Chinese Journal of Traumatology 22 (2019) 249–254

Contents lists available at ScienceDirect

Chinese Journal of Traumatology

journal homepage: http://www.elsevier.com/locate/CJTEE

Original Article

Multicentre collaborative cohort study of the use of Kirschner wires for the management of supracondylar fractures in children

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ARTICLE INFO

Article history:
Received 4 April 2019
Received in revised form
23 June 2019
Accepted 10 July 2019
Available online 5 August 2019

Keywords:
Fracture fixation
Humerus
Child
Nerve injury
Bone wires

ABSTRACT

Purpose: Supracondylar fractures of the humerus cause significant morbidity in children. Nerve damage and loss of fracture reduction are common recognised complications in patients with this injury. Uncertainty surrounds the optimal Kirschner wire configuration and diameter for closed reduction and pinning of these fractures. This study describes current practice and examined the association between wire configuration or diameter and outcomes (clinical and radiological) in the operative management of paediatric supracondylar fractures.

Methods: Children presenting with Gartland II or III supracondylar fractures at five hospitals in south-west England were eligible for inclusion. Collaborators scrutinised paper and electronic case notes. Outcome measures were maintenance of reduction and iatrogenic nerve injury.

Results: Altogether 209 patients were eligible for inclusion: 15.7% had a documented neurological deficit at presentation; 3.9% who were neurologically intact at presentation sustained a new deficit caused by treatment and 13.4% experienced a clinically significant loss of reduction following fixation. Maintenance of reduction was significantly better in patients treated specifically with crossed ×3 Kirschner wire configuration compared to all other configurations. The incidence of iatrogenic nerve injury was not significantly different between groups treated with different wire configurations.

Conclusion: We present a large multicentre cohort study showing that crossed ×3 Kirschner wires are associated with better maintenance of reduction than crossed ×2 or lateral entry wires. Greater numbers would be required to properly investigate nerve injury relating to operative management of supracondylar fractures. We found significant variations in practice and compliance with the British Orthopaedic Association Standard for Trauma (BOAST) 11 guidelines.

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Introduction

Supracondylar fractures (SCF) of the humerus are the commonest fracture about the elbow and represent 30% of all limb fractures in children under seven years old.[1–3] It has been reported that 97%–99% of SCF occur with the elbow in extension resulting in a characteristic fracture pattern, with the small remainder being flexion type.[4,5] Gartland's classification guides treatment by sorting these fractures into nondisplaced (type I), displaced in extension with a fracture of the anterior cortex and intact posterior cortex (type II), completely displaced (type III).

SCFs are commonly managed using closed reduction and percutaneous pinning with Kirschner wires. Plaster casts are then applied to protect the site of injury.[6] These can be arranged in various configurations, typically either in a crossed or lateralentry fashion (Fig. 1).[7]

The median nerve and its anterior interosseous branch, ulnar nerve and radial nerve are all at risk of injury from both the primary injury and the repair. In a meta-analysis of 5148 patients with SCF, 11.3% of patients had a neuropraxia at presentation.[8] In patients with nerve injury caused by their fracture, the anterior interosseous branch of the median nerve is most commonly affected (34.1% of nerve injuries).[8] Many cases of these nerve palsies spontaneously recover in the six months following injury.[9]

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Peer review under responsibility of Chinese Medical Association.

