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Radiographic study of carrying angle and morphometry of skeletal elements of human elbow

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Abstract

Lateral obliquity of the forearm from the arm when the forearm is supinated and extended is called carrying angle. In this study carrying angle was measured using radiographs of adult individuals and morphometry was done on dry bones taking part in formation of human elbow (on lower end of humerus–trochlear angle and inclination angle of olecranon fossa, on upper end of ulna–olecranon–coronoid angle and length and width of inferior medial trochlear notch). On radiographs, the difference between male and female carrying angle and difference between carrying angle of right and left limbs (in both sexes together as well as in same sex) was statistically not significant. All the morphometric parameters measured in this study did not show any significant sexual dimorphism or difference between right and left side except the inclination angle of olecranon fossa, which was significantly more on right side. Different findings of carrying angle as reported by various authors could be due to racial difference or due to different methods used to measure carrying angle. Morphometric parameters were similar to findings of radiographic method of measuring carrying angle. These factors should also be considered in construction of elbow prosthesis as well as use of carrying angle in identification of skeletal remains.

Keywords: carrying angle, trochlear angle, olecranon–coronoid angle, inferior medial trochlear notch.

Introduction

In fully extended and supinated position, forearm diverges laterally forming a carrying angle with the upper arm [1]. This angle is 155–180^0 or, if one uses the supplementary angle, usually 0–25^0. Supplementary angle is the smaller angle of deflection [2]. Supplementary angle = 180^0 – carrying angle. Various authors have used term carrying angle for both the angles [1, 3–7].

Carrying angle is partly due to more distal position of the tip of the medial lip of the trochlea [8]. A curved ridge joins the prominences of coronoid process and olecranon, the obliquity of the shaft of the ulna to this ridge accounts for most of the carrying angle at the elbow [9]. According to Purkait R and Chandra H [10] olecranon–coronoid angle shows high sexual dimorphism and it may be one of the causes of sexual difference observed in carrying angle.

Knowledge of the carrying angle can be important anthropologically for differentiation of sex in fragmentary skeletal remains [6]. It is also useful for reduction of fractures as the most common complication of supracondylar fracture is loss or increase in carrying angle resulting in cosmetic deformity and for designing total elbow prosthesis.

Aim of this study was to establish data on carrying angle on radiographs and morphometric parameters on dry bones taking part in formation of human elbow, its sex and side difference in South Indian population. We hypothesize that carrying angle determined by radiologic method will yield similar results as morphometric parameters on dry bones taking part in formation of human elbow. First objective of this study is to measure carrying angle on radiographs. Second objective is to note relevant morphometric parameters on dry bones. Sex and side difference in both sets of data will be noted. Both sets of data will be compared with previous studies conducted elsewhere in the world. Third objective of this study is to compare both sets of data to test our hypothesis.

Material and Methods

Radiographs of the elbow were taken from Kasturba Medical College by PACS (*Picture Archiving and Communication System*) technique. Adults of both sexes were considered for the study. Total 54 radiographs were examined, 31 belonged to male individuals in which 17 were of right side and 14 of left side, 23 belonged to female individuals (13 right side, 10 left side).

Carrying angle was measured on radiographs by the method described by Beals RK [4]. On the radiograph, two mid points were marked on the distal humerus, one at distal metaphysis and the other in the distal third of the diaphysis. Two mid points were marked on ulna, one at the level of radial tuberosity and other at the most proximal ossification of the ulna. Line was drawn through points of corresponding bone and the software gives the angle between the two lines (Figure 1).

