ORIGINAL PAPER/PŮVODNÍ PRÁCE

Comparison of Usability of Sagittal Plane Parameters with Baumann Angle in Radiological Imaging of Supracondylar Humerus Fractures

Porovnání použitelnosti parametrů sagitální roviny s Baumannovým úhlem při radiologickém zobrazení suprakondylické zlomeniny humeru

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ABSTRACT

Purpose of the study

Radiological studies in supracondylar humerus fractures (SCHF) often focus on coronal plane imaging. In our study, we focused on the measurements used in elbow sagittal plane imaging. We investigated the role of humeral shaft condylar angle (SCA) and lateral capitellohumeral angle (LCHA) in determining the reduction quality by comparing them with Baumann angle (BA). İnvestigated its effectiveness in assessing the reduction of the teardrop figure and in the follow-up period.

Material and methods

Eighty-eight patients with SCHF were included in the study. BA, SCA and LCHA measurements were taken on the non-fractured contralateral elbow. The same measurements were made on the post-reduction radiographs of the fractured side and the two groups were compared. Angular measurements were performed on 98 healthy children to determine the normal values of SCA and LCHA. Teardrop figure was evaluated and compared as present or absent in the pre-fracture, post-reduction and 3-month control radiographs of 88 surgically treated patients.

Results

SCA and LCHA were found to be statistically different between the two groups ($p = 0.002$ and $p < 0.001$). BA was statistically consistent in both groups ($p = 0.160$). The reformation of the teardrop figure compared to post-fracture; when compared in post-reduction and postoperative 3rd-month radiographs, was statistically significant ($p = 0.027$, $p < 0.001$).

Conclusions

BA is an important parameter for evaluating reduction. SCA and LCHA were found to be unsuccessful in evaluating reduction. Additionally, evaluating the teardrop figure after reduction and in follow-ups is important in terms of assessing reduction quality and monitoring healing.

Key words: pediatric elbow, supracondylar humerus fractures, Baumann angle, humeral shaft condylar angle, lateral capitellohumeral angle, teardrop figure.

INTRODUCTION

Supracondylar humerus fractures (SCHF) are the second most common fractures in children following forearm fractures (6). Unlike forearm fractures, supracondylar humerus fractures often require surgical treatment. In treatment, percutaneous pinning is applied after closed or open reduction (3, 9, 24). Malunion of a supracondylar humerus fracture can lead to permanent deformities due to limited remodeling in the distal humerus (4, 8). It is important to determine the quality of reduction clinically and radiologically to avoid missing

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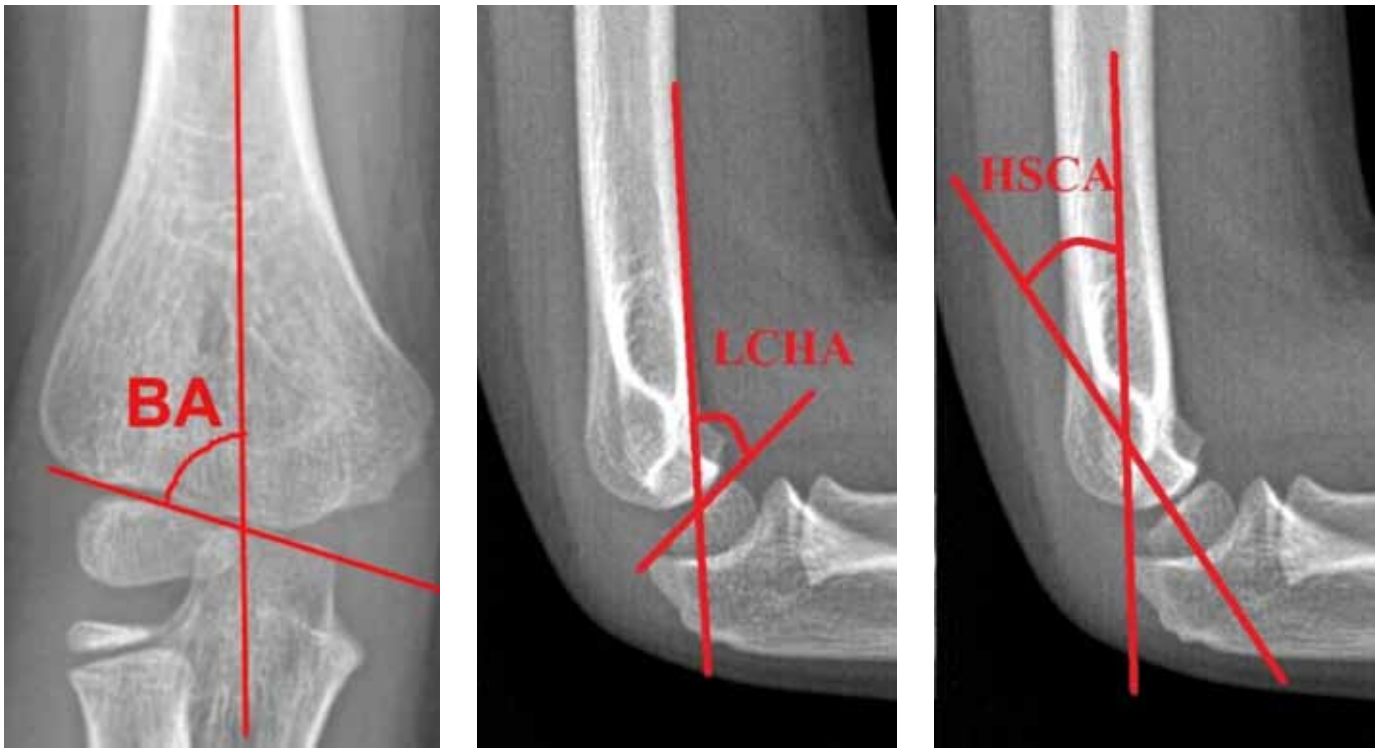