https://doi.org/10.1016/j.cjtee.2019.06.002
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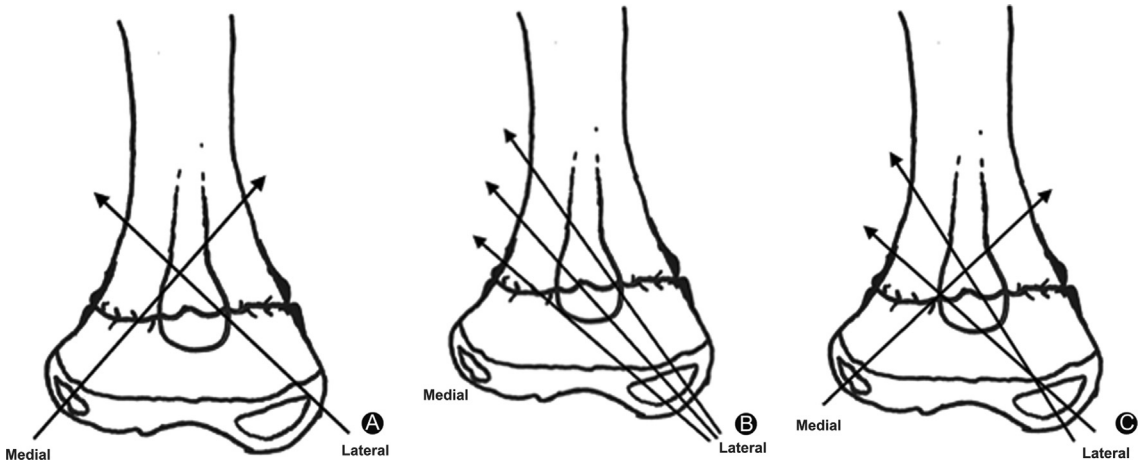


Fig. 1. Crossed×2 (A), lateral entry×3 (B) and crossed×3 (C) configuration Kirschner wires.

Other complications commonly encountered in SCF include vascular injury, compartment syndrome, malunion, functional impairment including reduced range of motion, and abnormal carrying angle.[10]

Iatrogenic nerve injury has been reported in up to 15% of supracondylar fractures, though in a large meta-analysis the pooled event rate for iatrogenic nerve injury was 2.3%.[8] Use of a medial entry pin in a crossed Kirschner wire configuration is associated with increased risk of ulnar nerve injury.[8,11–13] This may be due to constriction and/or tethering in the cubital tunnel rather than direct nerve injury.[14,15] No ulnar nerve injuries were seen in two separate case series of 189 and 124 cases managed with lateral only Kirschner wires.[16,17] A 2007 randomised controlled trial comparing crossed and lateral entry wires showed no difference between groups with respect to any clinical or radiographic outcome.[18] However, this trial had only 24 patients in the crossed pin group and as such may have been underpowered to detect a difference in nerve injury between groups. A 2010 systematic review and meta-analysis of 32 studies consisting of 2639 patients showed iatrogenic ulnar nerve injury is more likely with crossed pinning, and calculated a number needed to harm of 28 patients (95% *CI*: 17–71).[12] Furthermore, the finding that crossed wires are associated with higher rates of nerve injury is supported by a systematic review and meta-analysis of 35 studies on 2054 children.[11]

Biomechanical studies evaluating torsional strength favour crossed configuration Kirschner wires.[19,20] Divergent lateral wires have been shown to be superior to those in crossed format in extension and varus stress, though not in rotation.[21] A 2007 study found 8 of 279 (2.9%) patients suffered loss of reduction, and noted that 7 of 8 patients with this complication were treated with two lateral entry wires; though it should be stated that this represents only 7.3% of their cases treated with lateral wires.[22] A case series of 345 patients showed no difference in maintenance of reduction between crossed and lateral wires overall, or within Gartland II or Gartland III injuries.[23] A later case series on patients treated with lateral only wires found no loss of reduction, no clinically evident cubutis varus, no hyperextension, nor loss of motion.[17] However, a 2007 systematic review and meta-analysis showed the crossed wire group had a 42% lower incidence of loss of reduction compared to the lateral entry group.[11]

British Orthopaedic Association Standard for Trauma number 11 (BOAST 11) states that crossed wires are associated with improved maintenance of reduction, whereas divergent lateral wires reduce the risk of injury to the ulnar nerve. It is also suggested that 2 mm diameter wires should be used, where possible, to improve stability.[7] Adherence to BOAST guidelines regarding the documentation of neurovascular examination has recently been audited by our group in a multi-centre study in south west England.[24]

A retrospective study of 159 patients compared larger Kirschner wires (wire diameter >0.9 × humeral cortex diameter) with smaller wires (wire diameter <0.9 × humeral cortex diameter). This found large diameter wires were not associated with any immediate post operative advantage, but was associated with better maintenance alignment at final follow-up. There was no difference in infection or nerve injury between groups.[25]

The aims of this study were to examine current practice, and to investigate whether any correlations exist between wire configuration or diameter and radiological and clinical outcomes in the operative fixation of the paediatric supracondylar fracture. The secondary aim was to build a collaborative network of research ready medical students in south west England.

