EC CLINICAL AND EXPERIMENTAL ANATOMY
Research Article

Height Determines Upper Extremity Long Bone Length, Not Sex

Mark Orland*, Michael Patetta, Nitin Sukumar and Mark Gonzalez

Department of Orthopaedics, University of Illinois at Chicago College of Medicine, Chicago, IL, USA

***Corresponding Author**: Mark Orland, Department of Orthopaedics, University of Illinois at Chicago College of Medicine, Chicago, IL, USA.

Received: December 23, 2019; **Published:** January 11, 2020

DOI: 10.31080/eccmc.2020.03.height-determines-upper-extremity-long-bone-length-not-sex

Abstract

Background: Long bone length is considered a mechanism of differentiation between female and male skeletal remains. The aim of this study was to examine whether reported sex long bone differences were the result of an average height difference between the sexes or whether there was a length difference independent of height between sexes.

Methods: The distal and proximal ends of the humerus, radius, and ulna of thirteen cadavers were identified and the length of each of the long bones were measured. A nonparametric signed-rank test was performed to test differences between right and left extremities. Subsequently, a mixed error-component model was used on both arms of all of the cadavers (n = 26) to examine how left or right sidedness, sex, and height related to upper extremity long bone length.

Results: When comparing the left and right side of the cadavers, there was no significant difference in the length of the humerus, radius or ulna ($p > .05$). Additionally, comparing between females and males, there was no significant difference in the upper extremity long bones. However, there was a significant increase in the length of the radius and the ulna with an increase in the height of the cadaver ($p < .01$).

Conclusion: There is no significant difference in upper extremity long bone length when comparing between males and females. Therefore, the sex of incomplete anatomical remains cannot be determined solely based on forearm bone length; the height of the individual to which the remains belong can be estimated.

Keywords: *Forensics Anthropology; Skeletal Identification; Long Bone Variation; Sex Upper Extremity Variation; Medicine; Anatomic Variation; Biomechanics*

Introduction

Sex is often considered a differentiating factor used to determine the sex of the skeletal remains. Previous studies have examined long bone length and used it to correctly differentiate the sex of the remains [1]. However, there are currently no studies that have stratified for height when comparing long bone lengths; studies that have examined volume dimensions of long bones when matching sex, have found no significant difference [1]. The primary goal of this study was to examine whether there was a significant difference in long bone length of the humerus, ulna, and radius of males and females when stratifying for height.

Upper extremity disorders (UEDs) vary in definition across the literature typically classified as a combination of tendinitis, carpal tunnel syndrome, shoulder conditions, neck pain, and ganglion cysts [2,3]. While there is no universal definition for an UED, it is still important to understand factors that may lead to their etiology. Studies have estimated that more than 1 in 5 people in the United States will develop a UED during their lifetime, usually as a result of their profession [2,3].

Certain pathologic states, umbrellaed under the term UED, can be attributed to external loads relating to force, motion, vibration, and temperature, along with force magnitude, degree of repetition, and duration of each stress factor. The biomechanics of these states play an important role in understanding the underlying pathology that develops [4-6]. In this study, we used cadaveric measurements of the humerus, ulna, and radius relative to height, sex, and the left and right sides, to demonstrate possible biomechanical susceptibility to UEDs is independent of sex.

Materials and Methods

Defining bone length

To measure the length of the humerus, radius and ulna *in vivo*, bone length was defined using external structures. Specifically, the length of the humerus was defined as the distance from the inferolateral acromion (the head of the humerus) to the distal lateral epicondyle (the capitulum at distal end of the humerus). The radius was measured from the distal edge of the lateral epicondyle (proximal end of the radius) to the distal edge of the radial styloid process (distal end of the radius). The ulna was measured from the tip of the olecranon (proximal end of the ulna) to the distal ulnar styloid process (distal end of the ulna) [4-6].

Data collection

Thirteen (n = 13) cadavers were assessed for different anatomic variation. All measurements were taken with the cadaver in a supine anatomical position.

The cadaver's sex was determined via examination of the genitalia. The cadaver's height was measured from the inferior calcaneus to the top of the calvarium using a tape measure. On both arms, the acromion, lateral epicondyle, olecranon, ulnar and radial styloid process were identified and marked prior to taking any measurements. Any necessary dissection for identification of the anatomical landmarks' edges was performed.

