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Estimation of the angle of humeral torsion from digital images of dry humeri of South Indian origin

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Abstract

Objectives: The present study was undertaken to measure the angle of humeral torsion (AHT) on digital images. The aims of the present study were to estimate the: i) angle of humeral torsion, ii) difference in the AHT between right and left humeri, and iii) reliability of the method.

Methods: A total of 185 unpaired humeri (101 right and 84 left) from South India of unknown age and sex available at the department of anatomy were studied. Reference points for the long axis of the upper end of the humerus were marked. An end-on digital photograph of the articular surface of the head was taken. Using appropriate software, lines were drawn to define the AHT. Printouts of the above images were taken and the AHT measured with a protractor. The mean and standard deviation of the AHT were calculated for all the humeri and separately for each side. The unpaired t-test was used to determine the significance of the side differences. Inter- and intra-observer reliability was estimated using the technical error of measurement (TEM), relative technical error of measurement (rTEM) and coefficient of reliability (R).

Results: The mean AHT considering all the humeri was 59.65°±10.97. The corresponding values on the right and left side were 57.85°±9.80 and 61.83°±11.93 respectively, with a significantly greater (p=0.02) mean AHT on the left side. Acceptable rTEM values of 4.27% and 7.62% for intra-observer and inter-observer repeat measurements were obtained.

Conclusion: The mean values of the AHT lie within the range previously described, with significantly greater values on the left side. The method described showed acceptable inter- and intra-observer reliability.

Key words: angle of humeral torsion; digital image; dry humerus; measurement; South Indians

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Introduction

The term humeral torsion denotes twisting of the bone along its long axis. As a result of this twisting, the articular axis of the upper end lies in a plane different from that of the lower end. The two axes when superimposed on each other form an angle known as the angle of humeral torsion (AHT).[1] In quadruped mammals the humeral head is directed posteriorly, to articulate with the anterior facing glenoid fossa of the scapula.[2] In humans, the biologic necessity of humeral torsion has resulted from the development of upper extremities as prehensile appendages and assisting in the maintenance of an upright posture.[1] Associated with this evolved posture, torsion occurs between proximal and distal extremities of the humerus, with the humeral head facing postero-medially in anatomical position. The arc of humeral torsion is described by the rotation of the humeral head from the posterior position to the normal postero-medial position.[1] The angle which the axis of the humeral head now makes with the primitive antero-posterior position of the axis is the AHT.

There is a wide variation in the AHT with respect to sex, side and race.[3-5] From previous studies it has been noticed that an increase in the AHT places the humeral head more anteriorly, causing recurrent anterior dislocation of the shoulder.[6-8] Variations in the AHT depending on the type of usage of the upper limb in sporting activities have also been documented.[9]

The AHT can be measured by various methods using instruments like the torsiometer, parallelograph, and by radiological investigations like X-ray, CT scan and MRI.[1,5,8,10,11] Computer assisted methods have also been used more recently.[12,13] There is a paucity of data regarding the AHT in Indian populations especially in South Indians.[14] Also, previously described methods were cumbersome or required special instruments and investigations. Therefore the present study was undertaken to measure the AHT on digital images. The aims of the present study were to estimate the following: i) angle of humeral torsion, ii) difference in the AHT between right and left humeri, and iii) intra- and inter-observer reliability of the method.

Materials and Methods

Collection of humeri

The study was an analytical, cross-sectional study carried out at the Department of Anatomy, St John's Medical College, Bangalore from September, 2008 to August, 2009. Humeri of South Indian origin of unknown age and sex available at the department were used for the study. Dried and well preserved humeri without any external abnormality were included in the study. Damaged or deformed bones were excluded from the study. A total of 185 unpaired humeri (101 right and 84 left) that fulfilled the selection criteria were studied. Ten humeri (7 right and 3 left) with damaged upper ends were excluded from the study.

