Reliability and Validity of Radiographic Measurement of the Humerus-Elbow-Wrist Angle in Healthy Children

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Background: We conducted a retrospective cohort study to evaluate the normal value, range, reliability, and validity of measurement of the humerus-elbow-wrist angle, an index of valgus-varus angulation of the elbow, in healthy children. This measurement has been used to assess postoperative radiographic results.

Methods: Radiographs of the elbow in 62 healthy children ranging from 2 to 11 years of age were reviewed by 6 examiners at 2 sessions. The mean value and the reliability of measurement of the humerus-elbow-wrist angle, the carrying angle, and the Baumann angle were assessed. Intraobserver and interobserver reliability were calculated with use of intraclass correlation coefficients (ICCs). To determine concurrent validity, the association between the humerus-elbow-wrist angle and carrying angle measurements was examined with use of Pearson correlation coefficients.

Results: The mean humerus-elbow-wrist angle value was 12.0° (range, 1° to 24°), and the mean carrying angle was 14.6° (range, 4° to 28°). The ICCs for intraobserver measurements of the humerus-elbow-wrist angle were almost perfect for 4 examiners and were substantial for 2 examiners, with a mean value of 0.85 (range, 0.73 to 0.94). The ICCs for interobserver reliability with regard to the first and second measurements of the humerus-elbow-wrist angle were both substantial (0.76 and 0.78). A significant association between the humerus-elbow-wrist angle and the carrying angle was observed, with the Pearson correlation coefficients ranging from 0.74 to 0.90 (p < 0.001).

Conclusions: Measurement of the humerus-elbow-wrist angle demonstrated good reliability and validity. The humerus-elbow-wrist angle is a reliable radiographic measure of coronal alignment of the humerus and forearm.

Various radiographic parameters have been used for the evaluation of surgical treatment of pediatric elbow fractures or other disorders. The carrying angle and Baumann angle commonly have been used to assess cubitus valgus or varus deformity on anteroposterior radiographs[1-3]. In 1984, Oppenheim et al. first described the humerus-elbow-wrist angle, which is also an index of coronal alignment of the humerus and forearm, for the postoperative assessment of the results of humeral osteotomy[4]. In recent years, the humerus-elbow-wrist angle gradually has been adopted for the radiographic assessment of the results of corrective osteotomy for the treatment of cubitus varus deformity or supracondylar humeral fracture[5-14]. Some investigators have examined the normal range of the humerus-elbow-wrist angle in the uninjured elbow[9,11-13]. The mean age of the patients in those studies ranged from 9.2 to 28.9 years; therefore, the normal value and range of the humerus-elbow-wrist angle in skeletally immature subjects are not fully known. Furthermore, although recent studies have used the humerus-elbow-wrist angle instead of the carrying angle for the assessment of postoperative results[9-14], the association between these 2 angles is unclear.

To date, limited data have been available to assess the intraobserver and interobserver reliability of measurements of the carrying angle and Baumann angle. Recently, the reliability

of those measurements has been demonstrated[3,15-19], but the reliability and validity of measurements of the humerus-elbow-wrist angle have not been studied, to our knowledge. Evaluating the reliability of measurements of the humerus-elbow-wrist angle by means of a simple comparison with the carrying angle or Baumann angle as reported in the previous studies is difficult because each of those studies was performed in a different setting, with variations in terms of the sample size (number of examiners and subjects), the age and health status of the subjects (children or adults, healthy or injured), the number of years of experience of the examiners, and the number of measuring times. Comparison of reliability under the same conditions is desirable[20].

The purpose of the present retrospective cohort study was to evaluate the normal value, range, reliability, and validity of measurements of the humerus-elbow-wrist angle in healthy children. We also measured the normal value and reliability of measurements of the carrying angle and Baumann angle. To assess the meaning of the humerus-elbow-wrist angle, the results were compared with those for the carrying angle or Baumann angle, which represent the gold-standard assessments for coronal alignment of the elbow.

