Original Article Clinics in Orthopedic Surgery 2023;15:668-677 • https://doi.org/10.4055/cios22220

Comparison of Functional and Cosmetic Outcomes According to Fracture Level in Gartland Type III Pediatric Supracondylar Humerus Fractures

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Background: Supracondylar humerus (SCH) fractures in children have been traditionally categorized according to the Wilkins-modified Gartland classification scheme, which is solely based on the degree of displacement. As this classification does not consider fracture patterns in the coronal or sagittal plane, the relationship between the fracture pattern and prognosis in SCH fractures remains unclear. Therefore, the purpose of this study was to evaluate the relationship between the fracture level and prognosis of pediatric SCH fractures.

Methods: Medical records and radiographs of 786 patients with SCH fractures who underwent surgical treatment between March 2004 and December 2017 were reviewed. A total of 192 patients were included in this study. Anteroposterior elbow radiographs taken at the time of injury were evaluated to obtain the level of fracture. Functional outcomes were evaluated based on modified Flynn grading at the last follow-up.

Results: Of 192 patients included in this study, 24 (12.1%), 148 (74.8%), and 20 (10.1%) had fractures in zone 1 (metaphyseal-diaphyseal area), zone 2 (between zones 1 and 3), and zone 3 (metaphyseal-epiphyseal area), respectively. There were significant differences in age at the time of injury ($p = 0.011$), direction of fracture displacement ($p = 0.014$), and loss of carrying angle ($p < 0.001$) between fractures in zone 3 and those in zone 1 or zone 2. Zone 3 fractures and classic zone 2 fractures also showed significant difference in outcomes, with zone 3 fractures having more unsatisfactory outcome than classic zone 2 fractures ($p = 0.049$).

Conclusions: For SCH fractures, varus deformity of the elbow was more common in zone 3 (metaphyseal-epiphyseal area) than in the other zones. Thus, pediatric orthopedic surgeons should be mindful of the possibility of cubitus varus deformity when treating SCH fractures in zone 3. A thorough postoperative follow-up is required.

Keywords: *Supracondylar distal humerus fracture, Humerus, Children, Fracture level, Functional outcome*

Received June 29, 2022; Revised January 9, 2023; Accepted January 9, 2023

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Supracondylar humerus (SCH) fractures are the most common type of elbow fracture in children, accounting for nearly 17% of all childhood fractures and more than 50% of all elbow fractures.[1] The Wilkins-modified Gartland classification system[2] is the most widely used classification system for SCH fractures, dividing them into three types based on the initial fracture displacement. Many studies have reported satisfactory cosmetic and functional outcomes with percutaneous pinning after closed reduction in SCH fractures.[3,4] However, pediatric SCH fractures, especially Gartland type III, are often associated with clinically significant complications such as cubitus varus deformity, malunion, and avascular necrosis (AVN). Conventional wisdom considers a varus elbow deformity as a cosmetic problem. However, recent studies have revealed functional disadvantage associated with varus elbow deformity.[5,6] Various corrective osteotomy techniques have been described with reliable outcomes.[7-9] However, complications following surgical treatment of SCH fractures could not be explained by the severity of the fracture identified by the Gartland classification.[2,3]

Meanwhile, fractures involving more distal sites than common SCH fractures through the olecranon fossa are difficult to reduce and fix during operation.[10] Fractures involving more distal parts might be thought as intracapsular fractures similar to physeal, Salter-Harris type II or transphyseal injury. Because they have no periosteum, they are more unstable than common SCH fractures.[11]

Therefore, we hypothesized that the level of fractures might affect functional and cosmetic outcomes after surgical treatment in pediatric SCH fractures. We retrospectively analyzed whether fracture levels could affect functional outcomes of Gartland type III SCH fractures managed with surgical treatment.