Methods

Children presenting to emergency departments with Gartland type II or III SCFs in the three years preceding the study start date were eligible for inclusion in this retrospective cohort study. Patients were identified using International Classification of Disease (ICD-10) codes for SCF (S42.4).[26] Patients were included in a consecutive fashion at each site. Data were collected between January 2015 and May 2016 across five hospitals in south west England.

Collaborators were recruited using an online research system, the British Orthopaedic Network Environment (BONE).[27] The study background, aims, and objectives are published on an open-access webpage on BONE. Successful collaborators received central training on the study protocol and data collection process from the study lead. They were supervised by a consultant in Trauma & Orthopaedics or Emergency Medicine at their site. Collaborators scrutinised paper and electronic case notes and hospital records, recording information on a standardised form. Approval for the study was granted at each participating site by the research and development office.

Outcome measures were maintenance of reduction and iatrogenic nerve injury. Data on Gartland grade, wire diameter and wire configuration were sourced from the operation note; data were checked against the radiograph for Gartland grade and wire configuration. Maintenance of reduction was evaluated by

calculating the change in Baumann's angle, measured in the coronal plane and determined by comparing peri-operative radiographs with those taken during follow-up at the time of fracture union using the standardised method.[28] The Baumann angle is formed between the physeal line of the lateral condyle and a line perpendicular to the long axis of the humerus. A normal Baumann's angle is 9°–26°. Baumann's angle has been shown to vary 6° for every 10° of humeral rotation on the anteroposterior radiograph.[17] We considered a change in Baumann's angle of over 12° to constitute a clinically significant change (denoting loss of reduction) which is in keeping with similar large cohort studies.[6,11] This allows for variation in positioning during X-ray and measurement variability.

Data was summarized using mean and standard deviations or frequencies for continuous and categorical data, respectively. The Chi-squared test was used to compare differences among categorical variables. The Wilcoxon rank-sum and Kruskall-Wallis tests were used to compare categorical predictor variables with continuous outcome variables (following categorisation of data as non-parametric by the Shapiro-Wilk test). Statistical significance was ascribed when the p value was <0.05. Statistical analyses were performed using SPSS v25 (IBM Corporation, Armonk, New York, USA).

Results

Totally 209 patients were eligible for inclusion. The mean age was 6.4 years. Among them, 52% were male; 26% had Gartland 2 SCF and 74% Gartland 3 SCF.

The mean change in Baumann's angle was 5.4° (SD = 5.8°). Twenty-eight of 209 patients (13.4%) suffered clinically significant loss of reduction, indicated by greater change in their Baumann's angle than the pre-determined 12° threshold. Data on loss of reduction were not normally distributed, as determined by Shapiro-Wilk test ($p < 0.001$).

Thirty-three of 209 patients (15.7%) had documented neurological deficit at presentation, with many patients having a deficit in more than one nerve. The nerves affected by these 85 neurological deficits from the 33 patients are shown in Fig. 2. This neurological deficit failed to resolve by final follow-up in 7 of these 33. These patients were followed up for a minimum of six months post-operatively by the treating team.

In addition, 7 of 176 patients (3.9%) who were neurologically intact at presentation had a new neurological deficit at final follow-up, assumed to have been caused by treatment. There was no significant difference in the incidence of treatment related neurological deficit between patients treated with different Kirschner wire diameters or configurations. These patients were followed up for a minimum of six months post-operatively by the treating team, with four being followed up to twelve months.

Gartland grade was not significantly associated with use of any wire configuration or diameter by the treating surgeon.

