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ORIGINAL ARTICLE

Agreement on fixation of pediatric supracondylar humerus fractures

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Abstract

Background Pediatric supracondylar humerus fractures (pSCHFs) may be challenging injuries to treat because of the potential residual deformity. There is debate regarding the technical aspects of adequate closed reduction and crossed Kirschner wire (K-wire) fixation.

Purpose Do surgeons have an agreement on the aspects of the fixation of pSCHFs?

Methods Radiographs of 20 patients from a cohort of 154 patients with pSCHFs treated with closed reduction and crossed K-wire fixation were selected. Forty-four surgeons viewed the postoperative radiographs and diagnosed the presence or absence of technical flaws and made a recommendation for or against reoperation. An expert panel of three orthopedic and trauma surgeons provided a reference standard for technical factors. Furthermore, final outcome 2 years after trauma was assessed.

Results There was limited agreement on potential technical flaws (ICC 0.15–0.28), radiographic measures of alignment (ICC for anterior humeral line and Baumann angle of 0.37 and 0.23 respectively), the quality of postoperative reduction, position of the elbow in cast, and recommendation for repeat surgery (ICCs between 0.23 and 0.40). Sensitivity and specificity for these questions ranged from 0.59 to 0.90. There was no correlation between the voted quality of postoperative reduction and loss of reduction or final function.

Conclusions Surgeons have limited agreement on the quality of postoperative results in pSCHFs and the indication for reoperation. Reviewing postoperative radiographs may present a good learning opportunity and could help improve skills, but it is not a validated method for quality control and has to be seen in light of clinical outcome.

Keywords Supracondylar humerus fractures · Pediatric · K-wire fixation · Science

Introduction

Pediatric supracondylar humerus fractures (pSCHF) are the most common elbow fractures in children with a peak age at 5–7 years [1–3]. The Gartland classification is mostly used to classify these fractures [4]. Gartland type 1 could perfectly be treated in a conservative way with excellent long-term outcomes [5]. Surgeons agree that Gartland type 3 fractures are best treated with closed reduction and percutaneous Kirschner wire (K-wire) fixation [4, 6–8]. Treatment of Gartland type 2 fractures depends on rotational deformity, coronal malalignment, or significant extension of the distal fragment [9].

The incidence of malalignment after conservative or inadequate operative treatment differs between 3 and 57%, resulting mostly in a cubitus varus deformity. [10]. Long-standing elbow deformity can result in snapping of the medial border of the triceps, posterolateral rotatory instability (PLRI), and tardy ulnar nerve palsy, and it can give parents and children psychological stress [11].

There is a relation between the quality of the initial postoperative radiographic position of the fracture and further loss of reduction [12–14]. Loss of alignment was mostly associated with technical aspects of the fixation like failure to engage both fracture fragments with two pins or more,

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failure to achieve bicortical fixation with two pins or more, and inadequate pin spread to control for rotation. However, we do know what a right correction is to prevent long-term complications of disability's [7, 13, 15]. Even though nature seems to be forgiving with its potential for remodeling, adequate reduction and use of the fixation technique in pSCHF does matter. However, we do not know if surgeons worldwide agree on what an adequate fixation is and how it correlates with the clinical outcome.

The primary goal of this study is to determine the inter-surgeon agreement of the technical aspects of closed reduction and percutaneous fixation of pSCHF. Secondarily, we studied (1) the reliability of radiographic measures of potential technical errors on a postoperative X-ray; (2) the sensitivity and specificity of diagnosis of technical inadequacies compared to the consensus of three surgeon-experts; and (3) the relation between the judged quality of surgery and functional outcome at least 2 years after the procedure, in terms of the Flynn criteria [16] and range of motion.

Materials and methods

This study was approved by the Institutional Research Board at Leiden University Medical Center in The Netherlands (protocol no. 03-057).

Patients

In a consensus meeting between three senior surgeons, 20 cases, representative of daily practice, were selected from a retrospective cohort of 154 patients as a practical convenience sample.

These 20 patients aged 4–10 years with a displaced pSCHF, were treated with crossed K-wire fixation between 2002 and 2011 in two level I Trauma Centers.

The average age of the patients was 6.5 ± 1.5 years (4–10 years), and 50% were male. Eighteen patients of the 20 patients had a Gartland type 3 extension fracture and two patients a flexion fracture. The surgical procedure included closed reduction under general anesthesia and percutaneous K-wire fixation with two crossed pins, with one patient having an additional third lateral pin. The average follow-up time was 63 ± 29 months (23–121 months). At final follow-up, the average flexion and extension were 141 ± 5.8 degrees (range 125–150) and − 9.7 ± 8.1 degrees (− 20 to 10), respectively. A positive extension value represents a flexion contracture, whereas a negative value represents hyperextension. Two patients had cubitus varus (carrying angle of 10 degrees varus compared to 15 and 20 degrees valgus on the uninjured side). Elbow function at final evaluation was classified as excellent, good, fair, or poor according to the Flynn criteria [16]. All patients had a satisfactory elbow function at final follow-up: 13 patients had excellent postoperative function, 5 patients had good function, and 2 had fair elbow function according to the Flynn criteria.