Fig. 1. **Angular measurements: BA: Baumann Angle, LCHA: Lateral Capitellohumeral Angle, HSCA: Humeral Shaft Condylar Angle.**

the fracture and to prevent postoperative complications (1). Elbow radiography is the gold standard in the diagnosis and treatment of supracondylar humerus fractures, and angular measurements and lines have been defined in the literature (2, 5). Anterior Humeral Line (AHL) in the sagittal plane is an important parameter in evaluating the fracture and deciding on treatment (12).

Among long-term complications, coronal plane deformities such as cubitus varus are often observed. Therefore, radiological and clinical studies have mostly focused on coronal imaging. For this purpose, the most commonly used radiological measurement is the Baumann angle (BA), which has been found to have high inter-user reliability (14, 18). It is the angle between the physeal line of the lateral condyle and the line drawn perpendicular to the long axis of the humeral diaphysis on an AP radiograph (Fig. 1). Although studies including sagittal plane angular measurements are limited due to the knowledge that sagittal plane alignment disorders are better remodeled than coronal plane alignment disorders after supracondylar humerus fracture, it has been shown that permanent complications may develop in the sagittal plane (10).

The angular measurements evaluated in limited studies are the humerus shaft condylar angle (SCA) and lateral capitellohumeral angle (LCHA) (17, 19, 22, 23). The Lateral Capitellohumeral Angle (LCHA) is the angle between the AHL and the line connecting the physis of the capitellum on a lateral radiograph (17, 19). The Humerus Shaft Condylar Angle (SCA) is the angle between the line drawn along the midline of the humeral shaft and the long axis of the lateral condyle on a lateral radiograph (22, 23) (Fig. 1). However, there is no study evaluating the effectiveness of these two angles in determining the quality of reduction. The teardrop figure is the silhouette

Fig. 2. **Radiological image of teardrop figure.**

formed by the distal humerus structures on a lateral radiograph (11). Distortion in the contours is evaluated in favor of a fracture (Fig. 2). In our study, we aimed to measure the effectiveness of sagittal plane angular measurements and radiological lines evaluated in different studies in determining the quality of reduction. The Bauman angle, whose effectiveness has been proven in previous studies, was re-examined in our study and its effectiveness was compared with SCA and LCHA. Additionally, we aimed to investigate the usability of the teardrop sign, which is only used in detecting the fracture, in postoperative follow-ups.