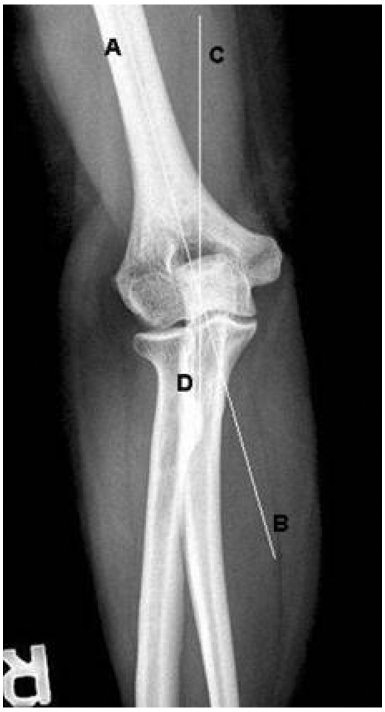

Figure 1 – *Radiograph showing lower end of humerus and upper end of radius and ulna. Line A–B passing through two mid points on humerus, one at distal metaphysis and the other in the distal third of the diaphysis. Line C–D passing through two mid points on ulna, one at the level of radial tuberosity and other at the most proximal ossification of the ulna.*

Rotation of arm or forearm is detectable on radiograph by overlapping of the forearm bones. Flexion is detectable on radiograph when the radial head overlaps the capitulum. Radiographs with such findings were excluded. Hyperextension is prevented as arm is placed on a flat cassette.

We used dry bones (humerus and ulna) from Department of Anatomy, Kasturba Medical College, Manipal. Bones belonged to adult cadavers of South Indian origin. Damaged bones were excluded. We observed 54 humeri, in which 26 belonged to right side and 28 belonged to left side, 30 belonged to male and 24 belonged to female individuals.

Sexing of humerus was done by using the parameters mentioned by Singh S and Singh SP [11]; i.e., the mean length of humerus in males on right side is 31.39±1.43 cm and on left side 31.13±1.94 cm whereas in females on right side is 27.98±1.49 cm and on left side 27.97±1.53 cm.

We measured morphometric parameters on dry bones taking part in formation of human elbow after Purkait R and Chandra H [10]. Trochlear angle was measured by placing the humerus on plain white sheet of paper with its posterior surface in contact with paper. Two points were marked on paper at upper 4/6th of humerus, one along its medial border and one along its lateral border. Similar two points were made at upper 5/6th of humerus. Mid points of the two points at both level were made on paper and line was drawn through them (A–B). A thread was adjusted in such a way that it was straight and touched the distal most point on lateral and medial projection on trochlea, point 'X' and 'Y' were marked. Angle ABY corresponds to the trochlear angle (Figure 2).

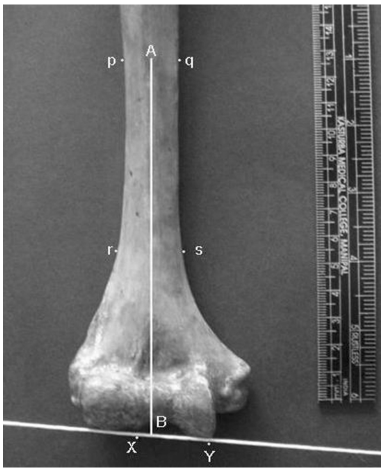

Figure 2 – *Photograph showing anterior aspect of lower end of humerus. Point 'p' and 'q' represents the marking on the paper at upper 4/6th and 'r' and 's' at upper 5/6th of humerus. Line A–B is passing through mid points of point 'p' and 'q' and point 'r' and 's'. Line X–Y is the thread adjusted in such a way that it touched the distal most point on lateral and medial projection on trochlea. Point 'X' and 'Y' represents marking on paper. Angle ABY is trochlear angle.*

Inclination angle of olecranon fossa was measured by placing the humerus on plain sheet of paper in such position that its anterior border is in contact with the paper. A thread was held straight along the maximum width of olecranon fossa, point 'P' and 'Q' were marked on paper. Point 'R' and 'S' were marked on paper by holding the thread straight, which passed through the two proximal most points on the articular surface of trochlea. Two straight lines were drawn one passing through point 'P' and 'Q' and other passing through point 'R' and 'S'. The angle between the two lines was measured represented the inclination angle of olecranon fossa (Figure 3).

Sexing of ulna was done after Ćwirko-Godycki M [12] i.e. the surface of sigmoid notch (trochlear notch) is divided in males and undivided in females.