In the study, 95.7% of cases were performed by a consultant, with the remainder performed by an orthopaedic registrar. Loss of reduction by final follow-up was documented in 5.7% of cases. Frequencies for diameter of Kirschner wire used are shown in Fig. 3A. Frequencies for Kirschner wire configuration are shown in Fig. 3B.

Patients treated with the crossed ×3 configuration had a smaller change in Baumann's angle than those treated with other configurations ($p = 0.001$) (Fig. 4). Maintenance of reduction was significantly better in patients treated specifically with crossed ×3 wire Kirschner wire configuration compared to all other configurations ($p = 0.021$) (Fig. 5). However, there was no significant difference in maintenance of reduction or degree of change in Baumann's angle when comparing all crossed wire configurations to all lateral wire configurations. The incidence of iatrogenic nerve injury was not significantly different between groups treated with different wire configurations.

Kirschner wire diameter did not significantly affect maintenance of reduction, degree of change in Baumann's angle, or incidence of iatrogenic nerve injury (Fig. 6).

Discussion

There is uncertainty in the literature as to whether crossed or lateral entry Kirschner wires offer the best patient outcome in the management of SCF by closed reduction and percutaneous pinning. There is a paucity of randomised controlled trial (RCT) evidence, with published trials showing no difference in outcome between groups.[18,29,30] Loss of reduction and nerve injury are relatively rare outcomes, though nerve injury is significantly more rare. Kocher

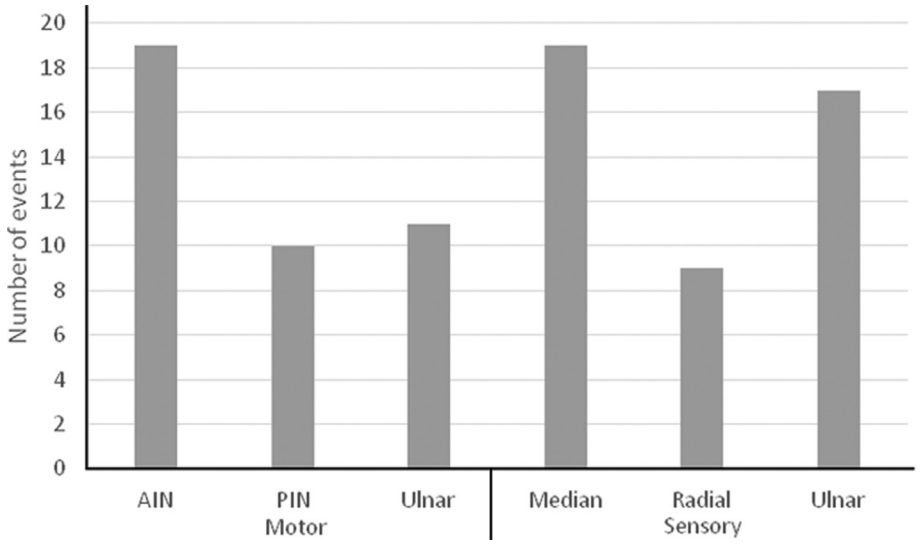


Fig. 2. Nerves affected by neurological deficit at presentation. AIN: anterior interosseous nerve, PIN: posterior interosseous nerve.

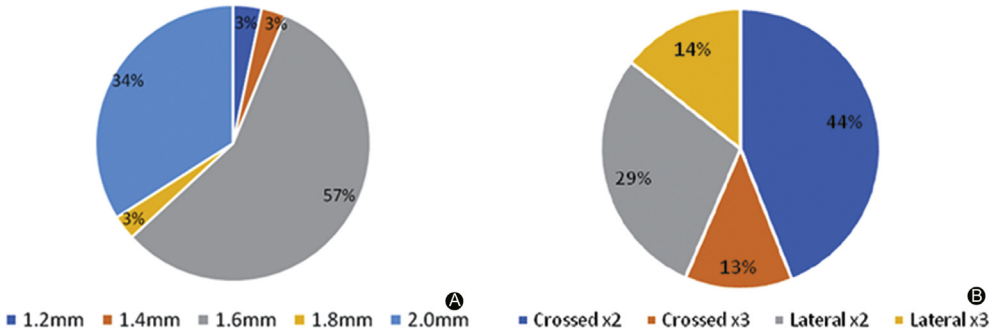


Fig. 3. Diameter (A) and configuration (B) of the Kirschner wires used.