MATERIAL AND METHODS

After obtaining approval from the local institutional review board, a retrospective review was conducted. Patients who presented to our clinic with supracondylar humerus fractures (SCHF) in our hospital between June 2019 and December 2022 were examined. To evaluate the quality of reduction, 88 patients who presented with SCHF and were surgically treated by us were included in the study. All surgically treated patients were treated with percutaneous pinning after closed or open reduction. The surgeries were performed by two orthopedic surgeons, one of whom was a pediatric orthopedist. Intraoperatively, under fluoroscopy, sagittal plane reduction was accepted as the AHL passing through the middle 1/3 of the capitellum. The contralateral elbow images of 78 of these patients, who had no fracture, were used to compare with the postoperative angles of the fractured side. Additionally, to determine the range of SCA and LCHA in normal elbows, 98 healthy children of similar ages to those with SCHFX, who had no fractures, were included in the study. For healthy group measurements, our radiology archive was retrospectively scanned and previously taken elbow radiographs for different complaints were used. Postoperative reduction evaluation used the portable digital radiographs taken in the ward by an orthopedic doctor. Remaining radiographs were taken in the radiology room by an experienced technician using standard techniques. True AP and lateral images were included in the study. The study was conducted using the radiographs in the hospital's radiological imaging system, and digital Cobb angle measurement was used for angular measurements.

Measurements were performed separately by three orthopedic surgeons, one of whom is a pediatric orthopedist. Observers received specific instructions on how to measure the angles to ensure a standardized technique. All radiographs were presented to the observers in a random order, and any identifying patient information was concealed.

The teardrop figure was evaluated as present or absent in the fracture radiograph, postoperative ward radiograph, and postoperative 3rd-month radiograph of the patients by three orthopedic surgeons together. The presence or absence was compared between the three periods in 75 patients who had radiographs for all three periods.

Table 1. **Patient groups and sizes**

Surgically treated patients	88
Healthy children	98
Individuals with a solid opposite elbow appearance	78
Individuals with reduction radiographs after surgical treatment	81
Patients with teardrop figure evaluation	75

BA, SCA, and LCHA were measured in the intact contralateral elbow and on the fractured side after reduction. SCA and LCHA were also measured in the elbows of 98 healthy children.

BA, SCA, and LCHA measurements were performed separately by the observers. The measurements were then placed in a new random order and measurements were performed a second time. Observers were blinded to the results of their first assessments. At least one month was allowed between the two measurements. Of the 88 patients with fractures, the postoperative films of 81 patients met the criteria for all three angles. Measurements of 78 patients' contralateral elbows were suitable for all three angles. SCA and LCHA angles were measured in the elbows of 98 healthy children without fractures. A total of 2,496 measurements were made for each angle on 257 elbow radiographs. Compared groups and sample sizes are shown in Table 1.

Descriptive statistics were calculated using the median, interquartile range, and minimum and maximum values for continuous data, while categorical data were presented as frequencies and percentages. The Kolmogorov-Smirnov test was used to assess the normality of continuous data. For normally distributed data, the Independent Sample T-Test was used for comparing two groups, and one-way analysis of variance (ANOVA) was used for comparisons among three groups. For non-normally distributed data, the Mann-Whitney U Test was used for paired group comparisons, and the Kruskal-Wallis test was used for comparisons among three groups. Statistical significance was set at a p-value of < 0.05. All statistical analyses were performed using IBM® SPSS® version 26.0.0.0.

RESULTS

It was observed that the average age of the 88 patients included in the study and surgically treated was 69.57 months (Range: 14–150 months). The gender was predominantly male (58%). The fracture side was more on the left side (64.6%).

The status of the teardrop figure was compared in three different groups. The presence or absence of the teardrop figure was evaluated in the post-fracture, post-reduction, and

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Table 2. **Comparison of the presence of the teardrop figure**

	TEARDROP FIGURE EVALUATION (N = 75)	
	ABSENT	PRESENT
Preoperative	61 (81.3)	14 (18.7)
Postoperative	49 (65.3)	26 (34.7)
P-value	**0.027**	
Postoperative	49 (65.3)	26 (34.7)
3rd-month control	33 (44)	42 (56)
P-value	**0.009**	
Preoperative	61 (81.3)	14 (18.7)
3rd-month control	33 (44)	42 (56)
P-value	**< 0.001**	

Values are represented as numbers (percentages). N: number of patients.

postoperative 3rd-month radiographs. When the post-fracture and post-reduction groups were compared, the reformation of the teardrop figure was found to be statistically significant ($p = 0.027$). When the post-reduction and postoperative 3rd-month groups were compared, the reformation of the teardrop figure was found to be statistically significant ($p = 0.009$). When the post-fracture and postoperative 3rd-month groups were compared, the reformation of the teardrop figure showed a strong statistical value ($p < 0.001$) (Table 2).