Marking of reference points

To mark the axis of the upper end, two points were marked with a marker pen (**Figure 1a**). The first point was taken as the center of the articular surface of the head. This point (P1) was marked where the transverse diameter of the articular surface was maximum. The second point (P2) was marked at the junction of the upper and middle impressions of the greater tuberosity of the humerus. The distal end of the humerus was oriented along a transverse axis using reference lines marked on graph paper and was drawn using Adobe Photoshop version CS2 software after the image acquisition as mentioned below.[15]

Image acquisition

Once the reference points were marked on the upper end, the humerus was placed on graph paper which was stuck onto a flat horizontal surface. The humerus was then centered on the graph paper and an end-on digital photograph of the articular surface of the head was taken after ensuring that the line on the graph paper that passed through the center of the head was aligned with the center of the lens of the digital camera (**Figure 1b**).

Image analysis

Once the photograph was taken, the image was transferred to a computer. On each image, a line was drawn joining the center of the two reference points to indicate the upper end axis. A horizontal line was drawn through the second point to indicate the lower end axis. Another

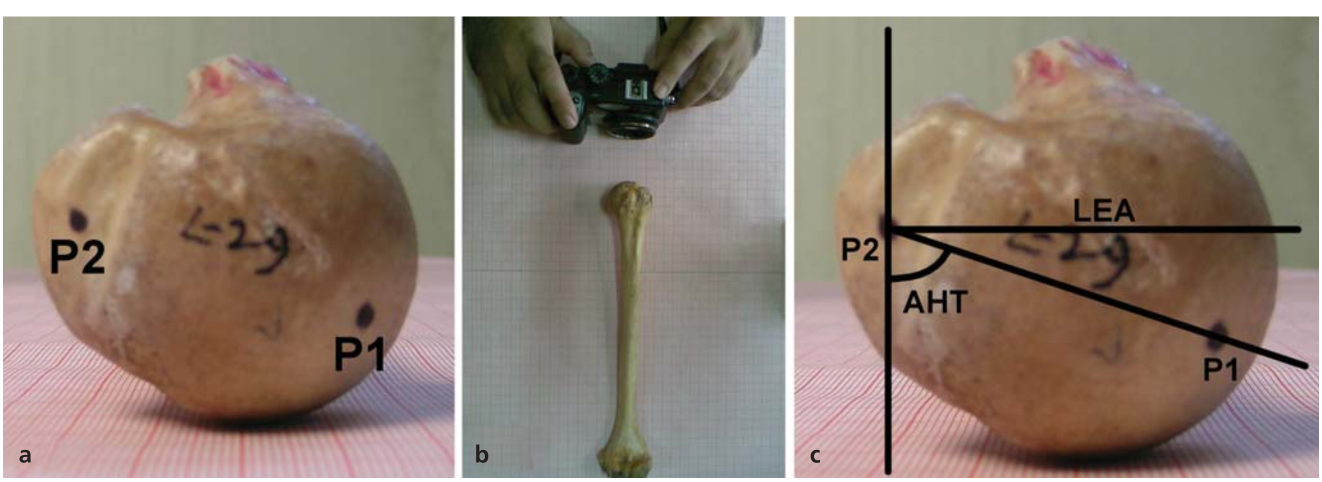

Figure 1. Method of estimation of the AHT. (**a**) Reference points for estimation of the upper end axis of the humerus. (**b**) Method for taking end on digital photographs of the upper end of the humerus. (**c**) Measurement of the AHT. AHT: angle of humeral torsion; LEA: lower end axis of the humerus; P1: the center of the articular surface of the head; P2: the junction of the upper and middle impressions of the greater tuberosity of the humerus.

line, perpendicular to the horizontal line was drawn through the second point to enable measurement of the AHT (**Figure 1c**). Once the lines were drawn, printouts of all images were taken after deleting the background image and the AHT was measured with the help of a protractor.

Intra- and inter-observer reliability

The principal investigator randomly selected twenty bones and erased the markings on them. The whole procedure was repeated on these twenty bones and similar measurements were taken to assess the intra-observer variability. Another investigator also randomly selected twenty bones and repeated the whole procedure to assess inter-observer reliability.

