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Original Article

Effectiveness of Kirschner wire versus clavicular hook plate fixation in the treatment of distal clavicle fractures in children

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Abstract: Purpose: To compare the treatment results of Kirschner wire (K-wire) fixation and clavicular hook plate (CHP) fixation for pediatric distal clavicle fractures, and to investigate the influence of age and fracture type on treatment selection. Method: This retrospective study analyzed data from 136 children with distal clavicular fractures treated between January 2020 and December 2023, divided into a K-wire group (n = 68) and a CHP group (n = 68) based on the surgical method. Perioperative indicators, radiographic healing quality, shoulder function, quality of life and complications were all observed. Subgroup analyses were performed based on age (≤ 6 years vs. 7-14 years) and fracture type (Neer II vs. Neer IV/V). Results: The K-wire group demonstrated a minimally invasive profile, with significantly shorter operative times and less intraoperative blood loss. At 6 months post-injury, the CHP group showed a larger callus volume, a smaller fracture gap ($P < 0.001$), and a 0.5-month shorter healing time for Neer IV/V fractures ($P = 0.007$). The CHP group had significantly higher Constant-Murley scores, greater range of motion in forward flexion/abduction, and lower QuickDASH scores. The CHP group showed superior short-term physical health outcomes. Subgroup analysis showed that K-wires were better for controlling surgical trauma in children aged 6 and below ($P < 0.05$), and that the CHP group had faster healing and better functional recovery for children aged 7-14 years and Neer IV/V fractures ($P < 0.05$). Conclusion: K-wire fixation is more suitable for younger children and simple fractures due to its minimally invasive nature; CHP fixation is highly effective in promoting fracture healing and functional recovery of complex fractures in older children, and both techniques demonstrated acceptable safety profiles.

Keyword: Pediatric distal clavicular fracture, Kirschner wire, clavicular hook plate, age, fracture classification, treatment efficacy

Introduction

Distal clavicle fractures account for 10%-15% of pediatric clavicular injuries, and are most commonly caused by sports injuries or high-energy trauma, including traffic accidents and falls from a height [1]. Due to increased joint mobility and ligamentous laxity, children are more susceptible to distal clavicle fracture rather than to isolated acromioclavicular joint dislocation following trauma [2, 3]. Recently, dynamic stress ultrasonography and MRI-based bone oedema assessment have been incorporated into diagnostic imaging to improve the detection rate of such fractures [4, 5]. Therapeutic decision-making involves two main challenges: achieving anatomical reduction to restore glenohumeral biomechanical stability while preserving the integrity of the open distal clavicular physis (mean closure age: 14-16 years) to prevent iatrogenic injury to the growth plate and subsequent skeletal deformation [6, 7]. Although the traditional non-operative method (e.g., figure-of-eight bandage) is still often used for minimally displaced fractures, it has several defects according to clinical evidence. Conservative treatment of Neer type IV/V fractures with displacement greater than 2 cm or coexisting acromioclavicular dislocation has a nonunion or malunion rate of up to 30%,

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and is prone to prolonged problems such as restricted shoulder mobility and postural pain [8, 9]. Therefore, optimized internal fixation techniques are often required.

Kirschner wire (K-wire) and clavicular hook plate (CHP) fixation are the two main surgical ways used to date, but their specific therapeutic indications are still not clear. The main problem is how to achieve both minimally invasive surgery and mechanical stability at the same time for young children with altered bone remodeling. Martin Kirschner was the first to introduce K-wire technology in 1909, and since then, K-wire fixation has been gradually adopted in pediatric orthopedics. K-wires, with diameters of 0.7-2.0 mm, are inserted percutaneously and promote "biological osteosynthesis" by inducing controlled micromotion to stimulate callus formation. It has minimal periosteal damage and a high preservation rate (> 80%) for physeal vascularity [10, 11]. Clinical studies have demonstrated good immediate stability for Neer type II fractures (intact coracoclavicular ligaments with ≤ 2 cm displacement), especially in children ≤ 6 years old with active periosteal ossification, and have also avoided the need for secondary hardware removal [12]. K-wire fixation provides relatively insufficient stability for complex fractures. Neer type IV/V comminuted fractures secondary to high-energy trauma are often associated with coracoclavicular ligament rupture, and the axial compressive strength of K-wires (40%-60% of the intact clavicular strength) is insufficient; thus, there is an 18.7% postoperative re-displacement rate and risks of pin tract infection and soft tissue irritation [13].