METHODS

We conducted this study in compliance with the principles of the Declaration of Helsinki. The design and protocol of this retrospective study were approved by the Institutional Review Board of Jeonbuk National University Hospital (No. 2017-02-019-002). The requirement of written informed consent was waived by the IRB due to the retrospective nature of this study. Medical records and radiographs of 786 patients with SCH fractures who underwent surgical treatment in two institutions (Jeonbuk National University Hospital and Seoul National University Bundang Hospital) between March 2004 and December 2017 were reviewed. Inclusion criteria were as follows: (1) isolated Gartland III fractures in patients younger than 13 years at the time of injury; (2) patients who underwent closed reduction and percutaneous pinning; and (3) at least 12 months of follow-up. Exclusion criteria were Gartland I and II fractures, previous history of surgery in the same elbow, other fractures in the same extremity, flexion-type SCH fracture, inadequate radiographs, or less than 12 months of follow-up period. Based on these criteria, 192 patients were included in this study (Fig. 1). Their charts were reviewed to obtain data including age at the time of injury, sex, injured side (right or left), follow-up period, operative technique, duration of immobilization in a cast, range of motion (ROM), carrying angle, and complications.

Radiological Evaluation

Radiographs were evaluated to obtain the direction of fracture displacement (posteromedial or posterolateral) and the level of fracture using anteroposterior (AP) and lateral elbow radiographs taken at the time of injury. Patients were divided into three groups according to the level of fracture. Zone 1 (metaphyseal-diaphyseal area) was at

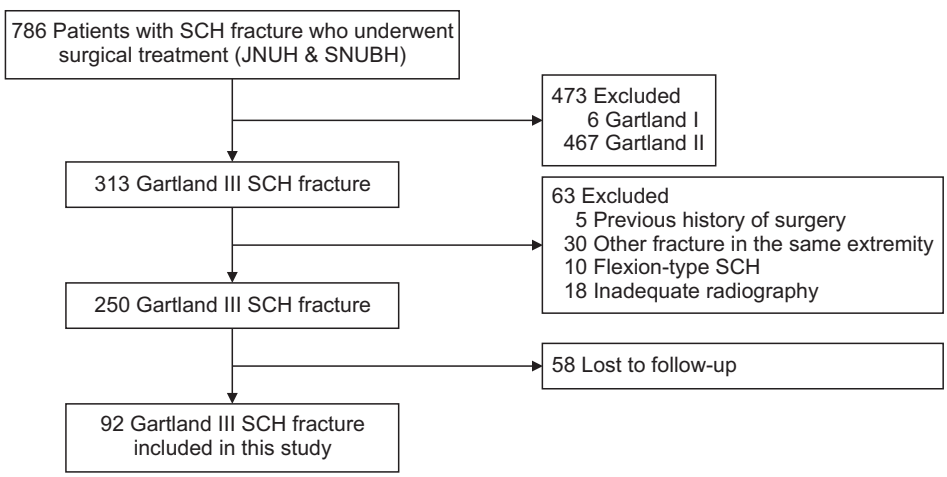

Fig. 1. Flow diagram showing the selection process of study participants. SCH: supracondylar humerus, JNUH: Jeonbuk National University Hospital, SNUBH: Seoul National University Bundang Hospital.

the top of the olecranon fossa and another drawn at the distal humerus where a consistent width of humeral shaft started changing. A reference line of zone 3 (metaphyseal-epiphyseal area) was defined on the AP radiograph as a line connecting the medial epicondyle, the olecranon fossa, and the lateral epicondyle and on the lateral radiograph at the isthmus of the distal humerus. In radiographs in which the secondary ossification center of the epicondyle was not visible, the most outer protrusion of the distal humeral condyle was regarded as the epicondyle. Zone 2 was bounded between zones 1 and 3 (Fig. 2).

Fig. 2. Anteroposterior (A) and lateral (B) radiographs of the elbow. Zone 1 (metaphyseal-diaphyseal area) is at the top of the olecranon fossa and a line drawn at the distal humerus where a consistent width of humeral shaft starts changing. A reference line of the zone 3 (metaphyseal-epiphyseal area) is defined on the anteroposterior radiograph as a line connecting the medial epicondyle, the olecranon fossa, and the lateral epicondyle. On the lateral radiograph, it is defined at the isthmus of the distal humerus. In radiographs in which the secondary ossification center of the epicondyle is not visible, the most outer protrusion of the distal humeral condyle is considered the epicondyle. Zone 2 is bounded by zones 1 and 3.