Materials and Methods

The study protocol was approved by our institutional review board. From April 2007 to December 2015, 75 patients who underwent surgical treatment of a supracondylar fracture of the humerus were retrospectively enrolled at our single institution, which specializes in trauma surgery. According to the protocol at our hospital, radiographs of the uninjured elbow were made at the time of the initial injury; these radiographs were reviewed for the present study. Only patients who were ≤12 years of age were included because the capitellar physis is closed in some patients who are ≥13 years of age and measurement of the Baumann angle is difficult[21]. Exclusion criteria included previous trauma or flexion contracture of the uninjured elbow, radiographs that did not include relevant anatomical landmarks needed for measurement (e.g., radiographs that did not include the top of the radial bowing), congenital disorders, and the absence of available radiographs of the uninjured side. A senior resident (M.H.), who did not participate in the measurement, reviewed medical records and radiographs of the 75 patients and selected radiographs according to the criteria.

All radiographs were reviewed independently by 6 orthopaedic surgeons with different durations of experience at our institution. The group included 2 hand specialists (K. Shizu and T.S.), 2 senior residents (T.K. and Y.O.), and 2 junior residents (A.M. and H.T.). The postgraduate durations of experience of the orthopaedic surgeons in this group were 23 and 13 years for the 2 hand specialists (Observers 1 and 2), 8 and 6 years for the 2 senior residents (Observers 3 and 4), and 3 years for the 2 junior residents (Observers 5 and 6). The observers were informed that radiographs of the normal, uninjured elbow had been made for the patients with a supracondylar fracture of the humerus. The imaging review was repeated twice in the same manner at an interval of 4 weeks in a blinded fashion. Each reviewer was blinded to the measurements made by the other reviewers.

Measurement of Radiographic Parameters

During the research period, anteroposterior radiographs were made by about 30 radiographers. To ensure anteroposterior positioning of the elbow, all of the radiographs were made in a standard manner, without the use of sedation, with the patient sitting in a chair with the arm in full extension and with the forearm in supination. When the elbows were hyperextensible, radiographs were made in 0° of extension. A senior resident (M.H.) selected radiographs for review and input the identification numbers of the radiographs into computer software (Excel 2010; Microsoft). These data were made available to each observer and were used to generate digital radiographic images that were then stored in a picture archiving and communication system (PACS) in our hospital. Digital electrogoniometers linked to a computer were used for angular measurements (Rapideye Core; Toshiba Medical Systems). To ensure that all evaluations were completed in the same manner, a senior resident (M.H.) explained to each reviewer how to measure each parameter before the measurements were made.

The longitudinal axis of the humeral shaft was determined by a line connecting the midpoints of 2 transverse lines (1 proximal and 1 distal) across the humerus that connected the medial and lateral cortices. To measure the humerus-elbow-wrist angle and the carrying angle, 2 transverse lines across the forearm were drawn, 1 at each level, to achieve the shortest distance between the 2 cortices.

Humerus-Elbow-Wrist Angle[5]

The humerus-elbow-wrist angle is the angle between the longitudinal axis of the humeral shaft and a line passing through the midpoints of 2 transverse lines across the forearm. The proximal line was drawn at the level of the radial tuberosity, and the distal line was made at the level of the top of the radial bowing (Fig. 1).

Carrying Angle[22,23]

The carrying angle is the angle between the longitudinal axis of the humeral shaft and the longitudinal axis of the shaft of the ulna. The axis of the ulnar shaft was determined by a line passing through the midpoints of 2 transverse lines (1 proximal and 1 distal). The proximal line was drawn at the level of the olecranon, and the distal line was drawn at the level of the radial tuberosity (Fig. 2).

Baumann Angle[19,21]

The Baumann angle is the angle between the longitudinal axis of the humeral shaft and a line along the open capitellar physis (Fig. 3).

Fig. 1

Radiograph illustrating the humerus-elbow-wrist angle.

Fig. 2
Radiograph illustrating the carrying angle.

Fig. 3
Radiograph illustrating the Baumann angle.

Evaluation

The primary objective was to determine the normal values and ranges of the humerus-elbow-wrist angle, carrying angle, and Baumann angle. The secondary objective was to determine the intraobserver and interobserver reliability of the measurements of the humerus-elbow-wrist angle, carrying angle, and Baumann angle. The third objective was to determine the association between the humerus-elbow-wrist angle and the carrying angle to determine concurrent validity. We selected the carrying angle because this angle is a reliable tool to assess angular deformity of the elbow[3,15-17,19] and because the concept of the carrying angle, which shows an association between the humeral and ulnar axes, is similar to the humerus-elbow-wrist angle.