SCA was measured as an average of 36.67° (6.39) in 98 patients in the group without fractures. LCHA was measured as an average of 50.15° (9.99) in the same group.

Comparisons were made between the angular measurements of the contralateral elbows of surgically treated patients and the angular measurements of the fractured side after reduction. In the contralateral elbow group, angular measurements of 78 patients met the standards, while in the post-reduction group, angular measurements of 81 patients met the standards. SCA and LCHA were found to be statistically different between the two groups ($p = 0.002$ and $p < 0.001$). The Bauman angle was statistically consistent in both groups ($p = 0.160$) (Table 3).

Table 3. **Comparison of elbow angles between the healthy contralateral elbow and the first postoperative radiograph measurements of the fractured side**

	CONTRALATERAL ELBOW N = 78	POSTOPERATIVE N = 81	P-VALUE
Baumann angle	74.32 (± 5.03)	75.56 (± 4.90)	0.160
Humerus shaft condylar angle	33.89 (± 8.52)	28.08 (± 11.51)	0.002
Lateral capitellohumeral angle	51.24 (± 9.74)	61.61 (± 14.58)	< 0.001

N: number of patients.

DISCUSSION

Supracondylar humerus fractures are the second most common childhood fractures, and debates regarding their treatment continue (6). Permanent deformities can occur if reduction is not adequately performed in treatment. Among long-term complications, coronal plane deformities such as cubitus varus are often observed (4, 8). Therefore, radiological and clinical studies have mostly focused on coronal imaging. Since sagittal plane malalignments after supracondylar humerus fractures are accepted to remodel better than coronal plane malalignments, studies including sagittal plane angular measurements are limited. In these limited studies, it is also reported that existing information sources cannot be accessed (19). However, studies have shown that deformities also develop in the sagittal plane (10, 20). France and Strong found that the LHCA was strongly associated with loss of flexion after supracondylar fractures and did not reliably remodel with growth (10). Simanovsky et al. examined 22 supracondylar fractures that were inadequately reduced in the sagittal plane and found that the LHCA was associated with loss of flexion at skeletal maturity (20). In short, there is evidence that significant sagittal plane angular deformity can cause clinical loss of motion. Therefore, in our study, we aimed to conduct a comprehensive examination to evaluate reduction in the sagittal plane after supracondylar humerus fractures. Including 88 patients who were surgically treated and the presence of measurements of 98 patients without fractures is a fairly good number compared to other studies. The fact that 78 of the 88 patients with fractures had contralateral elbow radiographs and provided us with the opportunity to make comparisons is a strong aspect of our study. Evaluating the teardrop figure in terms of reduction and healing is presented by us for the first time in the literature.

The anterior humeral line (AHL) is an important parameter for detecting the fracture and evaluating the reduction in sagittal imaging. In our study, the AHL was evaluated only in SCHF patients requiring surgical treatment. Since intraoperatively, reduction was based on bringing the AHL to the midline, a comprehensive AHL evaluation could not be performed in our study. Herman et al., in their study, report that the AHL does not always pass through the middle third of the capitellum and that a normal population where it passes through the anterior third exists (12). Additional studies are needed on the AHL in different age groups and populations. In our study, which offers a comprehensive sagittal plane evaluation, the lack of AHL evaluation constitutes a limitation of our study.

The Baumann angle (BA) has been found to have excellent intraobserver and interobserver reliability. It is the most commonly used angular parameter in detecting the fracture and evaluating the reduction since its effectiveness has been demonstrated in many studies. In our study, we wanted to compare the effectiveness of BA with sagittal plane angular

measurements. In the measurements made on the contralateral healthy elbows of patients with SCHF, BA was measured as 74.32 ± 5.03°. This value is consistent with values measured in the literature (7, 13, 21). The BA value measured after reduction was an average of 75.56±4.90°, and when compared with the measurements of the contralateral elbow, no statistical difference was found (p = 0.160). In our study, BA was found to be an important parameter in evaluating reduction.