Fractures in zone 1 were defined only above the top of the olecranon fossa (Fig. 3A and B). Fractures in zone 3 were defined as being only below the isthmus of the distal humerus (Fig. 3E and F). However, fractures with small metaphyseal fragments only in the medial condyle were considered as transphyseal fractures. All fractures involving zone 2 area, at least partially in the coronal and sagittal plane, were considered as zone 2 fractures (Fig. 3C and D). Baumann's angle[12] was measured from AP radiographs taken at the last follow-up and compared with a radiograph of the contralateral uninjured arm. Lateral humeral-capitellar angle was also measured from lateral radiographs. Each angle was compared with that of the contralateral arm. To evaluate the reliability of radiographic assessments, two stages of radiographic assessments were performed. In the first stage, a single orthopedic surgeon (SIW) performed radiographic assessments for all cases (15 cases at each fracture level, a total of 45 cases). In the second stage, three orthopedic surgeons (KHS, YJM, SCL) assessed the interobserver reliability of radiographic measurements. Intraclass correlation coefficients (ICCs) and their 95% confidence interval (CI) were calculated using a two-way random effect model assuming a single measurement and absolute agreement.[13] An ICC value of 1 indicated perfect reliability and an ICC greater than 0.8 indicated excellent reliability.

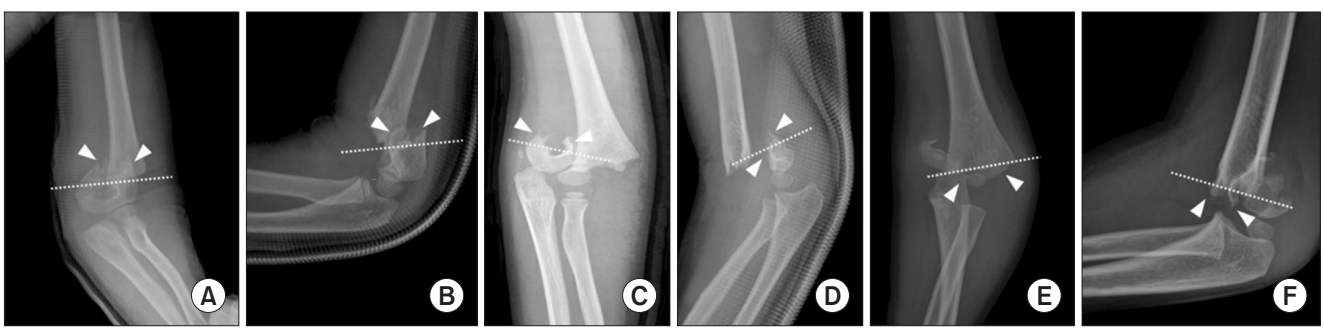

Fig. 3. Anteroposterior and lateral radiographs of the elbow demonstrating zone 1 (A, B), zone 2 (C, D), and zone 3 (E, F) fracture types in Gartland III supracondylar fractures. The level of fracture was identified independently by three orthopedic surgeons. Both pre- and intraoperative radiographs were used to avoid classification error due to fracture fragment superimposition. Fractures in zone 1 are defined as those (white arrowheads) only above the top of the olecranon fossa (A, B). Fractures in zone 3 are defined as those (white arrowheads) only below the isthmus of the distal humerus (E, F). All fractures (white arrowheads) involving zone 2 area, at least partially in coronal and sagittal planes, were considered zone 2 fractures (C, D). Interobserver reliability evaluated using intraclass correlation coefficients was 0.860 (95% confidence interval, 0.812–0.941), indicating satisfactory agreement.

Clinical Outcomes

Recorded clinical outcomes were the duration of time to restoration of full elbow movement and modified Flynn grading[14] at the last follow-up. Passive and painless range of elbow movement was measured with a goniometer at each visit from 2 weeks after cast removal.[15] Restoration of full elbow ROM was defined as greater than 10° hyperextension and 140° further flexion or elbow flexion/extension to within 5° of the range displayed by the uninjured elbow.[16] To analyze Flynn grade, results at the last follow-up were classified into two groups: (1) unsatisfactory group, those with the worst cosmetic or functional outcome (Flynn fair or poor) and (2) satisfactory, those with the best cosmetic and functional outcome (Flynn excellent or good).