Statistical Analysis

The mean value and standard deviation of each radiographic parameter was calculated with use of data from the first and second acquisition sessions. Intraclass correlation coefficients (ICCs) were calculated according to standard statistical methods (ICC 1,1 for intraobserver reliability and ICC 2,1 for interobserver reliability). The ICCs were classified as demonstrating slight (≤ 0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), substantial (0.61 to 0.80), or almost perfect agreement (0.81 to 1.00)[24]. The ICCs for intraobserver and interobserver reliability were calculated with use of data from both the first and second acquisition sessions. Pearson correlation coefficients were used to evaluate the association between the humerus-elbow-wrist angle and carrying angle measurements, as an indicator of concurrent validity, with use of data from the first and second acquisition sessions. The correlation coefficient was interpreted as weak (<0.35), moderate (0.35 to 0.70), or strong (>0.70)[25]. A prior sample-size calculation based on 6 raters, a 95% confidence interval (CI) of 0.2, and an ICC of >0.7, which is generally considered to be significant, indicated that 47 samples were needed[20,26]. A p value of <0.05 was considered significant. Statistical analyses were performed with use of SPSS software (version 23.0; IBM).

Results

Patients

A total of 75 patients were assessed for eligibility, and 13 were excluded: 7 with unavailable radiographs of the uninjured side, 3 with unmeasurable radiographs, 2 with previous trauma of the elbow, and 1 with a congenital disorder (van der Hoeve syndrome). No patient had a flexion contracture of the elbow. The remaining 62 patients constituted the study group; these patients included 45 boys and 17 girls with a median age of 7 years (range, 2 to 11 years) at the time of the injury. The right elbow was involved in 40 patients (65%).

Measurement of Radiographic Parameters

The mean values of each radiographic parameter, categorized by age, sex, and laterality, are shown in Table I. The mean humerus-elbow-wrist angle of the 62 patients was 12.0° (range, 1° to 24°), the mean carrying angle was 14.6° (range, 4° to 28°), and the mean Baumann angle was 71.1° (range, 56° to 86°). The mean difference between the humerus-elbow-wrist angle and the carrying angle was 2.6° (range, −4° to 10°).

Intraobserver and Interobserver Reliability of the Measurements

The ICCs for intraobserver and interobserver reliability of the humerus-elbow-wrist angle, carrying angle, and Baumann angle are shown in Table II. The ICCs for intraobserver reliability of the humerus-elbow-wrist angle measurements were

TABLE I Radiographic Measurements Categorized by Age, Sex, and Laterality*			
	Humerus-Elbow-Wrist Angle (deg)	Carrying Angle (deg)	Baumann Angle (deg)
Total	12.0 ± 3.6	14.6 ± 3.8	71.1 ± 5.4
Age in yr			
2 to 6 (n = 30)	11.8 ± 3.6	14.5 ± 3.9	72.3 ± 5.2
7 to 11 (n = 32)	12.2 ± 3.6	14.7 ± 3.6	69.9 ± 5.3
Sex			
Male (n = 45)	11.8 ± 3.9	14.5 ± 3.9	71.2 ± 5.5
Female (n = 17)	12.6 ± 2.6	14.7 ± 3.4	70.7 ± 4.9
Laterality			
Right (n = 40)	11.7 ± 3.7	14.3 ± 3.8	71.1 ± 5.1
Left (n = 22)	12.6 ± 3.4	15.1 ± 3.7	71.0 ± 5.8

*The values are given as the mean and the standard deviation.

TABLE II Intraobserver and Interobserver Reliability of Radiographic Measurements*			
	Humerus-Elbow-Wrist Angle	Carrying Angle	Baumann Angle
Intraobserver reliability			
Observer 1	0.88 (0.81 to 0.93)	0.74 (0.61 to 0.84)	0.75 (0.61 to 0.84)
Observer 2	0.94 (0.90 to 0.96)	0.92 (0.87 to 0.95)	0.75 (0.62 to 0.84)
Observer 3	0.73 (0.59 to 0.83)	0.74 (0.61 to 0.84)	0.66 (0.49 to 0.78)
Observer 4	0.77 (0.65 to 0.86)	0.78 (0.66 to 0.86)	0.83 (0.74 to 0.90)
Observer 5	0.84 (0.75 to 0.90)	0.74 (0.60 to 0.83)	0.72 (0.57 to 0.82)
Observer 6	0.92 (0.87 to 0.95)	0.83 (0.73 to 0.89)	0.70 (0.55 to 0.81)
Interobserver reliability			
1st measurement	0.76 (0.68 to 0.84)	0.71 (0.61 to 0.80)	0.52 (0.41 to 0.63)
2nd measurement	0.78 (0.71 to 0.85)	0.59 (0.44 to 0.71)	0.50 (0.39 to 0.62)

*The values are given as the ICC, with the 95% CI in parentheses.