Statistical analysis

The range, means, standard deviation (SD) and 95% confidence intervals (CI) of the AHT values for all the humeri, as well as for bones of each side were calculated. Bar charts were drawn to analyze the frequency distributions of the AHT. The Kolmogorov-Smirnov and Levene's tests were utilized to determine whether the AHT values on the right and left side were normally distributed and had equality of variances respectively. The independent sample t-test was used to check for significant differences ($p<0.05$) between the right and left AHT. Inter- and intra-observer reliability was estimated using the technical error of measurement (TEM), relative technical error of measurement (rTEM) and coefficient of reliability (R). For all statistical analysis SPSS software version 16 was used.

Results

The Kolmogorov-Smirnov and Levene's tests indicated the AHT values had a normal distribution and homogeneity of variance respectively. The mean values of the AHT were significantly greater ($p=0.02$) on the left side as compared to the right side (**Table 1**). The range of values of the AHT on the left side (30° to 92°) was greater than the right side (39° to 81°). **Figure 2** shows the extremes of the values of the AHT observed on the right and left sides, as well as humeri with AHT values close to the mean. The bar charts indicate that on the right side the greatest number of bones had AHT values between 51°-60° while on the left side it was between 61°-70° (**Figure 3**). The TEM, rTEM and R values for the intra-observer repeat measurements were 2.7°, 4.27% and 0.94 respectively. Similar values for the inter-

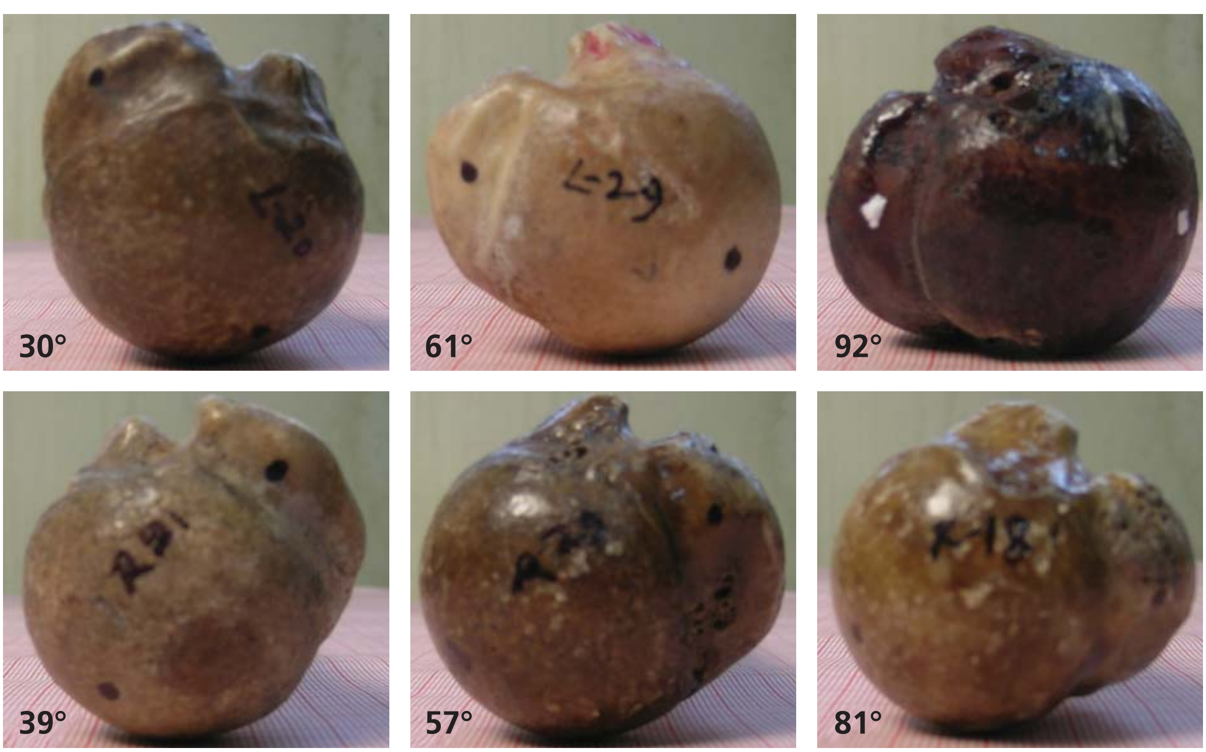

Figure 2. The range of AHT values seen on the left and right sides. The **top row** shows the minimum, mean and maximum values of the AHT on the left side. The bottom **row shows** similar values on the right side.