The following distances were measured with a 150 mm Mitutoyo 500-171-30 Digimatic caliper (sensitivity of .01 mm): distance from the distal radial styloid to the tip of the olecranon, distance from the distal radial styloid to the distal lateral epicondyle, distance from the distal ulnar styloid to the distal tip of the distal olecranon, and distance from the inferolateral edge of the acromion to the proximal, lateral epicondyle. These measurements were repeated on both arms of each cadaver.

As some measurements were larger than the length of the caliper (150 mm), the caliper was used multiple times. This was done by compressing and indenting the tissue with the end of the caliper leaving a mark. Then, the caliper was used to take the measurement from the indent to the point of interest. Figure 1a and 1b show the initial caliper measurement (left) and the subsequent one (right) measuring the distal part of the radial styloid to the distal part of the lateral epicondyle.

Data analysis

Continuous variables were summarized with medians and quartiles, while sex was presented as a frequency and percent. Given the small sample size, a non-parametric signed rank test was performed to detect differences between the right and left extremities within the subjects.

Extremity measurements were then analyzed together (n = 26). Separately modeled outcomes included measurements from the acromion to the lateral epicondyle, the tip of the olecranon to the ulnar styloid process, and the lateral epicondyle to the radial styloid process. As right and left measurements within each cadaver were correlated, mixed error-component models with a repeated measures design and an unstructured covariance matrix were used [6-8]. Each model used height, side of measurement (right or left) and sex as predictors. All tests were two-sided and p-values < .05 were considered statistically significant. All analyses were conducted using SAS 9.4 [9,10].

Results

Within the sample of 13 cadavers, there were 4 females and 9 males. The median height was 1.73 meters (m) with a first quartile (Q1) of 1.69 meters and third quartile (Q3) of 1.78 meters. The average distance from inferolateral acromion to proximal lateral epicondyle

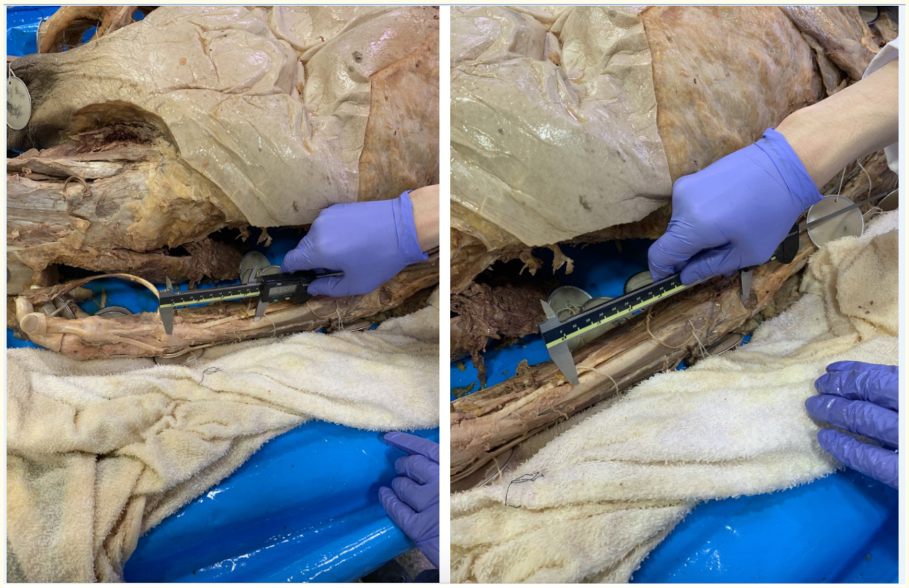

Figure 1a and 1b: *Measuring the radial styloid to the distal lateral epicondyle by indenting the muscle.*

was 345.0 mm (Q1, Q3: 310.0, 365.0) in the right arm and 345.0 mm (Q1, Q3: 330.0, 350.0) in the left arm. The tip of the olecranon to the distal ulnar styloid process distal portion was 265.0 mm (Q1, Q3: 255.0, 275.0) in the right arm and 260.0 mm (Q1, Q3: 250.0, 270.0) in the left arm. The distance from the distal lateral epicondyle to the radial styloid process was 260.0 mm (Q1, Q3: 250.0, 275.0) in the right forearm and 255.0 mm (Q1, Q3:245.0, 270.0) in the left forearm (Table 1).