The SCA and LCHA have been examined in a few studies. Studies on SCA are even more limited, and different values have been reported in studies (15, 16, 21, 23). Recently, Suangyanon et al., in their study, reported that the SCA had excellent intraobserver reliability and good interobserver reliability (21). Musikachart et al. reported good intraobserver reliability and moderate interobserver reliability for SCA (16). Turhan et al. reported an SCA of approximately 30° (23). Suangyanon et al. reported an SCA measurement of 40.10 ± 6.24° (21). Musikachart et al. recorded an SCA of 43.31 ± 4.66° (16). In our series, the SCA was found to be 33.89 ± 8.52° and 36.67 ± 6.39° in the contralateral and healthy elbow measurement groups, respectively. In our study, when the SCA was compared between the postoperative fractured and healthy sides, the difference was statistically significant (p = 0.002). Different studies have reported varying SCA measurements, and a common range has not been established. One reason for the different SCA values in these studies is the difficulty in measurement due to the small size and spherical nature of the capitellum at early ages. Current findings and differences in the literature show that SCA is not useful in diagnosing SCHF or determining reduction quality. Separately evaluating different age ranges may make the SCA more useful.

Simanovsky et al. defined the LCHA as the humerocondylar angle (HCA) in their study, they stated that HCA is significant for evaluating reduction but is not sufficient alone (19). Shank et al., in their study on LCHA and BA, good intraobserver reliability but moderate interobserver reliability for LCHA (17). In the same study, the average LCHA value was reported as 50.8 ± 6.2°. It did not vary significantly with age, sex, or side. Suangyanon et al. reported an average LCHA of 51.8 ± 7.56°, with excellent intraobserver reliability and good interobserver reliability (21). Musikachart et al. reported an average LCHA of 47.79 ± 5.13°, with excellent intraobserver reliability and moderate interobserver reliability (16). In our series, the LCHA values were 51.24 ± 9.74° and 50.14 ± 9.99° in the healthy contralateral elbow and healthy population, respectively, which was consistent with the literature. For reduction quality on the fractured side, LCHA averaged 61.61±14.58° after reduction in our series, showing a significant difference compared to the contralateral elbow (p < 0.001). In our clinic, a reduction is deemed sufficient during sagittal plane evaluation if the AHL passes through the middle third of the capitellum on lateral imaging. A millimeter difference in the relationship between the AHL and the capitellum causes angular differences between the SCA and LCHA. We believe that the statistical differences observed in our study arose from this finding. Therefore, there are limitations to the use of SCA and LCHA in evaluating reduction quality. The LCHA values measured in different studies and that in our study were similar. Although LCHA is inadequate for determining reduction quality, it appears more reliable than SCA.

In lateral elbow imaging, the teardrop figure is primarily evaluated in the initial detection of the fracture (3). In our study, differently, the teardrop figure was compared as present and absent in the post-fracture, post-reduction, and postoperative third-month outpatient control radiographs. When the post-fracture and post-reduction radiographs were compared, the reformation of the teardrop figure was statistically significant (p = 0.027). When the post-reduction and postoperative third-month radiographs were compared, the reformation of the teardrop figure was found to be statistically significant (p = 0.009). When the post-fracture and postoperative third-month radiographs were compared, the reformation of the teardrop figure showed a strong statistical value (p < 0.001). Evaluating the teardrop figure in follow-ups and observing its formation can be a guide in terms of correct reduction and good healing. There is no such study in the literature, and the idea of evaluating the teardrop figure during the follow-up period has been proposed by us for the first time.

Our study and other studies in the literature show that there is no measurement in sagittal imaging of the elbow that is as effective and reliable as BA. With our idea of evaluating the teardrop, we tried to obtain reliable parameter in sagittal plane evaluation. However, it does not seem possible at present to make an evaluation in the sagittal plane with a single parameter. Therefore, we recommend evaluating more than one parameter when making an assessment in the sagittal plane of the elbow.

Limitations:
Among the limitations of our study is that angular measurements were not evaluated separately in different age groups.

CONCLUSIONS

BA is an important parameter for evaluating reduction. SCA and LCHA were found to be unsuccessful in evaluating reduction. Although our LCHA values are consistent with the literature, the SCA value was found to be different. Additionally, evaluating the teardrop figure after reduction and in follow-ups is important in terms of assessing reduction quality and monitoring healing. ■

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