Observers

Three orthopedic trauma surgeons with a special interest in pediatric fractures and experience with pediatric fractures comprised the expert panel.

Forty-one of the 109 (38%) invited surgeon-members of the Trauma platform Study Collaborative (http://www.traumaplatform.org) felt that the survey was appropriate for their expertise and completed the survey (Table 1).

Survey

Observers viewed anteroposterior and lateral postoperative radiographs of the 20 patients along with a description of the demographic and injury characteristics in an online survey and answered nine questions (yes/no) about technique (Table 2). The reference standard for a "correct" answer to each question was the consensus of an expert panel of three orthopedic trauma surgeons with a special interest in pediatric fractures.

Table 1 Observer (surgeon-) characteristics

Demographics	Observers (%) ($n=41$)	Expert panel (%) ($n=3$)
Gender		
Male	39 (95)	3 (100)
Female	2 (5)	
Location of practice		
Europe	40 (98)	3 (100)
Other	1 (2)	
Years of surgical experience		
0–5	10 (24)	
6–10	11 (27)	
11–20	15 (37)	3 (100)
> 20	5 (12)	
Clinical specialty		
General orthopaedics	1 (3)	
Orthopaedic traumatology	25 (61)	2 (67)
Shoulder and elbow surgery	12 (29)	
Other	3 (7)	1 (33)
Annual number of treated paediatric patients with SCHF		
0–5	15 (37)	
6–10	16 (39)	
11–15	6 (15)	
16–20	3 (7)	2 (67)
> 20	1 (2)	1 (33)

Table 2 Agreement on the evaluation of the acceptability of postoperative reduction in 20 children with a supracondylar humerus fracture

Variable	Categorical	ICC	95% CI
(1) Is the insertion site of the K-wires appropriate?	Fair	0.22	0.13–0.38
(2) Is bicortical fixation achieved?	Fair	0.25	0.15–0.42
(3) Do the K-wires cross in the appropriate place?	Fair	0.28	0.13–0.57
(4) Do the K-wires engage both fracture fragments?	Poor	0.15	0.09–0.29
(5) Is the anterior humeral line intact?	Fair	0.37	0.24–0.55
(6) Is the Baumann Angle acceptable?	Fair	0.23	0.14–0.40
(7) Is the postoperative position/reposition acceptable?	Fair	0.40	0.27–0.59
(8) Is the position of the elbow in cast acceptable?	Fair	0.32	0.20–0.50
(9) Would you consider revision of the fracture fixation?	Moderate	0.43	0.23–0.53

ICC intraclass correlation coefficient, *CI* confidence interval

Statistical analysis

The reliability of diagnosis of potential technical errors on postoperative radiographs among observers was assessed using the intraclass correlation coefficient (ICC) which is identical with a weighted kappa, and which can be interpreted according to the guidelines by Landis and Koch [17]: 0.00–0.20, poor agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; greater than 0.81, almost perfect agreement, with 1.00 being the highest obtainable value. Sensitivity and specificity for the questions concerning quality of postoperative position/reposition (question 7) and the recommendation for repeat surgery (question 9) were calculated with respect to the surgeon panel reference standard. Sensitivity and specificity defined as the probability that a random observer classified the postoperative radiograph according to the expert panel's opinion (reference standard) were calculated with repeated-measures logistic regression using generalized linear mixed models, and presented as percentage with 95% CI.

For the relation between reported quality of the procedure and functional outcome at least 2 years after the procedure, Flynn scores were reported [16].

Results

The reliability of the radiographic technical evaluation was poor to fair (Table 2). There was limited agreement on potential technical errors (ICC 0.15–0.28), radiographic measures of alignment (ICC for anterior humeral line and Baumann's angle of 0.37 and 0.23, respectively), and the quality of postoperative reduction, position of the elbow in cast, and recommendation of repeat surgery (ICCs between 0.23 and 0.43). Interobserver agreement on acceptability of postoperative position/reposition and recommendation of revision of fracture fixation did not differ by years of surgical experience, specialization (i.e., orthopedic or trauma surgeon), or annual number of treated patients with pSCHFs (Tables 3 and 4).