Characteristic	Measurements
Gender, n (%)	
Female	4 (30.8%)
Male	9 (69.2%)
Measurements: Median (QI, Q3)	
Height (m)	1.73 (1.69, 1.78)
Acromion to Lateral Epicondyle (cm)	
Right	345.0 (310.0, 365.0)
Left	345.0 (330.0, 350.0)
Tip of Olecranon to Ulnar Styloid Process (cm)	
Right	265.0 (255.0, 270.0)
Left	260.0 (250.0, 270.0)
Lateral Epicondyle to Radial Styloid Process (cm)	
Right	260.0 (250.0, 270.0)
Left	255.0 (245.0, 275.0)

Table 1: *Measurements and corresponding quartiles of upper extremity.*

The signed-rank test showed no significant difference between the right and left extremity measurements: acromion to lateral epicondyle ($p = .93$), tip of the olecranon to ulnar styloid ($p = .84$) and lateral epicondyle to radial styloid ($p = .26$, Table 2).

Characteristic	Median (Q1, Q3)	P-value
Acromion to Lateral Epicondyle (cm)Right - Left Difference	0.0 (-15.0, 10.0)	0.93
Tip of Olecranon to Ulnar Styloid Process (an)Right - Left Difference	0.0 (-5.0. 5.0)	0.84
Lateral Epicondyle to Radial Styloid Process (cm)Right - Left Difference	5.0 (0.0. 10.0)	0.26

Table 2: *Signed-rank test of measurements in right and left arms.*

The repeated measures mixed effects model was run separately to examine height and its relationship with the distance from the acromion to lateral epicondyle, the tip of the olecranon to the ulnar styloid process, and the lateral epicondyle to the radial styloid process. When adjusting for the side of measurement (right or left) and sex, there was no significant difference in the distance between the acromion and the lateral epicondyle with increasing height (Q1, Q3: -0.65, 9.92; $p > 0.05$).

The distance from the tip of the olecranon to ulnar styloid process increased significantly by 3.37 cm (Q1, Q3: 1.76, 4.99; $p < 0.001$) with each 2.54 cm (1 inch) height increase. Additionally, the distance from the lateral epicondyle to the radial styloid process increased significantly by 4.21 cm (Q1, Q3: 1.44, 6.97, $p < 0.01$) with each 2.54 cm height increase of the cadaver. Sex of the cadaver and the side of the measurement were not significantly associated with any of the three outcomes ($p > .05$, Table 3).

Characteristic	Estimate (95% CI)	P-value
Acromion to Lateral Epicondyle (cm)		
Intercept	27.73 (-339.38, 394.84)	0.87
Height (m)	11.8 (-1.65, 25.2)	0.079
S ide (ref = left)	1.87 (-17.92, 21.65)	0.84
Gender (ref = male)	15.18 (-28.16, 58.52)	0.45
Tip of Olecranon to Ulnar Styloid Process (cm)		
Intercept	35.26 (-76.86, 147.38)	0.5
Height (cm)	8.56 (4.47, 12.7)	0.0009
Side (ref = left)	1.15 (-7.42, 9.72)	0.77
Gender (ref = male)	-2.50 (-15.73, 10.74)	0.68
Lateral Epicondyle to Radial Styloid Process (cm)		
Intercept	-32.51 (-224.82, 159.80)	0.71
Height (cm)	10.7 (3.66, 17.7)	0.007
Side (ref = left)	4.23 (-3.32, 11.78)	0.24
Gender (ref = male)	12.94 (-9.76, 35.64)	0.23

Table 3: *Mixed and unstructured covariance model for upper extremity measurements based on height, side, and sex.*

Discussion

Based on our results, the length of the humerus, radius, and ulna are not significantly different between men and women. A previous forensics study by Mall (2001) used the lengths of the radius and humerus to determine the sex of skeletal remains. While the study's analysis showed correct sex classification when examining humeral and radial length, our results show this conclusion was most likely confounded due to the average height difference between men and women, rather than inherently on their sex [11]. The average height difference in the United States between adult men and women is 13.7 cm, which, based on our analysis, would result in a clear differentiation in the upper extremity long bone length between two subjects, regardless of sex [12,13]. Studies have not previously stratified height when comparing sex long bone length differences in long bones [14]. A study by Gilsanz (1997) matched height in both sexes when comparing volumetric dimensions of the femur and found no significant difference. However, they did not examine the length of the femur to see if sex played a role in long bone length [1].