For olecranon–coronoid angle, a straight line A–B was drawn on plain sheet of paper and a wooden block was placed on paper in such position that its edge was parallel to the line A–B, ulna was placed with its medial surface facing the paper and styloid process and outermost point on proximal part of shaft of ulna, both touching the side of that wooden block. A thread was held touching the olecranon process and coronoid beak. Point 'C' and 'D' was marked on paper and line was drawn through these points. Angle between line A–B and the line passing through point 'C' and 'D' represented the olecranon–coronoid angle (Figure 4).

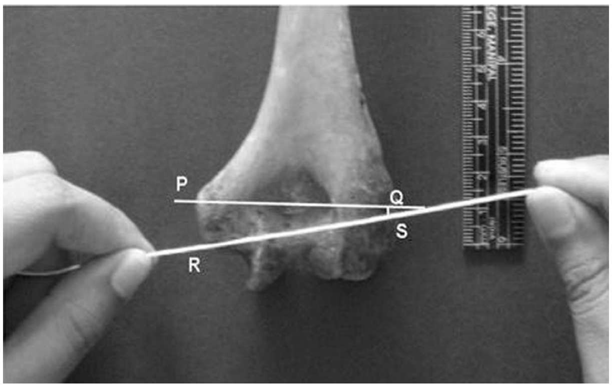

Figure 3 – ***Photograph showing posterior aspect of lower end of humerus. Line P–Q represents the line along the maximum width of olecranon fossa. Line R–S is thread held straight and passing through the two proximal most points on the articular surface of trochlea. Angle between the two lines is inclination angle of olecranon fossa.***

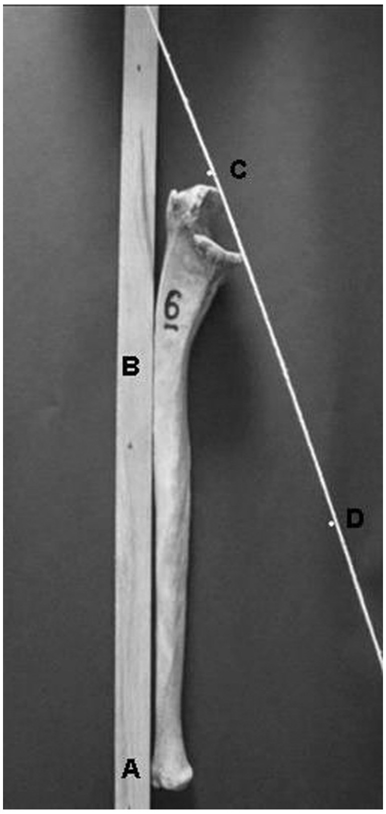

Figure 4 – ***Photograph showing the ulna. A straight line A–B is drawn on plain sheet of paper, a wooden block is positioned on the paper in such a way that its edge is parallel to the line A–B. Ulna is positioned on the paper with its medial surface in contact with the paper and styloid process and outermost point on proximal part of shaft of ulna, both touching side of the wooden block. A thread is held straight in such position that it touched the olecranon process and coronoid beak. Point 'C' and 'D' represent the points marked on paper and line was drawn through these points. Angle between these two lines is olecranon–coronoid angle.***

For length and width of inferior medial trochlear notch of ulna, ulna was held facing anteriorly. A wire was held along the deepest constriction of trochlear notch. Another wire was held in such a way that it touched the coronoid beak (point 'P') and its end was on transversely placed wire (point 'Q'). Length of inferior medial trochlear notch (IMTN) was measured between point 'P' and 'Q'. Width X–Y was measured at right angle to P–Q using divider where 'X' was medial most point on border of trochlear notch and 'Y' was the point on P–Q (Figure 5).

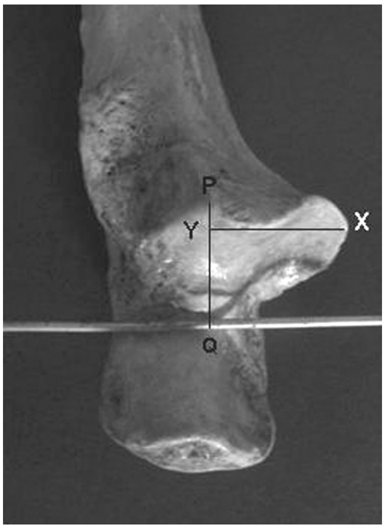

Figure 5 – ***Photograph showing anterior aspect of upper end of ulna. A wire held along the deepest constriction of trochlear notch. Line P–Q is the length of inferior medial trochlear notch. Line X–Y is the width of inferior medial trochlear notch.***

All measurements were conducted by three different observers at three different points of time.