The sensitivity and specificity for the acceptability of the postoperative position/reposition were 0.82 (95% CI 0.75–0.90) and 0.75 (95% CI 0.61–0.90), respectively. The sensitivity and specificity for the need of repeat surgery were 0.75 (95% CI 0.59–0.91) and 0.78 (95% CI 0.71–0.85), respectively. Subgroup analysis showed that sensitivity and specificity for these assessments did not seem to be influenced by observer characteristics.

In seven patients of the 20 patients, the expert panel recommended a second surgery to improve the alignment or fixation. Of these seven patients, six had a Gartland type 3 extension fracture and one a flexion type fracture. None of these patients underwent the second surgery. Total range of motion and Flynn scores at final follow-up for these seven patients were comparable with the average results of all included patients. Of the two cases with a fair Flynn score at final follow-up, one postoperative elbow position was classified as not acceptable according to expert panel opinion, and one was classified as acceptable. According to the expert panel, the other 13 cases had an acceptable quality of reduction with no need for revision surgery.

Discussion

This study measured the reliability of judgment of reduction and fixation of pediatric supracondylar humerus fractures (pSCHF) treated with crossed K-wires on postoperative radiographs and found poor-to-moderate agreement between surgeons. Worldwide, we still debate the technical criteria for adequate reduction and fixation and the role of revision surgery [18]. This is an important topic to prevent long-term complications in children. The treatment of pSCHF is challenging and this is probably why the agreement for an adequate reduction and fixation is poor [14, 19].

In this study, radiographic measures of potential technical errors had limited reliability. The sensitivity and specificity

Table 3 Agreement on acceptability of postoperative position/reposition by observer characteristics

Variable	*N*	Categorical	ICC (95% CI)	Sensitivity* (95% CI)	Specificity* (95% CI)
All observers	41	Fair	0.40 (0.27–0.59)	0.82 (0.75–0.90)	0.75 (0.61–0.90)
Years of surgical experience					
0–10	21	Moderate	0.43 (0.29–0.63)	0.86 (0.78–0.94)	0.74 (0.61–0.86)
> 10	20	Fair	0.37 (0.24–0.57)	0.78 (0.69–0.88)	0.76 (0.59–0.93)
Specialization					
General orthopaedics	1	–	–	–	–
Orthopaedic traumatology	25	Fair	0.40 (0.27–0.60)	0.82 (0.74–0.91)	0.77 (0.63–0.90)
Shoulder and Elbow surgery	12	Fair	0.34 (0.20–0.55)	0.81 (0.70–0.91)	0.69 (0.49–0.89)
Other	3	Fair	0.30 (0.05–0.58)	0.79 (0.64–0.95)	0.76 (0.61–0.91)
Annual number of treated patients with SCHF					
0–5	15	Fair	0.35 (0.22–0.56)	0.78 (0.68–0.89)	0.77 (0.66–0.88)
6–10	16	Fair	0.36 (0.23–0.57)	0.86 (0.79–0.92)	0.68 (0.49–0.87)
11–15	6	Moderate	0.41 (0.23–0.64)	0.86 (0.79–0.93)	–
16–20	3	Fair	0.31 (0.06–0.59)	0.67 (0.50–0.83)	0.86 (0.61–1)
> 20	1	–	–	–	–

ICC intraclass correlation coefficient, *CI* confidence interval

*The assessment of the expert panel was the reference standard

Table 4 Agreement on the need for revision of fracture fixation by observer characteristics

Variable	*N*	Categorical	ICC (95% CI)	Sensitivity* (95% CI)	Specificity* (95% CI)
All observers	41	Moderate	0.43 (0.23–0.53)	0.75 (0.59–0.91)	0.78 (0.71–0.85)
Years of surgical experience					
0–10	21	Fair	0.36 (0.23–0.56)	0.75 (0.60–0.90)	0.81 (0.74–0.89)
More than 10	20	Fair	0.32 (0.20–0.52)	0.75 (0.57–0.92)	0.74 (0.66–0.83)
Specialization					
General orthopaedics	1	–	–	–	–
Orthopaedic traumatology	25	Fair	0.38 (0.25–0.57)	0.76 (0.60–0.91)	0.78 (0.69–0.88)
Shoulder and Elbow surgery	12	Fair	0.25 (0.13–0.45)	0.69 (0.49–0.89)	0.76 (0.67–0.84)
Other	3	Moderate	0.44 (0.17–0.69)	0.74 (0.54–0.95)	0.81 (0.64–0.97)
Annual number of treated patients with SCHF					
0–5	15	Fair	0.26 (0.14–0.45)	0.76 (0.64–0.88)	0.73 (0.65–0.82)
6–10	16	Fair	0.33 (0.20–0.53)	0.68 (0.47–0.86)	0.83 (0.75–0.90)
11–15	6	Fair	0.38 (0.21–0.61)	0.81 (0.67–0.95)	0.85 (0.78–0.91)
16–20	3	Fair	0.35 (0.09–0.63)	0.90 (0.67–1)	0.64 (0.47–0.81)
More than 20	1	–	–	–	–

