Original Article

Importance of anterior humeral line for successful anatomical reduction in the surgical treatment of pediatric supracondylar humeral fractures

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ABSTRACT

Anterior humeral line (AHL) and tilting angle (TA) are used for the assessment of pediatric elbow sagittal plane alignment in surgical treatment of pediatric supracondylar humeral fracture. However, few studies exist that compare the reliabilities between these parameters. The purpose of this study is to determine whether measurements of radiographic parameters are reliable and useful for achieving anatomical reduction. In the current study, we demonstrated that the identifying the AHL location involves a simple and reliable measurement compared with TA. The intraoperative AHL identification is a good indicator for achieving anatomical reduction.

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1. Introduction

The minimum radiographic assessment of pediatric supracondylar humeral fractures involves anteroposterior (coronal) and lateral (sagittal) radiographic films. Most publications concerning pediatric supracondylar humeral fractures focus on malalignment in the coronal plane.¹ The reduction on the sagittal alignment has not received the same attention as that on the coronal alignment because hyperextension deformity is frequently expected to be corrected with growth. However, several reports demonstrate that patients with an underreduced supracondylar fracture in the sagittal plane still show radiographic abnormality until skeletal maturity and have limited elbow flexion.^{2,3} Therefore, orthopedic surgeons should be aware of this possible outcome and be more demanding in the reduction on the sagittal alignment.

In contrast to the coronal plane, there are numerous detailed studies on the sagittal plane investigating the influence of more than one radiological parameter on reduction. The anterior

humeral line (AHL) is a valuable radiographic tool to assess sagittal plane alignment for pediatric supracondylar humeral fractures.^{4–6} The AHL is drawn along the anterior humeral cortex and extended distally through the capitellum on the lateral projection of the elbow. AHL passes through the middle third of the capitellum in normal elbows. Only a few published reports have discussed the use of this measurement in the surgical treatment of pediatric supracondylar humeral fracture.^{7,8} Furthermore, the intraoperative interpretation of AHL location could be inconsistent because of distal fragment rotation,⁶ and information on capitellum orientation is not adequate.⁷

The tilting angle (TA) is also a measure of sagittal plane alignment following pediatric supracondylar humeral fractures. TA is the anterior tilt of the capitellum with respect to the long axis of the humerus in the sagittal plane.⁹ This relationship has been measured by multiple methods and referred to by multiple names in literature, such as humerocondylar angle,² lateral capitello-humeral angle,¹⁰ capitellar angle,¹¹ and humerocapitellar angle.^{8,12} The methods of measuring TA are quite simple; however, given the significant individual variations in TA, those methods alone are inadequate to make final decisions in the treatment of pediatric supracondylar humeral fractures.² TA can show the antero-posterior displacement of the distal humeral fragment, but it is not sufficient for the evaluation of rotation.¹³

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The clinical value of radiographic measurements depends on their reliability and the reproducibility with which they can be obtained. If a value cannot be measured with high reliability and reproducibility, changes in the value may represent measurement error rather than clinical reality. This study aimed to determine whether measurements of radiographic parameters in the elbow sagittal plane are reliable and useful to achieve anatomical reduction. Intra- and inter-observer agreement in the measurements of the fractures on radiographs was assessed by orthopedic surgeons with various levels of training.

2. Materials and methods

2.1. Study design

Institutional review board approval was obtained prior to initiation of this study. Radiographs were taken immediately postoperatively from patients who underwent closed reduction and percutaneous K-wire fixation following a displaced supracondylar humeral fracture at our institutions between 2004 and 2013. We excluded patients with other upper extremity fractures, or a previous history of fracture. We also excluded any patients for whom a true lateral radiograph could not be obtained. The true lateral radiograph should demonstrate superimposed posterior supracondylar ridges of the distal fragment of the humerus, in accordance with the observation by Skibo and Reed.⁶ Of the entire population enrolled in this study, 44 patients met these criteria and the mean patient age at the time of the fracture was 7 years (range 5–12 years).

Three observers with different levels of orthopedic training (orthopedic surgeon 1, 13 years board-certified surgeon; orthopedic surgeon 2, 8 years board-certified surgeon; and orthopedic surgeon 3, 3 years as a resident) measured three radiographic parameters, namely, the AHL location, TA, and Baumann's angle (BA), to determine the intra- and inter-rater reliabilities. The radiographs were distributed to the three observers in a random manner after any identifying patient information had been removed. To avoid recall bias, the observers repeated their measurements on all 44 radiographs in a similar manner following a period of at least two weeks from the initial assessment. They were blinded to the results of their first evaluation. An independent investigator (orthopedic surgeon 4, 14 years board-certified

surgeon) dissociated with the measurement process performed the blinding and randomization of the patients, as well as the collection and analysis of the data.