Surgical Technique

The operation was performed under general anesthesia in supine position. All patients were laid in supination with an injured elbow right over the fluoroscopy beam. Fractures were reduced through slow and consistent traction. After flexion of the elbow, Baumann angle was measured to assess alignment of the coronal plane in Jones' view. Alignment on the sagittal plane was measured in the lateral view based on the location of the anterior humeral line. The first pin was inserted when the reduction was fulfilled compared to the contralateral side. The elbow was then extended and the alignment was checked in the coronal plane again with fluoroscopy. Carrying angles of both elbows were also visually compared. If the carrying angle was appropriate compared to the contralateral side, the following pins were inserted in sequence. If not, the initial pin was removed and reduction was performed again. All Gartland III supracondylar fractures were stabilized with two to three percutaneous 0.062-inch Kirschner (K)-wires after closed reduction.

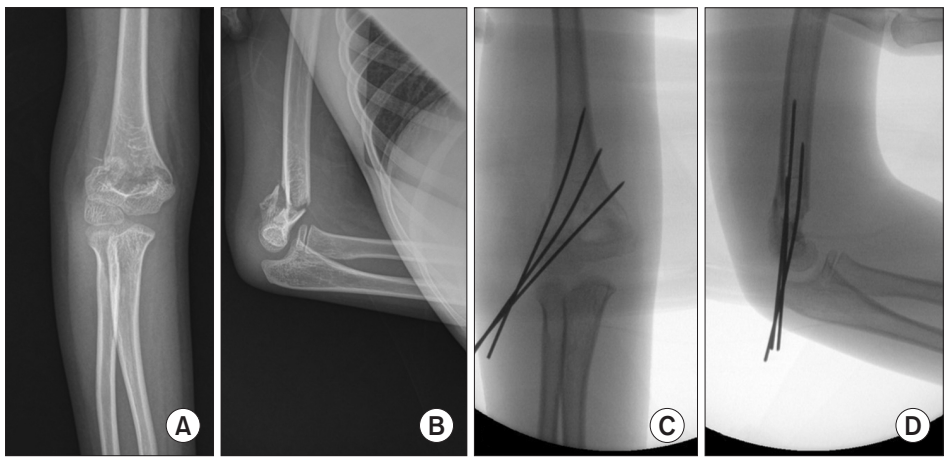

Fig. 4. (A, B) Anteroposterior and lateral radiographs of the elbow showing a Gartland III supracondylar fracture in zone 2. (C, D) After satisfactory reduction in coronal and sagittal planes with fluoroscopy, the fracture was stabilized with two to three percutaneous 0.062-inch Kirschner (K)-wires. Generally, two K-wires are inserted laterally, with stability assessed by intraoperative fluoroscopy. A third wire was inserted laterally or medially if necessary to obtain stable fixation.

Table 1. Fracture Characteristics and Treatment Data of 192 Gartland III Supracondylar Humerus Fractures

Characteristic	Zone 1 (n = 24)	Zone 2 (n = 148)	Zone 3 (n = 20)	*p*-value	Post hoc test
Age at the time of fracture (yr)	5.5 ± 2.5	6.0 ± 1.9	4.5 ± 2.7	0.011*	Zone 2/3
Injured arm (right : left)	8 : 16	45 : 103	8 : 11	0.677†	
Follow-up period (wk)	52 ± 28	72 ± 67	64 ± 36	0.316*	
Male : female	18 : 6	107 : 41	14 : 6	0.933†	
Direction of displacement				0.014†	Zone 12/3
Posteromedial	16 (66.7)	92 (62.2)	19 (95)		
Posterolateral	8 (33.3)	56 (37.8)	1 (5)		
Number of inserted Kirschner-wires	2.8 ± 0.9	2.6 ± 0.7	2.5 ± 0.7	0.381*	
Immobilization (wk)	4.7 ± 1.0	4.4 ± 0.9	4.35 ± 0.6	0.373*	

Values are presented as mean ± standard deviation or number (%).
*One-way analysis of variance. †Two-by-k chi-square test.