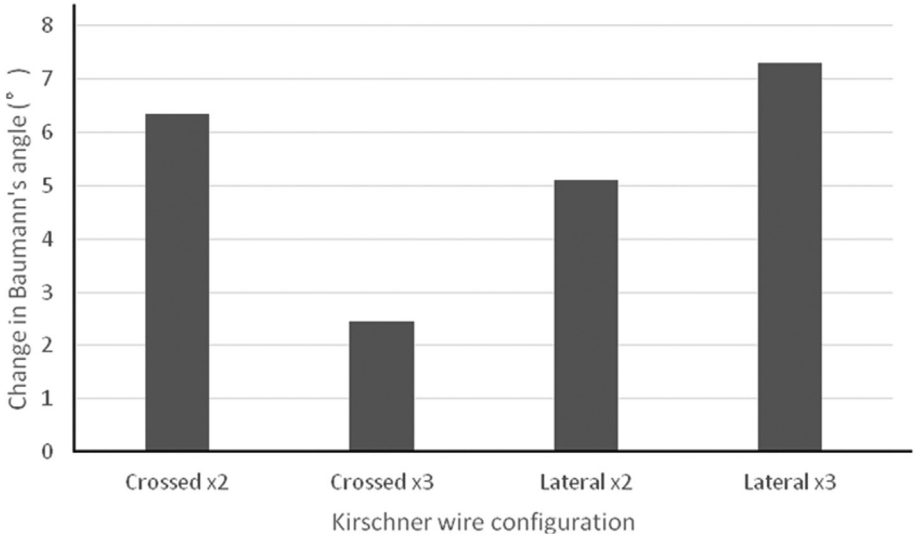


Fig. 4. Mean change in Baumann's angle (°) by wire configuration.

et al.[18] (2007) and Kaewpornsawan (2001)[30] were powered to study loss of reduction, though not to detect a difference in nerve injury. Foead et al. (2004)[29] did not report a sample size calculation, and as such may have been inadequately powered to detect a difference in either outcome. The lack of statistical power in these studies comes as no surprise considering the conclusion of a systematic review and meta analysis that performed a power calculation for investigating nerve injury based on their findings and concluded that around 2000 patients per treatment arm would be required.[11] None of the above quoted studies include such sample size calculations, with the largest cohort consisting of 66 patients spread across two trial arms.[29]

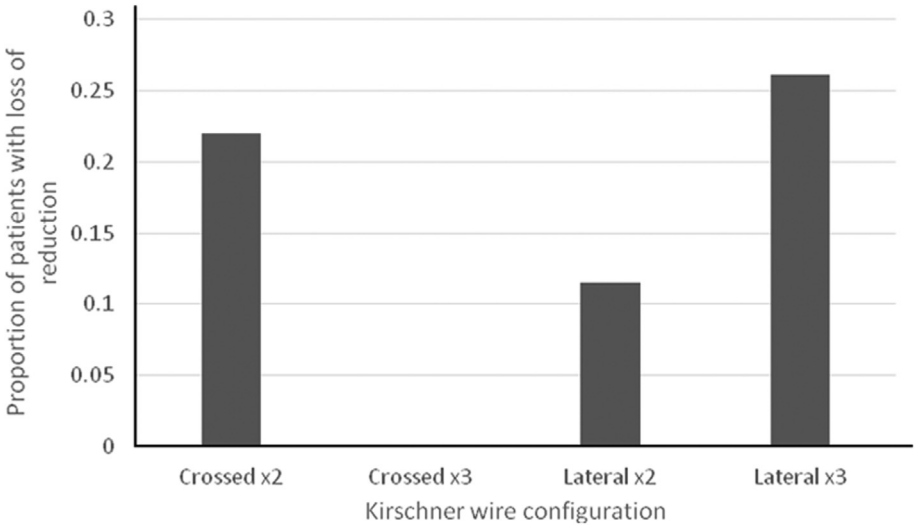


Fig. 5. Proportion of patients with loss of reduction by wire configuration.