Table 1
Mean values of the AHT with range

	Combined n=185	Right n=101	Left n=84
Mean±SD	59.66°±10.97°	57.85°±9.80°*	61.83°±11.94°*
95% CI	59.2° to 64.4°	55.8° to 60.1°	59.2° to 64.4°
Lowest	92°	81°	92°
Highest	92°	81°	92°

observer repeat measurements were 4.52°, 7.62% and 0.82. The mean of the differences in inter-observer values was 4.25°, with 16 of the measurements having a difference of less than or equal to 5°. The similar mean in intra-observer values was 2.85°, with 17 measurements having a difference of less than or equal to 5°.

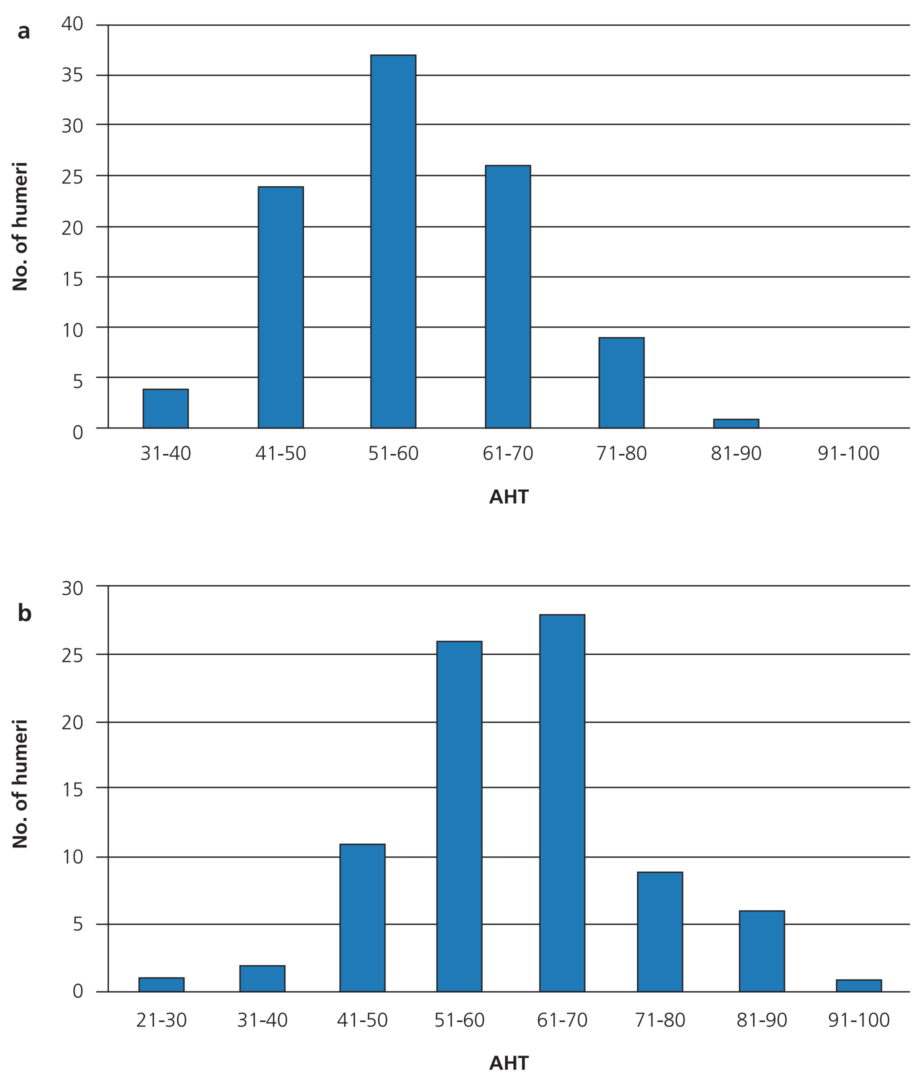

Figure 3. The frequency distribution of the AHT values. (**a**) Right side. (**b**) Left side.