TABLE III Association Between Measurements of Humerus-Elbow-Wrist and Carrying Angles			
	Humerus-Elbow-Wrist Angle* (deg)	Carrying Angle* (deg)	Correlation Coefficient†
Observer 1	12.3 ± 3.4	14.3 ± 3.3	0.83 (0.76 to 0.88)
Observer 2	11.6 ± 3.6	14.6 ± 3.6	0.90 (0.86 to 0.93)
Observer 3	12.9 ± 3.8	14.1 ± 4.0	0.89 (0.84 to 0.92)
Observer 4	11.7 ± 3.6	13.7 ± 3.5	0.90 (0.86 to 0.93)
Observer 5	11.4 ± 3.5	14.1 ± 3.5	0.84 (0.78 to 0.89)
Observer 6	12.0 ± 3.6	16.7 ± 3.9	0.74 (0.66 to 0.82)

*The values are given as the mean and the standard deviation. †The values are given as the ICCI, with the 95% CI in parentheses.

almost perfect for 4 examiners and substantial for 2 examiners, with a mean value of 0.85 (range, 0.73 to 0.94). For the carrying angle measurements, the ICCs were almost perfect for 2 examiners and substantial for 4 examiners, with a mean value of 0.79 (range, 0.74 to 0.92). For the Baumann angle measurements, the ICCs were almost perfect for 1 examiner and substantial for 5 examiners, with a mean value of 0.74 (range, 0.66 to 0.83).

The ICCs for interobserver reliability between the first and second measurements were both substantial (0.76 and 0.78) for the humerus-elbow-wrist angle, substantial and moderate (0.71 and 0.59) for the carrying angle, and both moderate (0.52 and 0.50) for the Baumann angle.

Concurrent Validity of Measurement of the Humerus-Elbow-Wrist Angle

Table III shows the association between the humerus-elbow-wrist angle and carrying angle measurements by each observer to determine concurrent validity. The Pearson correlation coefficients were strong for all of the observers, ranging from 0.74 to 0.90. All correlations were significant (p < 0.001).

Discussion

In the present study, we performed radiographic measurements to determine the normal value and range of the humerus-elbow-wrist angle in healthy children. The intraobserver and interobserver reliabilities of humerus-elbow-wrist angle measurements were good and were equal to or greater than those for the carrying angle and the Baumann angle. The concurrent validity of measurement of the humerus-elbow-wrist angle was confirmed by the strong association between the humerus-elbow-wrist angle and carrying angle measurements.

Measurement methods for the carrying angle and the Baumann angle have limitations. Generally, radiographic measurement of the carrying angle is defined by the axes of the shafts of the humerus and ulna[21]. Because the ulnar shaft is complicated by the S shape of the ulna[17], definition of the axis of the ulnar shaft is different for each investigator. Different investigators have used the proximal part of the ulna[27], the diaphysis of the ulna[21,28], or the midline between the central points at 2 locations along the ulna of the ulna[17,19,22,23], whereas others have provided no clear definition[1,2,15]. Therefore, the reported value of the carrying angle varies according to the definition. The Baumann angle is defined by the axis of the humeral shaft and a line along the capitellar physis[21]. Some investigators have doubted the reliability of the Baumann angle because of the difficulty of identifying capitellar growth and distal humeral osseous landmarks[19,29,30]. Other authors have indicated that the metaphyseal border is too irregular in early adolescence, which can alter the measurement of the Baumann angle[31]. The humerus-elbow-wrist angle shows the angulation of the longitudinal axis of the humerus and forearm. The axis of the forearm is defined by a line passing through the midpoints of 2 transverse lines connecting the cortices, which help to determine the central axis of the forearm. Although the

original literature and other reports regarding the humerus-elbow-wrist angle only described the level of 2 transverse lines across the forearm as "1 proximal and 1 distal,"[4-14] we determined the level of these lines at the radial tuberosity and the top of the radial bowing. This definition might lead to good measurement reliability.