Our analysis also showed no difference in upper extremity bone length when comparing between the left and right side. However, the majority of the literature reports a right-left difference in the length of bones of the upper extremity [15]. This discrepancy may be due to the limited size diversity amongst the cadavers used in our study and can be rectified in the future by using a larger sample variety.

There was a significant increase in the length of the ulna and the radius with increasing height.

While we cannot claim an exact associated increase due to a limited sample size, our results demonstrated that for an increase in height by 2.54 cm, the length of the ulna and the radius increased by 4.21 cm and 3.37 cm respectively. Future studies utilizing a larger, more physically diverse set of cadavers could determine the precise relationship between height and the length of both the radius and the ulna.

Further Implications

Increased radius length causes muscles and tendons of the forearm to increase in length [2]. The extensor carpi radialis brevis (ECRB) is often implicated in lateral epicondylitis from tendinopathy from repetitive use [16]. The ECRB originates on the lateral epicondyle and inserts on the base of metacarpals II and III. It can be reasonably approximated as the length of the radius which inserts directly on the carpal bones [17,18]. An increase in length of the ECRB increases the moment arm on the lateral epicondyle during extension. The moment arm is determined by the line of muscle–tendon unit force and the center of joint rotation and is based on the equation of torque: $\tau = r \times F$ where τ is torque on the lateral epicondyle, r is the length of the lever arm (the ECRB) and F is the force applied at the end of the ECRB [19]. The logic for increased torque on the medial epicondyle is the same as for the lateral epicondyle.

Epicondylitis is normally not attributed to acute joint reaction forces or trauma; the literature shows that individuals who are repetitively engaged in extension-based activities (tennis players, manual laborers) exhibit higher degrees of lateral epicondylitis [20]. An increase in the torque on the elbow joint with each extension adds more cumulative stress and theoretical wear to the lateral epicondyle. Thus, a taller population may have a higher sensitivity to developing lateral epicondylitis, which has not previously been examined in studies.

The causes of medial and lateral epicondylitis are well-documented as a combination of kinetic, vibration, temperature, and kinematic factors. However, studies attribute the majority of cases to kinematic mechanical factors [11]. Our results show that an increase in height of an individual increases the length of their radius and ulna and our calculations above show this increases the kinetic stress on their medial and lateral epicondyles possibly leading to higher susceptibility to epicondylitis [21,22]. While a logical conclusion, previous studies have found no sex difference in the incidence of epicondylitis. Given the studies did not stratify for height and that males were taller in the populations analyzed, we would have expected to see an increased risk and thus incidence of epicondylitis in males [20]. This discrepancy may be due to a larger insertion of extensor and flexors tendons at their origin and more efficient distribution of the increased stresses generated. However, until more studies explore the relationship of height and epicondylitis, careful observation of elbow pain may be necessary in taller individuals.

Future Studies

More research is needed to examine how muscle length variation in the forearm impacts wrist flexion and extension. This may influence the degree of epicondylitis as well as the stability of the distal radioulnar joint (DRUJ) [9,23,24]. Given that many radioulnar joint injuries feature acceptable levels of shortening of the radial and ulnar bones and corresponding muscle lengths, it is a necessary topic of study [9]. The mechanical implications of these procedures on wrist and elbow joint loads could be analyzed and prophylactic measures taken. Nishiwaki., *et al.* found that ulnar-shortening can stabilize the DRUJ, but only when the radioulnar ligament (RUL) is attached [23-25]. In situations without RUL attachment, alternative treatment methods could be examined, or more extensive physical therapy could be recommended in recovery of these patients. Additionally, given the nature of torque and how factors including tendon stiffness, imprinting on the bone, and muscle contraction play a role in torque dissipation, further research on live subjects examining torque on the elbow in use is needed [26,27].

Conclusion

There is no significant difference in upper extremity long bone length when comparing between males and females. Therefore, the sex of incomplete anatomical remains cannot be determined solely based on forearm bone length; the height of the individual to which the remains belong can be estimated.

Authors Note

The article does not contain information about medical devices/drugs. Institutional review board approval was not required for the submitted work at our institution.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Bibliography

1. Mall G., *et al*. "Sex determination and estimation of stature from the long bones of the arm". *Forensic Science International* 117.1-2 (2001): 23-30.