Discussion

Varying terminologies used to describe the AHT

Two main terms have been used describing the degree of twisting of the upper end of the humerus, torsion and retroversion. In the human clinical and sports literature, the presumption is that the default condition for the human shoulder joint is to have a glenoid fossa facing directly laterally and a humeral head pointing directly medially. Deviation of the humeral head from this ideal to a more posterior orientation is called retroversion. It is important to appreciate is that retroversion is the angular complement to humeral torsion as traditionally measured, so that increasing retroversion means reduced torsion and vice versa.[2] The third method of calculating the degree of twist was used by Broca and other French authors by subtracting an acute angle from 180°.[2,16] **Figure 4** shows the different definitions of the degree of twisting of the upper end of the humerus. In the discussion that follows, only the term AHT will be used. For easy comparison with the present study, all values of retroversion and the other method of measuring the AHT used by French investigators will be converted to the AHT as defined in this study.

Axes used to define the AHT

Few controversies exist regarding the axis of the upper end of the humerus. The upper end axis of the humerus is defined as the the line joining the center of the articular surface of the head and the greater tuberosity approximately between the insertions of supraspinatus and of the infraspinatus muscles.[17] The center of the articular surface of the head is where transverse diameter of articular surface is maximum. However the lower end axis has been variably defined. Some authors consider the lower end axis as the line passing through the center of the two epicondyles which is almost horizontal.[18] Others consider the line passing through the center of the trochlea and capitulum.[5,17] In the present study, the lower end axis was oriented transversely using reference lines marked on graph paper.[15]

Variations in the values of the AHT

Standard anatomy textbooks mention that the average AHT is 74°.[19] However, the values of the AHT are dependent on a number of factors such as race, method of measurement and the type of activities involving the upper limb.[1,4,5,10,11,13,15,17,18,20,21] Among all the investigators who have studied torsion in different races, the highest average degree of torsion is found to occur in white races.[17] Levels of humeral torsion are generally lower in the populations predicted to be participating in high levels of strenuous activity and elevated in less active more urban groups.[15] Sex and side differences in the values of the AHT have also been described.[1,3,5,9,22] In view of the great variability in the mean AHT, the results of the present study will be discussed in relation to only those studies done on dry bones.

The mean AHT in previous studies done worldwide on dry bones vary from 48.5° to 74.4°.[5,23] However, the mean values of studies done in India vary from 55° to 68.5°.[1,3] The results of previous studies are compared

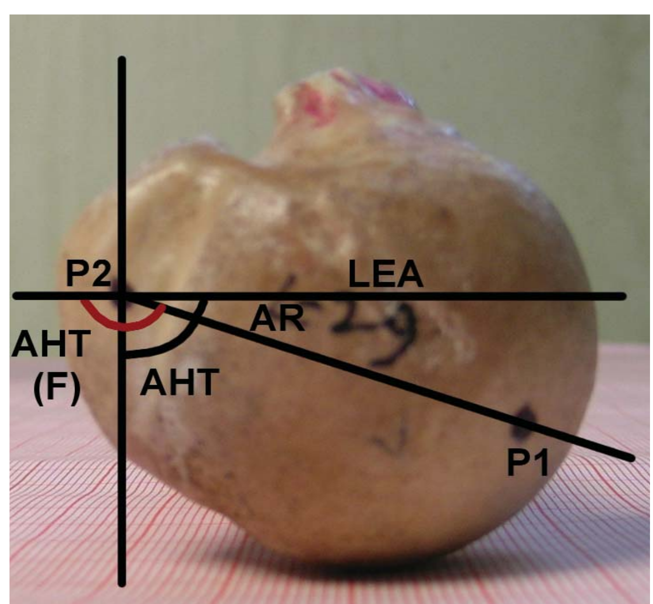

Figure 4. The various methods of defining the twisting of the upper end of the humerus. AHT: angle of humeral torsion; AHT(F): angle of humeral torsion as defined by French investigators; AR: angle of retroversion; LEA: lower end axis; P1: the center of the articular surface of the head; P2: the junction of the upper and middle impressions of the greater tuberosity of the humerus.