Statistical analysis was done using Student's *t*-test.

Results

Among 54 radiographs examined, the mean carrying angle in males was 17.023±1.93^0 and in females 17.77 ±2.13^0. The difference between males and females carrying angle was statistically not significant (p>0.5).

The mean carrying angle on right side in both sexes was 17.56±2.15^0 and on the left side was 17.06±1.88^0. The difference between carrying angles of two sides was statistically not significant (p>0.5).

The mean carrying angle in males on right side was 17.18±1.926^0 and on left side was 16.829±2.0^0, and the difference was statistically not significant (p>0.5).

The mean carrying angle in females on right side was 18.06±2.40^0 and on left side was 17.39±1.75^0, the difference was statistically not significant (p>0.5).

Trochlear angle and inclination angle of olecranon fossa was measured on 54 dry humeri. The mean trochlear angle in males was 99.10±4.95^0 and in females 99.33±6.479^0 and on right side (in both sexes) it was 100.08±5.72^0 and on left side (in both sexes) was 98.39 ±5.513^0 (Table 1). The difference between trochlear angle in males and females and right and left sides was statistically not significant (p>0.5).

The mean inclination angle of olecranon fossa in males was 11.80±5.293^0, in females was 10.08 ±6.331^0, on right side was 15.12±4.663^0, and on left side was 7.25±3.826^0 (Table 1). The difference between right and left side was statistically significant (p<0.5) and the difference between males and females was statistically not significant (*p*>0.5).

Table 1 – ***Statistical analysis for angles measured on humeri***

Angles [^{0}]	Males Mean ±SD	Females Mean ±SD	*p*-value	Right side Mean±SD	Left side Mean±SD	*p*-value
Trochlear angle	99.10± 4.95	99.33± 6.479	>0.05	100.08± 5.72	98.39± 5.513	>0.05
Inclination angle of olecranon fossa	11.80± 5.293	10.08± 6.331	>0.05	15.12± 4.663	7.25± 3.826	<0.05

Measurements on ulna was done on 69 bones in which 34 belonged to right side and 35 belonged to left side, 40 belonged to male and 29 belonged to female individuals. The mean olecranon–coronoid angle in males was 18.53±4.674^0, in females was 18.55 ±4.404^0, on right side was 17.94±5.234^0, and on left side was 19.11±3.708^0 (Table 2). The difference between males and females and right and left side was statistically not significant (*p*>0.5).

Table 2 – ***Statistical analysis for measurements on ulnae***

Variable	Males Mean ±SD	Females Mean ±SD	*p*-value	Right side Mean±SD	Left side Mean±SD	*p*-value
Olecranon –coronoid angle [^{0}]	18.53± 4.674	18.55± 4.404		17.94± 5.234	19.11± 3.708	
Length (BC) of IMTN [cm]	1.698± 0.1761	1.559± 0.1593	>0.05	1.629± 0.1624	1.649± 0.2005	>0.05
Width (MN) of IMTN [cm]	1.495± 0.1709	1.355± 0.2164		1.368± 0.2026	1.503± 0.1807	

The mean length of the IMTN (BC) in males was 1.698±0.1761 cm, in females was 1.559±0.1593 cm, and on right side was 1.629±0.1624 cm and on left side was 1.649±0.2005 cm. The mean width of the IMTN (MN) in males was 1.495±0.1709 cm, in females was 1.355±0.2164 cm, on right side was 1.368±0.2026 cm, and on left side was 1.503±0.1807 cm (Table 2). The difference between males and females and right and left side in both length and width was statistically not significant (*p*>0.5).