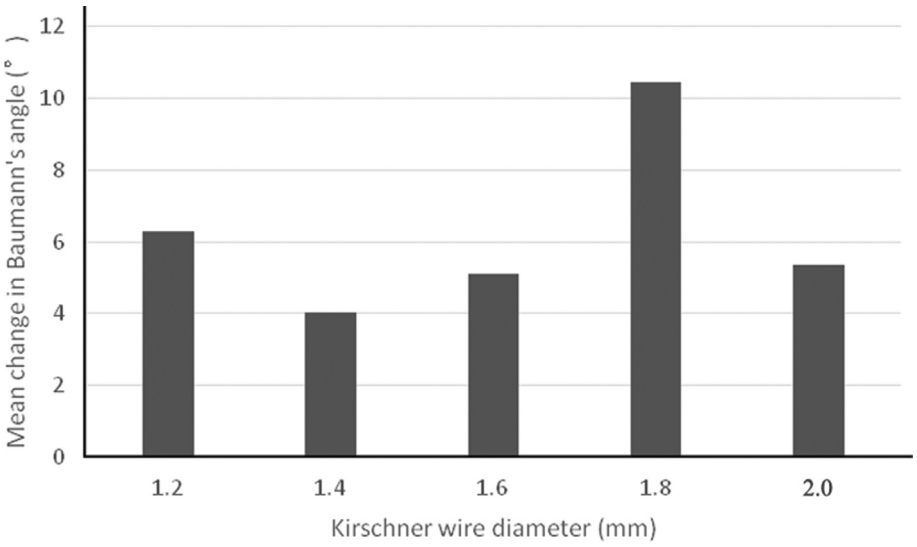


Fig. 6. Mean change in Baumann's angle (°) by wire diameter.

The two principal systematic reviews with meta analysis in the literature have concluded that crossed wires are associated with lower incidence of loss of reduction compared to lateral only wires, but that crossed wires increase the risk of injury to the ulnar nerve.[11,12]

There are no published randomised controlled trials comparing different diameter Kirschner wires in the management of supracondylar fracture.

In this study we present evidence that crossed ×3 Kirschner wires are associated with a lower probability of resultant loss of reduction than other configurations. Around one third of surgeons in our study followed BOAST 11 guidance and use 2.0 mm Kirschner wires. We showed no difference in any measured radiological outcome between patients treated with different diameter Kirschner wires. We did not show a difference in nerve injury rate between patients treated with different Kirschner wire diameters or configurations, though far more patients in each group are required to adequately investigate this outcome.

Our findings partially support the BOAST 11 guidance that crossed wires are associated with a lower risk of loss of fracture reduction, in that we found the crossed ×3 configuration to be associated with improved radiographic outcome. Furthermore, the evidence support the statements in the BOAST guidelines that medial wires should only be used (to give a crossed configuration) if the potential increased risk of ulnar nerve injury is outweighed by the benefit of increased stability.

Using medical student collaborators to collect data, including measuring loss of reduction from radiographs, is a potential limitation of this study due to their relative clinical inexperience. Nevertheless, setting our minimally clinically important difference for Baumann's angle change at 12° when defining loss of reduction is on the upper end of the tolerances of the variability of measurements. Repeatability of measurement was therefore not assessed. We further mitigated this limitation by providing centralised training to collaborators and ensuring consultant supervision at each site. Different wire diameters and configurations may have affected the method of wire removal, as no data were collected on wire removal this should be considered a limitation of the study. This study did not assess wound infection rate, which may be influenced by wire diameter or configuration. This is a limitation as a significantly different infection rate between groups may influence treatment decisions. As such, we recommend further work in this area. As a retrospective multicentre study, this work is at risk of selection bias and variation between treatment methods at different sites. For example, nerve injury may have been influenced by different approaches to manipulation and attempts at pin fixation across sites.