2.2. Radiographic measurement

The AHL is drawn along the anterior humeral cortex and extended distally through the capitellum on the lateral projection of the elbow. The AHL location was measured by drawing a second line from the anterior to the posterior aspect of the capitellum and dividing the capitellum into three equal parts. It was assessed as the relationship between AHL and capitellum, which was classified as the anterior middle third, middle third, and posterior middle third (Fig. 1).

TA was measured by drawing two transverse lines across the humerus connecting the anterior and posterior cortices of the radius. A line connecting the midpoints of the two lines was then drawn along the humerus for the long axis of the humerus. Another line along the long axis of the humeral diaphysis was also drawn. Finally, TA was measured as the angle made by the two lines (Fig. 2).

BA is the angle formed by the capitellar physis and the line along the humeral shaft axis. BA was measured by drawing two transverse lines across the humerus connecting the medial and lateral cortices of the radius. A line connecting the midpoints of the two lines was then drawn along the humerus for the long axis of the humerus. Finally, BA was measured as the angle made by the two lines (Fig. 3).

2.3. Statistical analysis

The AHL location is a categorical variable, and the kappa statistic with 95% confidence intervals was used to test both inter-rater and intra-rater reliabilities. Although no standard value exists for acceptability, a kappa statistic of 0–0.20 represents slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and >0.80, almost perfect agreement according to the definitions of Landis and Koch.⁹

TA and BA are continuous variables, and intraclass correlation coefficients were used to assess inter-rater and intra-rater reliabilities. Similar to the kappa statistic, correlations from 0 to

Fig. 1. **a.** Anterior humeral line (AHL); a line was drawn along the anterior border of the distal humerus in the proximal fragment. **b.** A second line was drawn from the anterior to the posterior aspect of the capitellum and perpendicular to the axis of the distal part of the humerus shaft. The second line divided the capitellum into three equal parts. The relationship between the AHL and capitellum was classified as anteriorly loss (A), middle third (M) and posteriorly loss (P).

Fig. 2. Tilting angle (TA); the angle is measured as the anterior tilt of the articular condyles with respect to the long axis of the humerus.

0.20 indicate poor reliability; 0.21 to 0.40, fair reliability; 0.41 to 0.60, moderate reliability; 0.61 to 0.80, substantial reliability; and >0.80, almost perfect reliability.

BA was also analyzed for any correlations with the radiographic parameters in the elbow sagittal plane. The correlation between the AHL location and BA was evaluated with Student's *t*-test. The correlation between TA and BA was assessed with Pearson product-moment correlation coefficient (*r*). Analysis of the data was conducted using the SPSS software (version 22.0; SPSS Inc., Chicago, IL).

3. Results

AHL passed through the anterior middle third in 63%, the middle third in 37%, and posterior middle third in 0%. The mean TA and BA were 37 ± 9 degrees and 71 ± 6 degrees, respectively. The AHL locations showed substantial-to-almost perfect intra-rater (0.79–0.91) and substantial inter-rater reliabilities (0.75). TA exhibited substantial intra-rater (0.70–0.75) and moderate inter-rater reliabilities (0.57). BA showed substantial-to-almost perfect intra-rater (0.62–0.90) and substantial inter-rater reliabilities (0.70) (Table 1).

The AHL location had a statistically significant difference in the mean BA between the middle third (69 ± 3 degrees) and the anterior middle third (74 ± 8 degrees) in orthopedic surgeon 1 ($p < 0.05$). Pearson product-moment correlation coefficient showed no significant correlation between TA and BA in orthopedic surgeon 1 ($r = 0.06$, $p > 0.05$).

Fig. 3. Baumann's angle (BA); the angle is formed by the capitellar physis and the line along the humeral shaft axis.

4. Discussion

The current study demonstrates that the AHL location showed substantial-to-almost perfect intra-rater and substantial inter-rater reliabilities. TA had substantial intra-rater reliability, but its inter-rater reliability was worse. These results suggest that TA can be measured reproducibly by a single observer, but with lower inter-observer reliability. TA is a good tool to compare radiographic treatment outcomes among multiple surgeons. Previous reports demonstrated that the intra-rater and inter-rater reliabilities for TA range from 0.67 to 0.87 and 0.37 to 0.60, respectively,^{10,14} which are similar to the current study. Identifying the AHL location is a

Table 1
Reliability of radiographic measures.