Discussion

Apes and humans are distinguished from other primate species in possessing carrying angle at the elbow. The evolution of a carrying angle in apes is related to the need to bring the center of mass of the body beneath the supporting hand during suspensory locomotion as seen in lower limbs of humans in which the valgus knee brings the foot nearer the center of mass of the body during the single limb support phase of walking [13].

In the present study, the mean carrying angle in males was 17.023±1.93^0 and in females 17.77±2.13^0. The difference between males and females carrying angle was statistically not significant (*p*>0.5).

Punia RS *et al.* [6] conducted study on 50 males and 50 females from Northern States of India using radiographs, according to them mean carrying angle was 164.4^0 in males and 162.86^0 in females. They also reported the difference of mean between the two sexes was significantly greater than that in studies on western population using comparable technique.

Paraskevas G *et al.* [2] studied carrying angle in 600 living individuals from Greece, aged 18–28 years. They measured supplementary angle using goniometer. In the age group of 19–28 years, carrying angle was significantly greater in females. Carrying angle was 12.23±0.3^0 in males and 15.77±0.41^0 in females.

According to Khare GN *et al.* [14], the carrying angle does not help in keeping the forearm away from the side of pelvis during walking as during walk the forearm is pronated and carrying angle disappears in pronation of forearm. They found that carrying angle is inversely related to the height of a person, since the average height of females is lesser than the average height of males so average-carrying angle is greater in females than males. This study was done in North India.

Steel FLD and Tomlinson JDW [8] investigated the left upper limb of 100 European adults using radiographs to measure carrying angle and obtained no statistically significant difference (males 19.28^0 and females 18.38^0).

Beals RK [4] conducted study on various age groups including adult population in New Zealand, using radiographs. According to him, the mean carrying angle in adults was 17.8^0 and difference between males and females carrying angle was statistically not significant.

Our findings on sex difference in carrying angle were similar to observations by several of the previous authors.

The mean carrying angle on right side in both sexes was 17.56±2.15^0, in males was 17.18±1.926^0 and in females was 18.06±2.40^0. On the left side was 17.06 ±1.88^0, in males was 16.829±2.0^0, in females was 17.39±1.75^0. The difference between two sides was statistically not significant (*p*>0.5) in all cases.

Paraskevas G *et al.* [2] reported that carrying angle was significantly greater in the right upper limb than the left in both sexes, 12.20±3.8^0 in right and 11.46±3.2^0 in left upper limb in males and 16.52±4.23^0 in right and 15.36±3.23^0 in left upper limb in females. They also reported that in right-handed subjects angle was significantly greater in right upper limb in both sexes and in left-handed subjects, it was significantly greater in left upper limbs in both sexes.

Shetty S [15] conducted study using radiographs on 52 subjects in South India and found that mean carrying angle in the left upper limb in males was 158.9^0 and in females 158.7^0 with the mean difference of 0.2. In right upper limb, mean angle in males was 160.5^0 and in females it was 160.2^0 with the mean difference of 0.3.

In the present study, the difference between carrying angle of right and left upper limb in both sexes and in same sex was statistically not significant (*p*>0.5).

Different authors have found different values of carrying angle; this could be due to different methods used by different authors and due to racial difference of the population studied.

Steel FLD and Tomlinson JDW [8] measured trochlear angle in 50 adult humeri of known sex belonging to European population and reported that there is no significant difference between males and females trochlear angle.

Purkait R and Chandra H [10] conducted study in North India on 20 humeri of each sex and found that trochlear angle was 104.23±2.42^0 in males and 104.53 ±1.76^0 in females. Inclination angle of olecranon fossa was 4.88±1.6^0 in males and 5.43±2.15^0 in females, the difference between males and females in both these angles was statistically not significant. They also investigated 100 males and 60 female ulnae and reported that olecranon coronoid angle was 22.26±3.47^0 in males and in females 14.73±4.46^0, the difference was statistically significant. The mean length and width of IMTN in males (length 16.01±1.4 cm and width 14.1±1.24 cm) and in females (length 14.39±0.98 cm and width 12.47 ±1.59 cm) was significantly larger in males than that of females.