This trial joins an increasing number of surgical studies which have been delivered by medical student and trainee collaboratives. We have demonstrated that the medical student model can provide useful data across several sites, and support the scaling up of these efforts to the national level tying in medical students and trainees to provide observational and interventional data sets to answer meaningful questions to patients.

We found significant variations in practice and compliance with the BOAST 11 guidelines. This is likely to be mirrored on a national and international scale. Conducting a large, multi-centre randomised controlled trial would require agreement from surgeons treating a condition which is fraught with technical difficulty, and for which they will likely have personal preference on surgical technique. It may therefore be difficult to ask them to carry out wire configurations that they are unaccustomed to. Furthermore, many surgeons may not feel that equipoise exists, and for this reason, will be unwilling to take part in a trial. Hence, it may be that at the current time, the most feasible robust method to answer further questions on wire configuration and diameter, such as that of nerve injury, is large scale cohort projects such as our own.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

We would like to acknowledge the work of medical records departments at all participating sites for their work in aiding the collection of data for this study.

Ethical statement

Approval for the study was granted at each participating site by the research and development office.

Conflicts of interest

None declared.

References

1. Cheng JC, Shen WY. Limb fracture pattern in different pediatric age groups: a study of 3,350 children. *J Orthop Trauma*. 1993;7:15–22.
2. Herring J. *Tachdjian's Pediatric Orthopaedics: From the Texas Scottish Rite Hospital for Children*. fourth ed. Philidelphia: Saunders Elsevier Inc; 2008.
3. Green NEVZN. Fractures and dislocations about the elbow. In: Green NESM, ed. *Skeletal Trauma in Children*. Philidelphia: Saunders Elsevier; 2009:211–212.
4. Cheng JC, Lam TP, Maffulli N. Epidemiological features of supracondylar fractures of the humerus in Chinese children. *J Pediatr Orthop B*. 2001;10:63–67.
5. Mahan ST, May CD, Kocher MS. Operative management of displaced flexion supracondylar humerus fractures in children. *J Pediatr Orthop*. 2007;27:551–556.
6. Omid R, Choi PD, Skaggs DL. Supracondylar humeral fractures in children. *J Bone and Joint Surg Am*. 2008;90:1121–1132. https://doi.org/10.2106/JBJS.G.01354.
7. British Orthopaedic Association Standards for Trauma. BOAST 11: Supracondylar Fractures of the Humerus in Children. Available at: http://dickyricky.com/Medicine/Guidelines/BOAST%20-%20British%20Orthopaedic%20Association%20Standards%20for%20Trauma/BOAST-11%20Supracondylar%20Fractures.pdf.
8. Babal JC, Mehlman CT, Klein G. Nerve injuries associated with pediatric supracondylar humeral fractures: a meta-analysis. *J Pediatr Orthop*. 2010;30:253–263. https://doi.org/10.1097/BPO.0b013e3181d213a6.
9. Louahem DM, Nebunescu A, Canavese F, et al. Neurovascular complications and severe displacement in supracondylar humerus fractures in children: defensive or offensive strategy? *J Pediatr Orthop B*. 2006;15:51–57.
10. Sinikumpu JJ, Victorzon S, Pokka T, et al. The long-term outcome of childhood supracondylar humeral fractures: a population-based follow up study with a minimum follow up of ten years and normal matched comparisons. *Bone Joint J*. 2016;98-B:1410–1417.
11. Brauer CA, Lee BM, Bae DS, et al. A systematic review of medial and lateral entry pinning versus lateral entry pinning for supracondylar fractures of the humerus. *J Pediatr Orthop*. 2007;27:181–186. https://doi.org/10.1097/bpo.0b013e3180316cf1.