Measurements	Inter-rater reliability	Intra-rater reliability for orthopedic surgeon 1	Intra-rater reliability for orthopedic surgeon 2	Intra-rater reliability for orthopedic surgeon 3
Categorical variables Kappa (95% CI)				
AHL	0.75 (0.63–0.84)	0.91 (0.78–1.0)	0.85 (0.69–1.0)	0.79 (0.60–0.98)
Continuous Variables ICC (95% CI)				
TA	0.57 (0.38–0.73)	0.75 (0.59–0.86)	0.72 (0.54–0.84)	0.70 (0.52–0.83)
BA	0.70 (0.56–0.82)	0.90 (0.83–0.95)	0.85 (0.73–.91)	0.62 (0.40–0.77)

ICC; intraclass correlation coefficients. CI; confidence interval. AHL; anterior humeral line. TA; tilting angle. BA; Baumann's angle.

simple and reliable measurement among multiple surgeons. It has become a useful tool for achieving accurate anatomical reduction in the treatment of pediatric supracondylar humeral fractures.

Takeyasu et al. demonstrated that 80% of cases with cubitus varus deformity have extensional and rotational deformities.¹⁴ Their result suggested that the extensional and rotational malalignment reduction was also important in the treatment of pediatric supracondylar humeral fracture. Although TA shows the antero-posterior displacement of the distal humeral fragment, it is not sufficient for the evaluation of rotation.¹³ The intraoperative anterior bony spike of the proximal fragment demonstrated the residual extensional and rotational malalignments. However, TA cannot take the anterior bony spike into consideration in the measurement. On the other hand, AHL can reflect the anterior bony spike and can assess residual extensional and rotational malalignments. In the current study, the AHL location showed a statistically significant difference in the mean BA between passing through the middle third and passing the anterior middle third. The residual extensional and rotational malalignments cause varus malalignment, particularly in cases with oblique fracture line from anterior to posterior in the sagittal plane.¹⁵ The intraoperative reduction with AHL passing through the middle third of the capitellum was important to achieve successful anatomical reduction not only in the sagittal plane but also in the coronal plane.

Herman et al. demonstrated that the kappa value of AHL ranges from 0.56 to 0.68, with the analysis of all radiographs regardless of age⁵; their finding was lower than that of the current study. We assumed these differences to be related to the anatomical feature of mild posterior bowing in the humerus. In the measurement of AHL, little information is available about how to draw a line along the anterior cortex of the humerus that considers bowing. We used only the distal third of the humerus, the anterior border of the proximal fragment, for the measurement of AHL to eliminate the bowing effect. The differences in measurement between the present study and Herman et al. may be related to the reliability results. Our measurement method can reduce error in the reliability of AHL.

The current study has several limitations. First, we did not investigate whether the AHL location in the unaffected side passes through the middle third of the capitellum. Ryan et al. demonstrated that the AHL passes through the middle third of the capitellum in all patients ≥ 5 years, but the AHL falls outside of the middle third of the capitellum in a quarter of patients < 5 years.⁴ Because all the collected radiographs were ≥ 5 years, the AHL location in our collected data was considered to pass through the middle third of the capitellum. However, in skeletally immature patients < 5 years, the reliability of the AHL location may be worse compared with the results of the current study. Second, we investigated the correlation between the AHL location and BA in 2-dimensional evaluations. The correlation can be evaluated with more accuracy in 3-dimensional evaluations. However, the 2-dimensional evaluation reflects typical images that are obtained postoperatively, which may have more clinical significance. Finally, we only compared the AHL location with TA. Turhan et al. recommended that a few radiological criteria should be combined on the sagittal plane for an adequate reduction.¹³ The combination of AHL location and other radiological criteria on the sagittal plane may improve reliability, even in skeletally immature patients. Whether the combination of the AHL location and a few other radiological criteria on the sagittal plane improves the anatomical reduction should be evaluated in the future.

In conclusion, identifying the AHL location is a reliable measurement compared with TA. The AHL location correlated with BA, suggesting that intraoperative identification of the AHL location is a good indicator for postoperative elbow deformity. The

reduction of the distal fragment with AHL passing through the middle third of the capitellum is important to achieve anatomical alignment in the treatment of pediatric supracondylar humeral fracture.

Conflicts of interest

The authors have none to declare

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Individual contributions

T. Shimizu, A. Yoshida, and S. Santo designed this study. T. Shimizu, T. Onishi, and H. Hasegawa conducted the measurements on the radiographs. A. Yoshida and T. Kira conducted the collection and analysis of the data. S. Omokawa, K. Kawamura, and Y. Tanaka served as scientific advisors and jointly interpreted the results. T. Shimizu and A. Yoshida wrote the manuscript. T. Shimizu and S. Omokawa conducted critical revision of the article for important intellectual content. All authors have approved the manuscript for submission.

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