Generally, two K-wires were inserted laterally, with stability assessed by intraoperative fluoroscopy. A third wire was inserted laterally or medially if necessary to obtain stable fixation (Fig. 4). Postoperatively, a cast was applied with the elbow flexed at approximately 80°. Active movement of the elbow was encouraged from the time when K-wires were removed.

Statistical Analysis

A two-by-k chi-square test was used to determine relationships of discontinuous variables (injured arm, sex, direction of displacement, operative method) among the three groups according to the level of fracture. A two-by-k chi-square test was also used to compare functional outcomes based on modified Flynn grading among the three groups. One-way analysis of variance was used to compare mean values of continuous variables among the three groups. SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. Statistical significance was considered when *p*-value was less than 0.05.

RESULTS

Of 192 patients included in this study, 24 (12.1%), 148 (74.8%), and 20 (10.1%) had fractures in zone 1 (metaphyseal-diaphyseal area), zone 2, and zone 3 (metaphyseal-epiphyseal area), respectively. There was no statistically significant difference in the follow-up period, sex, number of inserted K-wires, or immobilization period among the three groups (Table 1). However, age at the time of injury showed a significant difference between zone 2 and zone 3 ($p = 0.011$). Regarding the direction of fracture

Table 2. Radiological Outcomes

Variable	Zone 1 (n = 24)	Zone 2 (n = 148)	Zone 3 (n = 20)	*p*-value*
Baumann angle (°)				
Contralateral	67.4 ± 5.8	65.4 ± 5.2	67.7 ± 5.2	
Injured	70.3 ± 6.4	68.8 ± 6.6	73.7 ± 8.8	0.210
Loss of angle	2.91 ± 5.8	4.00 ± 5.4	5.95 ± 7.6	0.089
Humerocapitellar angle (°)				
Contralateral	43.8 ± 5.8	47.2 ± 5.8	45.5 ± 4.5	
Injured	44.2 ± 8.2	45.3 ± 9.6	45.1 ± 8.7	
Loss of angle	–0.45 ± 10.1	1.72 ± 7.3	0.45 ± 10.3	0.210

Values are presented as mean ± standard deviation.
*One-way analysis of variance.

Table 3. Clinical Outcomes

Variable	Zone 1 (n = 24)	Zone 2 (n = 148)	Zone 3 (n = 20)	*p*-value*	Post hoc test
Carrying angle (°)					
Contralateral	15.5 ± 2.9	15.8 ± 2.8	16.0 ± 2.0		
Injured	11.1 ± 5.9	12.3 ± 6.0	1.45 ± 12.8		
Loss of angle	4.5 ± 6.1	3.60 ± 5.7	13.9 ± 12.5	0.001	Zone 12/3
Range of motion (°)					
Extension	–1.8 ± 3.8	–3.1 ± 6.0	–0.75± 7.99	0.183	
Flexion	139 ± 4.3	137.2 ± 4.6	137 ± 6.3	0.185	
Recovery of range of motion (wk)	13.5 ± 4.1	16.2 ± 5.6	16.5 ± 4.0	0.065	

Values are presented as mean ± standard deviation.
*One-way analysis of variance.

displacement, fractures in zone 3 had significantly more posteromedial displacements than fractures in the other two zones (p = 0.014) (Table 1). Meanwhile, there was no significant difference in loss of Baumann (p = 0.089), capitellar angle (p = 0.210), or recovery time to the final ROM range (p = 0.210) among the three groups (Tables 2 and 3). The loss of carrying angle of the injured arm compared to the contralateral arm was 4.50 ± 6.1 in zone 1, 3.60 ± 5.7 in zone 2, and 13.9 ± 12.5 in zone 3. There was a significant loss of carrying angle for fractures in zone 3 compared to fractures in zone 1 or zone 2 (p = 0.001) (Table 3). Functional outcome based on modified Flynn grading was satisfactory for 18 (75%) cases of zone 1, 118 (79.7%) cases of zone 2, and 11 (55%) cases of zone 3. Fractures in zone 3 had significantly unsatisfactory functional outcome than those in zone 2 (p = 0.049) (Tables 4 and 5).

