	0.991	0.983	0.000
IHL = 2.875 + (0.473 _ H13) + (1.077 _ H37)	2.664	0.992	0.983	0.000
IHL = 0.006 + (1.118 _ H03) + (1 _ H36) + (0.662 _ H67)	2.401	0.993	0.987	0.000

length of long bones, measurements of bone fragments, length of individuals, and length of long bones. Each population has been identified with specific regression equations (Udhaya *et al*.; Somesh *et al*., 2011).

The humerus is the longest and largest bone of the upper limb. Estimation of stature by applying the regression formula can also be done using humeral length in the absence of other more appropriate long bones, such as the femur or tibia. Accordingly, the total length of the humerus is derived from its segments by applying regression formulas among different population groups (Wright & Vásquez; Premchand & Manjappa; Salles *et al*.; Udhaya *et al*.; Somesh *et al*.).

In this study, we used a regression equation for each humerus segment in our population to estimate the total length of the humerus. The total humerus length was found to be 30.89 ± 2.0 cm. This result is similar to Udhaya *et al*. study in South India, with an average humeral length of 30.28 ± 2.44 cm. In this study, we also obtained the mean total length of the humerus and its segments for the right and left sides and compared the data with the results of other Indian studies (Premchand & Manjappa; Udhaya *et al*.; Somesh *et al*.; Mohanty *et al*., 2012; Prasad *et al*., 2017; Samoon *et al*., 2019). Our results show that the average humerus length of the right side is 30.48 ± 2.26 cm and 30.97 ± 1.93 cm on the left side. No statistically significant differences between the right and left sides of the humerus length were noticed ($p < 0.005$) (Table I). In India, Prasad *et al*. and Samoon *et al*. have reported major differences in the humerus lengths between the right and left sides and have calculated different equations for both sides.

Somesh *et al*. examined 100 dry humeri (49 right and 51 left) in five different segments and used regression equations for the estimation of the humerus length from its segments. They reported that the mean humeral length value was 309.6 + 20.6 on the right side and 299.6 + 22.5 mm on the left side. Their results are comparable with our findings. They also reported positive results in the estimate of the humeral length with the right-side segments—distance between the most proximal point of the head of the humerus and the surgical neck of the humerus (HB) (SEE = 2.67) and distance between the most proximal edge of olecranon fossa and most proximal point of trochlea of humerus (HE) (SEE = 2.02) (Somesh *et al*.). If longer segments of the humerus are available, a single regression equation can be used for the estimation of the total length. However, this is not a very accurate tool for ancestry identification. Longer segments help in the estimation of the total length and stature of an individual with greater accuracy (Singhal & Rao, 2011).

It has also been reported that smaller segments are more specific, although they are less accurate and more unique to South Indian and North Indian population groups (Singhal & Rao). In this study, except for H23, which is a small segment length (r = 0.173), all the measurements exhibit statistically significant correlation coefficients with the total humerus length ($p < 0.05$). The greatest correlation coefficients between stature and humerus segment lengths were observed in the H17 (r = 0.994), H2-6 (r = 0.9749), H2-5 (r = 0.958), H3-6 (r = 0.976), H3-5 (r = 0.964), and H2-7 (r = 0.987) segments (Table II). On further analysis, we formulated a linear regression equation for each segment to estimate the length of the humerus, which yielded good results (Table III). We observed that the lowest SEE = 2.25 for the H17 segment, and the results were comparable with the other studies (Wright & Vásquez; Premchand & Manjappa; Salles *et al*.; Udhaya *et al*.; Mohanty *et al*.; Singhal & Rao). Likewise, in their study, Wright & Vásquez studied 100 Maya skeletons from forensic examinations using 27 different segmental measurements of the humerus. They drew on regression equations for bone length estimation from segmental measurements. In the relationship between the segments and the humerus length, they observed the greatest correlation coefficient in the H17 segment. It was also seen that the standard estimated error ranged between 2.86 and 17.48 mm in the linear regression equations (Wright & Vásquez).

It has been stated that regression analysis is an appropriate method for defining the relationship between the length of long bones and the living height of individuals; it has also been noted that it is appropriate for examining the relationship between the length of measurements of long bone fragments and their maximum length (Ocakoglu & Ercan, 2013). As regression deviations tend to be population-specific, researchers have recommended that regression equations obtained in a certain population group should not be applied to other groups (Krishan, 2007).

The morphometric analysis of humerus segments suggests some differences in different population groups. The humerus bones used for this study were of unknown age and sex, and there was no available information on the height and nutritional status of individuals whose bones were used. Therefore, it was not possible to correlate the measurements of the segments of the humerus with the height of the individuals. Thus, a more detailed analysis is recommended to attain these data.

In conclusion, this study provided useful and detailed data on the total length and different segments of the humerus in our population. These findings are crucial not only for anatomists, forensic experts, and archaeologists but also for orthopedic surgeons who undertake reconstructive surgeries for proximal and distal humeral fractures.

MUTLUAY, S. D.; ACIKGOZ, A. K. & BOZKIR, M. G. Estimación de la longitud máxima del húmero a partir de las longitudes de sus segmentos. *Int. J. Morphol., 38(5)*:1350-1355, 2020.

RESUMEN: Los huesos largos de los miembros y las porciones fragmentarias, como el húmero, se usan y examinan comúnmente en investigaciones forenses y arqueológicas. Este estudio tuvo como objetivo estimar la longitud máxima del húmero a partir de las mediciones de las longitudes de sus segmentos. Fueron evaluados 100 húmeros secos, derechos e izquierdos, pertenecientes a individuos adultos, de sexo desconocido. Se obtuvieron 28 segmentos distintos de 8 puntos de referencia anatómicos diferentes, denominados H0, H1, H2, H3, H4, H5, H6 y H7. La longitud de cada segmento se comparó con la longitud máxima del húmero (MHL). Se realizó una prueba t independiente, la correlación de Pearson y análisis de regresión lineal y múltiple y se asignó significación estadística a valores de p <0,05. Las diferencias en las medidas del húmero derecho e izquierdo no fueron estadísticamente significativas (p> 0,05). Todos los segmentos del húmero indicaron una alta correlación en comparación con la longitud máxima del húmero (p <0,05). El segmento H2-3 mostró una correlación débil con MHL r = 0,173 (p> 0,05).Este estudio demostró que las ecuaciones de regresión lineal y múltiple se pueden usar para estimar la longitud del húmero a partir de las longitudes de sus segmentos.

PALABRAS CLAVE: Longitud del húmero; Longitud del segmento; Ecuación de regresión.

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