Table 2
Comparison of mean values of the AHT among studies conducted on dry humeri

Sl. No.	Author (Year)		Number of humeri	Race	Mean AHT
1.	Broca[4]	(1881)	600	Caucasian	74°
2.	Mathews et al.[26]	(1893)	NA	Salado-Indian	69°
3.	Martin[23]	(1928)	NA	Australian	45.5°
4.	Martin[23]	(1928)	NA	Paltacalo-Indian	48.5°
5.	Martin[23]	(1928)	NA	Feugian	53.9°
6.	Martin[23]	(1928)	NA	Peruvian	60.2°
7.	Martin[23]	(1928)	NA	Swiss	74°
8.	Chillida[27]	(1943)	NA	Argentine Aborigine	61°
9.	Ayer and Upshon[14]	(1943)	NA	South Indian	62.1°
10.	Krahl and Evans[5]	(1945)	178	Caucasian	74.4°
11.	Krahl and Evans[5]	(1945)	NA	American black	72.6°
12.	Kate[3]	(1969)	100	Central Indian	55°
13.	Mehta[1]	(1971)	200	Indian (Rajasthan)	68.5°
14.	Kummer et al.[28]	(1998)	420	American	62.7°
15.	Shah et al.[17]	(2006)	500	Indian (Gujarat)	68.5°
16.	Present study		185	Indian (Karnataka)	59.66°

NA: information not available

with those of the present study in **Table 2.** The mean value of the present study falls in the range mentioned above, and is similar another South Indian study done by Ayer and Upshon.[14] From **Table 2** it can be observed that the values of the mean AHT are higher among North Indians compared to other regions in India. This is likely to be a reflection of the racial variations and difference in patterns of upper limb usage in various regions of India. Methodological differences may also be a minor contributor. It would be interesting to note that with lower degree of torsion the incidence of recurrent anterior dislocation may be less common in Indians but so far no clinical data is available to support this hypothesis.[17]

Bilateral differences in the values of the AHT

The results of various studies conducted worldwide on bilateral differences in the mean AHT show wide variations. The results of the present study are in concordance with those conducted by Kate,[3] Broca,[4] and Krahl and Evans[5] (study conducted on American blacks) which show a greater mean AHT on the left side. Of these, the present study showed a significant difference. On the other hand, a significantly higher average AHT on the right side was noted by Mehta and Chaturvedi1 and Krahl and Evans[5] (study conducted on Caucasians). Many other studies do not show significant side differences.[11-13,17] An explanation for the disparities in the results of previous studies probably lies in the fact that the populations studied had different patterns of upper limb usage.

The best evidence that preferential use of one upper limb influences the mean AHT comes from analysis of these values in sportspersons. Previous studies have clearly demonstrated that in baseball and handball professionals the mean AHT is significantly less on dominant side.[9,22,24] This decrease in the AHT on the dominant side seems to be an adaptation to extensive external rotation in throwing practice during growth. This increased retroversion allows more external rotation of the shoulder before the humeral head puts excessive strain on the anterior capsulolabral complex. A decrease in the AHT could thus be interpreted as a protection mechanism for the anterior capsulolabral complex.[22] In one of the studies on handball players and controls, significant side differences in the mean AHT were seen only in players but not in controls.[22] This suggests that for significant side differences in the mean AHT to occur, there has to be a marked difference in the pattern of upper limb usage on either side. In the present study, the mean AHT was significantly less on the right side as compared to the left. In all likelihood this can be attributed to the fact that the right limb is more commonly the dominant limb. This is especially true in many parts of India, where use of the left upper limb is actively discouraged from early childhood due to cultural beliefs.