12. Slobogean BL, Jackman H, Tennant S, et al. Iatrogenic ulnar nerve injury after the surgical treatment of displaced supracondylar fractures of the humerus: number needed to harm, a systematic review. *J Pediatr Orthop*. 2010;30:430–436. https://doi.org/10.1097/BPO.0b013e3181e00c0d.
13. Eberl R, Eder C, Smolle E, et al. Iatrogenic ulnar nerve injury after pin fixation and after antegrade nailing of supracondylar humeral fractures in children. *Acta Orthop*. 2011;82:606–609. https://doi.org/10.3109/17453674.2011.623574.
14. Rasool M. Ulnar nerve injury after K-wire fixation of supracondylar humerus fractures in children. *J Pediatr Orthop B*. 1998;18:686–690.
15. Karakurt L, Ozdemir H, Yilmaz E, et al. Morphology and dynamics of the ulnar nerve in the cubital tunnel after percutaneous cross-pinning of supracondylar fractures in children's elbows: an ultrasonographic study. *J Pediatr Orthop B*. 2005;14:189–193.
16. Ariño VL, Ramirez AM, Ferrer J, et al. Percutaneous fixation of supracondylar fractures of the humerus in children. *J Bone Joint Surg Am*. 1977;59:914–916.
17. Skaggs DL, Cluck MW, Mostofi A, et al. Lateral-entry pin fixation in the management of supracondylar fractures in children. *J Bone Joint Surg Am*. 2004;86:702–704.
18. Kocher MS, Kasser JR, Waters PM, et al. Lateral entry compared with medial and lateral entry pin fixation for completely displaced supracondylar humeral fractures in children. A randomized clinical trial. *J Bone Joint Surg Am*. 2007;89:706–712.
19. Zionts LE, Mckellop HA, Hathaway R. Torsional strength of pin configurations used to fix supracondylar fractures of the humerus in children. *J Bone Joint Surg Am*. 1994;76:253–256. https://doi.org/10.2106/00004623-199402000-00013.
20. Onwuanyi ON, Nwobi DG. Evaluation of the stability of pin configuration in K-wire fixation of displaced supracondylar fractures in children. *Int Surg*. 1998;83:271–274.
21. Lee SS, Mahar AT, Miesen D, et al. Displaced pediatric supracondylar humerus fractures: biomechanical analysis of percutaneous pinning techniques. *J Pediatr Orthop*. 2002;22:440–443.
22. Sankar WN, Hebela NM, Skaggs DL, et al. Loss of pin fixation in displaced supracondylar humeral fractures in children: causes and prevention. *J Bone Joint Surg Am*. 2007;89:713–717.
23. Skaggs DL, Hale JM, Bassett J, et al. Operative Treatment of supracondylar fractures of the humerus in children. The consequences of pin placement. *J Bone Joint Surg Am*. 2001;83:735–740.
24. Goodall R, Claireaux H, Hill J, et al. Comparison between a multicentre, collaborative, closed-loop audit assessing management of supracondylar fractures and the British Orthopaedic Association Standard for Trauma 11 (BOAST 11) guidelines. *Bone Joint J*. 2018;100-B:346–351. https://doi.org/10.1302/0301-620X.100B3.BJJ-2017-0780.R2.
25. Srikumaran U, Tan EW, Belkoff SM, et al. Enhanced biomechanical stiffness with large pins in the operative treatment of pediatric supracondylar humerus fractures. *J Pediatr Orthop*. 2012;32:201–205. https://doi.org/10.1097/BPO.0b013e31824536c8.
26. Brämer GR. International statistical classification of diseases and related health problems tenth revision. *World Health Stat Q*. 1998;41:32–36.
27. British Orthopaedic Network Environment. Available from: https://www.bone.ac.uk. Accessed July 13, 2018.
28. Williamson DM, Coates CJ, Miller RK, et al. Normal characteristics of the Baumann (humerocapitellar) angle: an aid in assessment of supracondylar fractures. *J Pediatr Orthop*. 1992;12:636–639.
29. Foead A, Penafort R, Saw A, et al. Comparison of two methods of percutaneous pin fixation in displaced supracondylar fractures of the humerus in children. *J Orthop Surg (Hong Kong)*. 2004;12:76–82.
30. Kaewpornsawan K. Comparison between closed reduction with percutaneous pinning and open reduction with pinning in children with closed totally displaced supracondylar humeral fractures: a randomized controlled trial. *J Pediatr Orthop B*. 2001;10:131–137.