In the present study, we found that the difference between male (99.10±4.95^0) and female (99.33±6.479^0) trochlear angle as well as difference between right side (100.08±5.72^0) and left side (98.39±5.513^0) trochlear angle was statistically not significant (p>0.5). The difference between inclination angle of olecranon fossa in males (11.80±5.293^0) and females (10.08 ±6.331^0) was statistically not significant (p>0.5) though this angle was more on right side in both sexes. The difference between right (15.12±4.663^0) and left side (7.25±3.826^0) in both sexes was statistically significant (p>0.5). Measurements on ulna i.e. olecranon–coronoid angle and length and width of IMTN, the difference between males (18.53±4.674^0, 1.698±0.1761 cm, 1.495 ±0.1709 cm) and females (18.55±4.404^0, 1.559 ±0.1593 cm, 1.355±0.2164 cm) and difference between left (19.11±3.708^0, 1.649±0.2005 cm, 1.503±0.1807 cm) and right side (17.94±5.234^0, 1.629±0.1624 cm, 1.368 ±0.2026 cm) in both sexes was statistically not significant (p>0.5).

We found only one study where authors have measured carrying angle on radiographs and trochlear angle of humerus on dry bone, Steel FLD and Tomlinson JDW [8] reported that both carrying angle and trochlear angle does not have statistically significant difference between males and females, in present study we found the same.

In the present study, excellent correlation exists between radiographic and morphometric findings on dry bones wherein we observed that the difference between males and females carrying angle, trochlear angle, inclination angle of olecranon fossa, measurements on ulna i.e. olecranon coronoid angle and length and width of IMTN was statistically not significant (p>0.5).

While comparing data obtained from radiologic study and morphometry on dry bones, we found similar results in most instances. The difference between carrying angle of right and left upper limb in both sexes and in same sex was statistically not significant (p>0.5). Likewise, difference between right side and left side trochlear angle was statistically not significant. In the same way, the difference between inclination angle of olecranon fossa in males and females was statistically not significant (p>0.5). Moreover, in measurements on ulna i.e. olecranon–coronoid angle and length and width of IMTN, the difference between males and females and difference between left and right side in both sexes was statistically not significant (p>0.5). Only difference we observed was that the difference between inclination angle of olecranon fossa of right and left side (in both sexes) was statistically significant (p<0.5).

While measuring the carrying angle on radiographs after the method described by Beals RK [4] the distal metaphysis and distal 1/3rd of diaphysis was taken approximately to get the axis of humerus. To get a more appropriate axis better method was described by James and Pedro [5] in a cadaveric study wherein the author inserted a Steinmann's pin inside the medullary cavity of humerus. In the present experimental set-up for radiographic study, such procedure was not possible to conduct in living subjects. In the present study, the dry bones used for morphometric study were non-articulated and belonged to different individuals. This can help in establishing preliminary data on correlation between radiographic method of measuring carrying angle and morphometry on dry bones. Future studies can be conducted to overcome this limitation by taking radiograph of an articulated cadaveric limb and then conduct morphometric study after disarticulating the same limb.

Punia RS *et al.* [6] mentioned that according to Moore KL [16] knowledge of carrying angle is useful anthropologically for differentiation of sex in fragmentary skeletal remains but according to us racial differences in carrying angle should also be taken into consideration.

Carrying angle is of cosmetic significance [17]. The carrying angle of the elbow remains constant as the elbow flexes [5]. Moreover, Paraskevas G *et al.* [2] mentioned that according to An KN *et al.* [18] the variability of the carrying angle is reflected in differences in design of resurfacing and semiconstrained elbow replacement implants. They also stated that clinical results with elbow prostheses have been disappointing and detailed knowledge of elbow joint geometry and mechanics is necessary to improve prosthetic design.

Conclusions

Present rich photographic documentation aids to determine the carrying angle in adult population by radiological method and to correlate with morphometric parameters on dry bones taking part in formation of human elbow. It also aids to establish data on carrying angle, its sex and side difference in South Indian population. This study will assist the orthopedic surgeons and manufacturers preparing for elbow replacement implants.

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