Intra- and inter-observer reliability

A review of the literature shows that a multiplicity of methods has been used to measure the AHT.[1,5,8,10-13] However, not many studies have analyzed the reliability and repeatability of the method.[12,13,21,25] The most commonly used measure of the magnitude of error associated with a certain measurements is the TEM, which is the square root of the measurement error variance.[29] It is expressed in the same unit of measurement as used in the original measurement. It indicates the amount of error an investigator (or a pair of collaborators) demonstrates in making a measurement.[30] The rTEM (derived from the TEM) provides an estimate of error magnitude relative to the size of measurement and is expressed as a percentage. It has the advantage of being simple to calculate, has no units and allows direct comparisons of all types of anthropometric measure.[29] The value of R indicates the proportion of between-subject variance free from measurement error. It has a value between 0 and 1, and is independent of the units used in making a measurement.[30]

Determination of acceptable levels for the TEM, rTEM and R is not easy and depends on the variable being measured.[29] In anthropometric measurements of variables such as height and weight, an rTEM of 1.5% and 2% for beginners, for intra-observer and inter-observer reliability are considered as acceptable. Similar values for the expert are 1% and 1.5%. However for measurements such as skin-fold thickness which are more complex rTEM values of 7.5% and 10% for beginners for intra-observer and inter-observer reliability are considered as acceptable. Similar values for the expert are 5% and 7.5%.[31] The measurement of the AHT involves several steps and the acceptable levels of the rTEM could be set at levels defined for skin-fold measurements. The present study thus fulfills the levels of acceptable rTEM values. The acceptable minimum R value in most anthropometric studies is considered to be 0.95.[29] In the present study the value of R for repeat intra-observer measurements approached this value. The values of R for the inter-observer repeat measurements were however not as close to the acceptable limit. The use of R is not as widespread as TEM and rTEM, and acceptable levels are largely unknown even for parameters in which TEM has been reported.[30] Some authors suggest that the acceptable R value has to be set depending on the investigators particular purpose.[32]

In a study conducted by Boileau et al.,[25] two observers measured the humeral head retroversion in 10 specimens. Using the computer-assisted method, the standard deviation for both intra- and inter observer error was less than 1° for angular measurements. Each observer performed five measurements using direct, radiographic, and computer assisted method. The intra-observer variation in the measurements was noted to less than 3° for each measurement method, which was similar the present study.

Any differences in repeat measurements in the present study are likely to have been caused due to the variability in the estimation of the upper end axis, as the lower end axis was assumed to be horizontal. The two points used to determine the upper end axis were the center of the articular surface of the head (P1) and the junction of the upper and middle impressions of the greater tuberosity of the humerus (P2). While P2 can be easily determined, a greater degree of subjectivity in the localization of P1 is the likely reason for any variability in the estimation of the upper end axis (**Figure 1a**).

Limitations of the present study

The humeri used in the present study were of unknown sex and unpaired. A more detailed analysis could have been conducted if this data was available. Additionally it would have been useful if the occupations and patterns of upper limb usage of the individuals whose bones were studied were known. A functional correlation with the values of the AHT obtained could have then been performed. The accuracy and reliability of the methods used in the present study cannot of course be compared to methods using sophisticated instruments and complex computer-assisted three dimensional reconstructions.[12,13,25] Also the accuracy of the present study could have been improved if an image analysis program such as NIH Image or ImageJ had been used.

Conclusion

The term humeral torsion denotes twisting of the bone along its long axis. There is a paucity of data regarding the value of AHT in South Indians. Previously described methods were either cumbersome or required sophisticated and expensive equipment. The present study was undertaken to measure the AHT on digital images. The mean AHT was similar to the previous study conducted in South Indians.[14] The mean value of the AHT was significantly higher on the left side as compared to the right. The method used showed acceptable intra- and inter-observer reliability. Despite its limitations, the authors feel that the method described in the present study will be valuable in estimating the AHT in a simple and reliable manner.

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