Table 4. Functional Outcome by the Modified Flynn Grading System

Result	Cosmetic factor : loss of carrying angle (°)	Functional factor : loss of movement (°)
Satisfactory		
Excellent	0–5	0–5
Good	6–10	6–10
Unsatisfactory		
Fair	11–15	11–15
Poor	>15	>15

Complications

In zone 1 group, reoperation was performed for 1 case due to the progress of postoperative displacement, and varus deformity correction osteotomy was performed for another case. In zone 2 group, reoperation was performed due to postoperative displacement, deep infection, AVN of the capitellum, or valgus deformity of 14° (1 case each). The valgus deformity was corrected with a translation step-cut osteotomy at 18 months postoperatively (Fig. 5). In zone 3 group, there was 1 case of severe keloid formation. There was also 1 case of radial nerve palsy accompanied by an initial injury. However, it recovered normally after 8 weeks. Corrective osteotomy for varus deformity was performed for 5 cases. One case among them underwent percutaneous pinning for a zone 3 fracture (Fig. 6A-D), but physical examination showed extension limitation of 30°, and radiographs showed varus deformity of 17° and flexion deformity of 15° (Fig. 6E and F). Therefore, valgus and extension osteotomy was performed at 12 months post-

Table 5. Functional Outcome

Result	Zone 1 (n = 24)	Zone 2 (n = 148)	Zone 3 (n = 20)	p-value*	Post hoc test
Satisfactory	18 (75)	118 (79.7)	11 (55)	0.049	Zone 2/3
Unsatisfactory	6 (25)	30 (20.3)	9 (45)		

Values are presented as number (%).
*Two-by-k chi-square test.

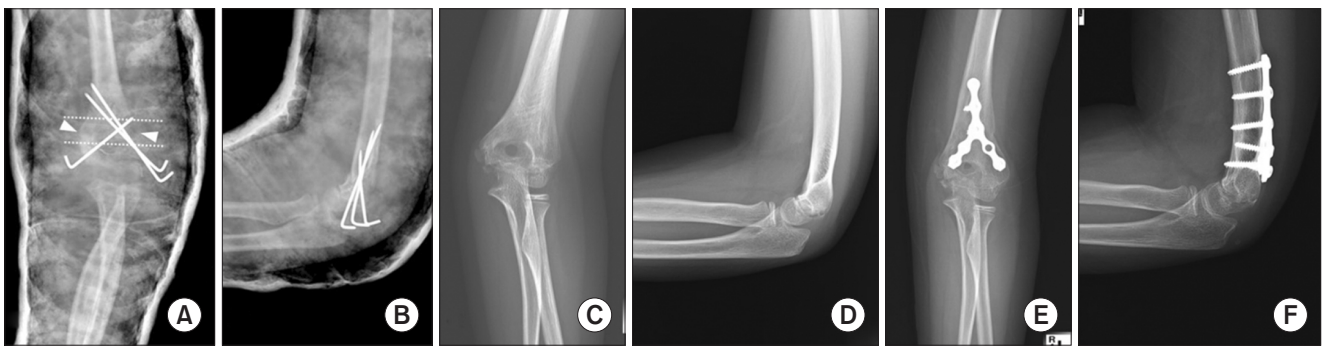

Fig. 5. (A, B) A Gartland III supracondylar fracture in which both proximal parts of the distal fragments (white arrowheads) are located in zone 2 in an 8-year-old boy was stabilized with two percutaneous 0.062-inch Kirschner (K)-wires laterally and one K-wire medially. (C, D) Anteroposterior radiographs at 18 months postoperatively, showing 14° valgus deformity compared to the contralateral arm. (E, F) Elbow deformity was corrected with a translation step-cut osteotomy using a Y plate and screws.

Fig. 6. (A, B) A Gartland III supracondylar fracture in which both distal parts of the proximal fragments (white arrowheads) are located in zone 3 in a 9-year-old boy. (C, D) The fracture was stabilized with three percutaneous 0.062-inch Kirschner (K)-wires laterally. (E, F) At 12 months postoperatively, the patient's physical examination showed 30° of flexion contracture. On anteroposterior and lateral radiographs of the elbow, varus deformity of 17° with avascular necrosis of the trochlea and flexion deformity of 15° were observed compared with contralateral radiographs. (G, H) Elbow deformity was corrected with a translation step-cut (valgus–extension) osteotomy using a Y plate and screws.