*The assessment of the expert panel was the reference standard

ICC intraclass correlation coefficient, *CI* confidence interval

of diagnosis of technical errors compared to the expert panel was moderate (75–82%), which might suggest that postoperative radiographs of pSCHF are of questionable use in the evaluation of radiographic measures of potential technical errors. This moderate accuracy is consistent with previous studies [18, 20]. If surgeons tend to disagree on the diagnosis of technical errors on postoperative radiographs, the use of these radiographic measures could be questionable. Previous studies found substantial individual and age-related variability in the location of the anterior humeral line (AHL) in uninjured pediatric elbows [20]. Furthermore, as the distal humerus with open physis can remodel in the sagittal plane [18, 21], the AHL might have limited clinical relevance in the sagittal plane. A study in which 175 observers assessed 35 radiographs, Baumann angle was found to be a reliable measure [22]. However, we asked for the acceptability of

Baumann angle rather than to measure Baumann angle itself. This suggests that the variation in an objective measurement is much less than the variation in the subjective categorization of what is acceptable.

The results of this study should be interpreted in light of its limitations. First, we did not standardize the postoperative radiographs, so the quality and the way of reviewing an X-ray varied. This situation represents the daily situation, but a standardized view ensures every doctor can judge a postoperative radiograph the same way. A standardized intra-operative lateral and AP radiograph would improve the way these radiographs are reviewed. In addition, the web interface we used is somewhat different from the usual way in which doctors view radiographs, although these differences are known to have a relatively small influence [23]. Also, this study used a built in DICOM viewer that allowed window leveling, zoom and contrast enhancement, similar to what doctors use on a daily basis. Another limitation was that the observers did not receive training nor instruction regarding how to define and measure Baumann's angle, the AHL, or the respective acceptable ranges, as we were interested in the surgeons' habitual assessments based on their experience and training. Previous studies from our group found that specific training can improve the reliability of making a diagnosis to some extent [24]. We asked surgeons to evaluate the acceptability of the anterior humeral line and the Baumann angle rather than to measure the angles themselves. The interpretation of these questions was complicated by the fact that acceptability is likely to depend on personal opinions and perceptions. Furthermore, the inclusion of a relatively high number of patients with fracture reduction that was judged inadequate may introduce a spectrum bias (i.e., the prevalence of inadequate fixation is substantially greater in the survey than in practice). This is often necessary for reliability studies to avoid the Kappa paradox [25]. The use of a consensus opinion of an expert panel for the reference standard for "acceptability" in the analysis of diagnostic accuracy may also be subject to discussion, as it does not eliminate the subjectivity of the determination of acceptability. However, it is the best standard we could produce, since no generally accepted criteria on the topic exist.

Agreement among the observers was higher for the more general questions (questions 7–9, Table 2). A possible explanation for this is the overall quality of reduction based on those specific characteristics is easier to evaluate, while surgeons disagree on specific characteristics of a radiograph. Thereby, surgeons did not judged about the initial indication for treatment. Maybe, if there was disagreement for initial treatment, there should be also little agreement on the quality of reduction and need for reoperation. Further research is needed to investigate the agreement for operative fixation between surgeons.

However, moderate agreement was only found for the question about the need for revision surgery, suggesting that an additional explanation might be true: surgeons feel comfortable criticizing specific characteristics, but have reservations about revision surgery, either because of unwillingness to repeat a surgery associated with psychological distress for the child and its parents, or because they know from clinical experience that the outcome is good or excellent in the majority of children possibly due to remodeling potential.

This study shows no relation between reported quality of reduction and clinical outcomes. Forty-one observers answered the questions on quality of reduction inconsistently. An important reason for this inconsistency in evaluation might be that evaluating the quality of reduction or need for revision surgery purely based on postoperative radiographs does not reflect clinical practice. In reality, a decision for revision surgery is based on clinical results in combination with a radiograph.

However, it does reflect the situation during the morning quality assurance rounds, where all X-rays are judged by radiologists and surgeons together. They often tend to base their comments on subjective categorization of what is acceptable. And even if comments are made based on objective criteria, the results of this study show that the radiological evaluation of technical inadequacies of crossed K-wire fixation, radiographic alignment, and recommendation for reoperation has limited reliability and does not correlate with functional outcome. As minor surgical technical imperfections are consistent with good functional and radiographic results, repeat surgery to revise fixation may only be advisable in uncommon circumstances if major problems are present. In our opinion, these data suggest that reviewing postoperative radiographs may present a good learning opportunity and could help improve skills, but it is not a validated method for quality control and has to see in light of clinical outcome.

Declarations

Conflict of interest Each author certifies that he or she has no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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