In 1984, Oppenheim et al. first reported on the measurement of the humerus-elbow-wrist angle with use of full-view radiographs of the humerus and forearm[4]. In that report, the distal transverse line of the forearm was drawn around the distal part of the radius. In 2005, Kim et al. modified the measurement methods by using only radiographs of the elbow[5]. They drew the distal transverse line more proximally, around the top of the radial bowing. Many other studies have evaluated the humerus-elbow-wrist angle with use of radiographs of the elbow[5,7-10]. We believe that it is not practical to routinely make full-view radiographs of the humerus and forearm in the course of postoperative evaluation of an elbow injury. Therefore, we evaluated the humerus-elbow-wrist angle with the modified methods described by Kim et al.[5].

In previous studies, the ICCs of the carrying angle measurement have ranged from 0.83 to 0.98 (intraobserver reliability) and from 0.66 to 0.97 (interobserver reliability)[3,15-17,19]. The ICCs for the Baumann angle measurement have ranged from 0.77 to 0.98 (intraobserver reliability) and from 0.37 to 0.96 (interobserver reliability)[3,15,18,19]. Reliability has varied among studies, with a wide range in the values of ICCs, especially for the interobserver reliability of the Baumann angle. Our data are roughly consistent with those of previous reports. The wide range of ICCs can be explained by the different research settings in each study[20]. We compared the reliability of measurement of the humerus-elbow-wrist angle, carrying angle, and Baumann angle under the same conditions, which improves the interpretation of the association of these parameters. Furthermore, we believe that other studies performed in settings similar to ours confirm the reliability of the humerus-elbow-wrist angle measurement[20].

To our knowledge, no previous studies have evaluated the association between the humerus-elbow-wrist angle and the carrying angle. It is well known that the normal carrying angle ranges from 0° to 25°[3,16,17,19]. An increasing angle represents valgus alignment, and a decreasing angle represents varus alignment. The present study provides evidence that the humerus-elbow-wrist angle is significantly associated with the carrying angle and is about 3° smaller than the carrying angle. This finding suggests that the humerus-elbow-wrist angle also can be used to evaluate valgus or varus angulation of the elbow.

The present study has some limitations. First, subjects with a supracondylar fracture of the humerus were enrolled retrospectively and radiographs of the uninjured side were used. In the present study, 40 subjects (65%) were between 4 and 8 years of age, which represents the age range in which pediatric elbow fractures most commonly occur[1,13,23]. Our results may not accurately reflect all skeletally immature children. Furthermore, 73% of the subjects were male and 65% of the evaluations were for the right elbow. Some

previous authors have indicated that the values of the carrying angle differ by sex or side[28,32]. The uneven distribution by sex or laterality in the present study could have affected the normal value and range calculated for each radiographic parameter. An unbiased population-based large cohort study with an enrollment of healthy volunteers is desirable to obtain true normative data on coronal alignment of the upper limb in the growing child. Second, as described above, the original literature and other previous reports regarding the humerus-elbow-wrist angle did not clearly define the level of the proximal and distal transverse lines of the forearm[4-14]. For accurate measurements, we used our own method for measuring the humerus-elbow-wrist angle. Our measurement method for the carrying angle was selected because it is widely used to determine the axis of the ulnar shaft[17,19,22,23], but there are many different definitions of the carrying angle. The utility of our information regarding the humerus-elbow-wrist angle and carrying angle may be necessarily limited. Third, the humerus-elbow-wrist angle and carrying angle cannot be correctly measured in patients with elbow contractures, which represents a disadvantage of this measurement method.

Despite such limitations, we found that the measurement of the humerus-elbow-wrist angle was associated with good reliability and validity. We conclude that the humerus-elbow-wrist angle is a reliable radiographic measure of coronal alignment of the humerus and forearm. ■

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Update

This article was updated on May 4, 2017, because of a previous error. The proximal line drawn in Figure 1 was different from the line described in the Materials and Methods section, which reads "The proximal line was drawn at the level of the radial tuberosity, and the distal line was made at the level of the top of the radial bowing (Fig. 1)." The correct figure is presented in this version of the article.

An erratum has been published: JBJS Open Access. 2017 May 26;2(2):e0012ER.