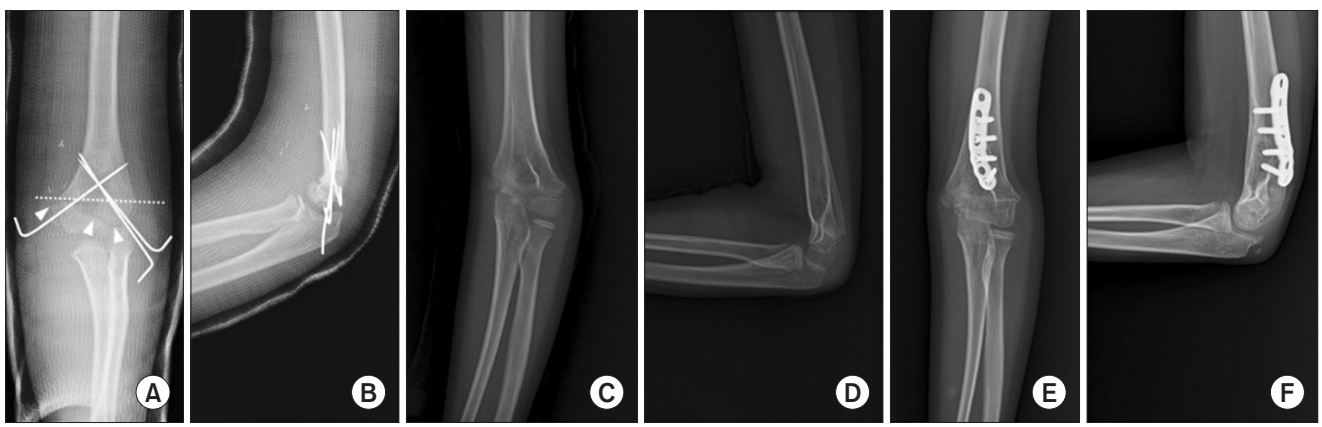

Fig. 7. (A, B) A supracondylar humerus fracture of zone 3 (white arrowheads) in an 8-year-old girl was stabilized with two percutaneous 0.062-inch Kirschner (K)-wires laterally and one K-wire medially. (C, D) At 18 months postoperatively, on physical examination of the patient, a mild decrease in grip strength and weakness in hand intrinsic muscle were observed. On radiographs of the elbow, varus deformity of 22° and avascular necrosis of the trochlea were observed compared with contralateral radiographs. (E, F) Elbow deformity was corrected with a translation step-cut osteotomy using a locking plate.

operatively (Fig. 6G and H). Another case showed a mild weakness in grip strength and varus deformity of 22° with AVN of the trochlea on radiographs. Elbow deformity was then corrected with a translation step-cut osteotomy using a locking plate at 18 months postoperatively (Fig. 7).

DISCUSSION

SCH fractures in children have been traditionally categorized according to the Wilkins-modified Gartland classification scheme, which is solely based on the degree of displacement. As this classification does not consider

the fracture pattern in the coronal or sagittal plane, the relationship between the fracture pattern and prognosis in SCH fractures remains unclear.[11,17] Therefore, we conducted a radiographic review to determine the relationship between the fracture level and prognosis of pediatric SCH fractures. Findings of the present study confirmed that different fracture levels had several unique clinical features. First, those with SCH fractures in zone 3 were significantly younger at the time of fracture than those with classic SCH fractures in zone 2 ($p = 0.011$). Distal fragments in zone 3 showed significantly more posteromedial displacements than those in the other two zones ($p = 0.014$) (Table 1).