2. Clark EM., *et al*. "Sex differences in the ratio between humerus width and length are established prior to puberty". *Osteoporosis International* 18.4 (2007): 463-470.

3. Nieves JW., *et al*. "Males Have Larger Skeletal Size and Bone Mass Than Females, Despite Comparable Body Size". *Journal of Bone and Mineral Research* 20.3 (2004): 529-535.

4. McCormack RR., *et al*. "Prevalence of tendinitis and related disorders of the upper extremity in a manufacturing workforce". *The Journal of Rheumatology* 17.7 (1990): 958-964.

5. Gold JE., *et al*. "Specific and non-specific upper extremity musculoskeletal disorder syndromes in automobile manufacturing workers". *American Journal of Industrial Medicine* 52.2 (2009): 124-132.

6. Huisstede BMA., *et al*. "Incidence and prevalence of upper-extremity musculoskeletal disorders. A systematic appraisal of the literature". *BMC Musculoskeletal Disorders* (2006): 7.

7. Ma CC., *et al*. "Work-related upper extremity musculoskeletal disorders in the United States: 2006, 2009, and 2014 National Health Interview Survey". *Work* 60.4 (2018): 623-634.

8. Stockstill JW., *et al*. "Prevalence of upper extremity neuropathy in a clinical dentist population". *Journal of the American Dental Association* 124.8 (1993): 67-72.

9. Biomechanics - Musculoskeletal Disorders and the Workplace - NCBI Bookshelf (2019).

10. Rau G., *et al*. "Movement biomechanics goes upwards: From the leg to the arm. In: Journal of Biomechanics". *Elsevier Science Ltd* 33 (2000): 1207-1216.
11. Drake R., *et al*. "Gray's Anatomy for Students". 3rd Edition (2005).
12. Mixed models for repeated measures-part (2019).
13. Westgate PM and Burchett WW. "A Comparison of Correlation Structure Selection Penalties for Generalized Estimating Equations". *American Statistical Association* 71.4 (2017): 344-353.
14. SAS 9.4 Software | SAS (2019).
15. FastStats - Body Measurements (2019).
16. Gilsanz V., *et al*. "Differential Effect of Sex on the Sizes of the Bones in the Axial and Appendicular Skeletons 1". *The Journal of Clinical Endocrinology and Metabolism* 82.5 (1997): 1603-1607.
17. Hiramoto Y. "Right-left differences in the lengths of human arm and leg bones". *Kaibogaku Zasshi* 68.5 (1993): 536-543.
18. Papaloucas M., *et al*. "The asymmetry in length between right and left humerus in humans". *Pakistan Journal of Biological Sciences* 11.21 (2008): 2509-2512.
19. Handsfield GG., *et al*. "Relationships of 35 lower limb muscles to height and body mass quantified using MRI". *Journal of Biomechanics* 2014 47.3 (2014): 631-638.
20. Vaquero-Picado A., *et al*. "Lateral epicondylitis of the elbow". *EFORT Open Reviews* 1.11 (2016): 391-397.
21. Buchanan TS., *et al*. "Neuromusculoskeletal modeling: Estimation of muscle forces and joint moments and movements from measurements of neural command". *Journal of Applied Biomechanics* 20.4 (2004): 367-395.
22. Hwang B and Jeon D. "A method to accurately estimate the muscular torques of human wearing exoskeletons by Torque sensors". *Sensors (Switzerland).* 15.4 (2015): 8337-8357.
23. Roetert EP., *et al*. "The biomechanics of tennis elbow: An integrated approach". *Clinics in Sports Medicine* 14.1 (1995): 47-57.
24. Nesbit SM., *et al*. The Effects of Racket Inertia Tensor On Elbow Loadings And Racket Behavior For Central And Eccentric Impacts 5 (2006).
25. Lee AT and Lee-Robinson AL. "The Prevalence of Medial Epicondylitis Among Patients with C6 and C7 Radiculopathy". *Sports Health: A Multidisciplinary Approach* 2.4 (2010): 334-336.
26. Yoshii Y., *et al*. "Measurement of wrist flexion and extension torques in different forearm positions". *BioMedical Engineering On Line* 14.1 (2015).
27. Canham CD., *et al*. "Distal radioulnar joint reaction force following ulnar shortening: Diaphyseal osteotomy versus wafer resection". *The Journal of Hand Surgery: American* 40.11 (2015): 2206-2212.

Volume 3 Issue 2 February 2020