Second, SCH fractures in zone 3 tended to have a significantly higher incidence of cubitus varus than those in the other two groups. Although the cause of varus deformity remains uncertain, many authors believe that angular and rotational deformities are causes of varus deforimity.[18] de Gheldere and Bellan[19] have reported that laterally torn periosteum is associated with posteromedially displaced fractures, whereas medial periosteal rupture is associated with posterolateral displaced fractures, providing a higher Baumann value inducing cubitus varus deformity in the posteromedially displaced type. Small distal bone fragments might cause varus deformity by making accurate closed reduction difficult.[11] In the present study, loss of carrying angle was significantly higher in zone 3 fractures than in zone 1 or zone 2 fractures ($p = 0.001$). These results revealed that zone 3 fractures showed significantly lower satisfactory outcomes than classic zone 2 fractures. Fractures in zone 3 might be considered as intracapsular fractures. Thus, injury of joint capsules and ligaments might be more likely to occur in zone 3 Gartland III fractures. In our cases, it was more difficult to accurately reduce and stably fix fractures in zone 3 due to small distal bone fragments and injured surrounding tissues than for fractures in the other two zones. Although further research is needed, union of fractures showed a tendency to have partial bone resorption around small bone fragments, similar to union of the intra-articular fractures.

Meanwhile, Kang et al.[11] have reported that low fracture type of SCH fracture is more common in those aged more than 10 years. However, in the current study, zone 3 fractures occurred mainly in those younger than 5 years of age. Such difference might be because Kang et al.[11] only defined fractures above the isthmus of the distal humerus as high fractures. In other words, they included an oblique fracture commonly observed in classic SCF that partially crossed below the reference line as a low type fracture. However, in our study, an oblique fracture that partially crossed the reference line dividing zone 3 was not included in zone 3. Only a fracture that occurred below the reference line was defined as a zone 3 fracture.

In the present study, fractures in zone 3 occurred at a younger age compared to classic zone 2 fractures. Zone 3 fractures showed significantly more posteromedial displacements than fractures in the other two zones. It was thought that zone 3 fractures might have to be considered equivalent to transphyseal fractures. Transphyseal fractures in older children (age >3 years) typically have a metaphyseal piece attached to the distal fragment (Salter-Harris II injury). A rotational force and twisting mechanism or a fall onto an outstretched hand with the elbow extended can result in such fractures.[20-23] Posteromedial displacement is the most common fracture pattern. Cubitus varus is the most common complication. It is more commonly associated with a distal humerus transphyseal fracture than a supracondylar fracture.[24] Oh et al.[25] have suggested that varus deformity is secondary to AVN of the medial humeral condyle. Other authors have claimed that growth plate injury might also be involved in the deformity as previous studies have reported progressive varus deformity in toddlers with transphyseal fractures.[24,26]

In the present study, zone 3 fractures showed significantly ($p = 0.001$) larger varus carrying angles than zone 1 or 2 fractures. Five (25%) cases in zone 3 group underwent corrective osteotomy. Two of these who underwent corrective osteotomy were accompanied by AVN of the trochlea. One case was accompanied by AVN of the capitellum. However, none of our patients developed progressive varus deformity during the follow-up period. Therefore, inadequate or insufficient reduction could be the main cause of cubitus varus in zone 3 fractures.

This study has some limitations. First, it was a retrospective study of 192 consecutive patients. Second, four surgeons used a variety of pinning techniques. This might be a confounding factor for fracture outcomes. The number of cases in zone 1 or zone 3 was smaller than that in zone 2, which might cause biased results due to an imbalanced distribution. To eliminate this variable, a prospective controlled study is needed as a further study. However, fractures of the metaphyseal-diaphyseal or metaphyseal-epiphyseal area are rare fracture subtypes. Thus, a prospective controlled study might be difficult. We studied cases of two institutions to compensate for these limitations. Third, since this study was conducted on Gartland type III fractures, this subclassification could not show the severity for all SCH fractures. Therefore, further studies including all types of fractures, not just Gartland type III fractures, are needed. Future studies also need to identify risk factors that might affect results of this study through more detailed clinical data analysis.

In summary, varus deformity of the elbow was more common in zone 3 (metaphyseal-epiphyseal area) SCH fractures than in zone 1 or zone 2 fractures. Thus, pediatric orthopedic surgeons should be mindful of the possibility of cubitus varus deformity when treating SCH fractures in zone 3. A thorough postoperative follow-up is required.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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