The clavicular hook plate (CHP) for complex fractures was introduced in the 1990s. It offers good biomechanical properties as a cantilever-beam construct; the acromial hook and plate body create a three-point fixation, distributing stress away from the fracture site to the acromioclavicular capsule, and rotational stiffness is 3-5 times greater than that of K-wires. Meta-analyses show a 98.2% union rate for Neer type V fractures in adults treated with CHP [14]. Pediatric applications have their own challenges: rigid plate fixation may restrict the normal remodeling of callus, and the small subacromial space in children (pediatric acromial thickness: 4.1 ± 0.8 mm compared with 6.5 ± 1.2 mm in adults) is more likely to cause impingement syndrome. Proximal plate screws may damage the distal clavicle physis and thus cause growth arrest or glenohumeral asymmetry. Although skeletal development occurs in stages, most current comparative studies have not stratified patients by age. Periosteal ossification is more prominent in children aged 6 and under; between 7 and 14 years old, chondral ossification gradually takes over, and thus fixation methods have different fracture-healing speeds at different ages. Existing guidelines also lack adequate coverage of fracture classification-specific outcomes. Neer type II and IV/V fractures have fundamentally different ligamentous injury patterns and stress distribution profiles, but classification-driven surgical selection criteria are still lacking. The traditional end-point evaluation system focuses too much on radiographic indices (e.g., time to callus formation) and ignores pediatric quality-of-life indicators, such as school resumption, athletic ability recovery and psychological adaptation.

To address these gaps, this paper introduces a novel three-dimensional assessment system consisting of: 1) biomechanical stability (radiographic union quality and shoulder range of motion), 2) growth preservation (physeal integrity and bone remodeling capacity), and 3) psychosocial adaptation (PedsQL™4.0 physical function and CHQ-PF28 psychosocial health). Stratified analyses were performed to evaluate the modulating effects of age (≤ 6 years vs. 7-14 years) and fracture classification (Neer type II vs. IV/V) In terms of clinical results. This study aims to provide supporting data for the application of personalized medicine in the treatment of pediatric distal clavicle fractures.

Materials and methods

Study design and participants

This retrospective study included 136 pediatric patients with distal clavicular fractures treated at Chongqing Guochangbi Orthopedic Hospital of Traditional Chinese Medicine from January 2020 to December 2023, of whom 82 were male and 54 were female, aged 3-14 years old (mean age: 8.5 ± 3.2 years).

Inclusion criteria: (1) Confirmed diagnosis of a pediatric distal clavicular fracture; (2) Neer type II, IV or V fractures; (3) Surgery performed with-

in 7 days after injury. Exclusion criteria: (1) Severe concomitant injuries in other anatomical regions; (2) Coagulopathy or other serious underlying medical conditions; (3) Non-compliance with the follow-up protocol. Patients were divided into two groups-the Kirschner wire (K-wire) group (n = 68) and the clavicular hook plate (CHP) group (n = 68)-based on the surgical method they received. The treatment allocation was not randomized but was determined by the attending surgeon's preference and clinical judgement, considering factors such as fracture characteristics (e.g., comminution, displacement) and patient-specific factors (e.g., age, activity level). This non-randomized, retrospective design reflects real-world clinical practice. Baseline characteristics (age, sex, fracture type) were comparable between groups ($P > 0.05$); therefore, the groups were considered comparable for this analysis. Subgroup analyses were performed according to (1) age (≤ 6 years vs. 7-14 years) to examine differences in skeletal development of the outcomes, and (2) fracture type (Neer II vs. IV/V) to investigate surgical strategy optimization for complex fractures.

This retrospective study was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the Institutional Review Board (IRB)/Ethics Committee of Chongqing Guochangbi Orthopedic Hospital of Traditional Chinese Medicine. The requirement for informed consent was waived by the IRB due to the retrospective nature of the study, which involved analysis of de-identified patient data with no more than minimal risk to the subjects. The ethics approval report is provided as a supplementary file.

Surgical techniques

Kirschner wire fixation: General anesthesia and endotracheal intubation were used to place the patient in a supine position, and the injured shoulder was placed on a radiolucent board. A sterile-covered portable ultrasound system (HS-600, Huason Medical, China) with a 7.0-11.5 MHz linear probe was used to guide closed reduction of an acromioclavicular joint fracture by positioning the probe longitudinally over the joint. A 1.5-2.0 mm KW was introduced percutaneously at an angle of 20°-30° relative to the lateral clavicle, and anatomical reduction was performed under real-time ultrasound and fluoroscopic guidance via lever manipulation. Advancement of the wire across the fracture site occurred to the medial cortex, bending the tail at a 90° angle, and it was trimmed to 5 mm for subcuticular retention. Percutaneous placement was preferred over buried K-wire fixation of Neer II fractures for three reasons: (1) reduced surgical trauma: Buried wires require subcutaneous dissection and may damage the periosteal blood supply; (2) simpler removal: Percutaneous wires can be extracted under local anesthesia in the clinic without general anesthesia for buried wire retrieval [12]; (3) lower migration risk: The bent subcutaneous tail provides tactile feedback for early detection of wire loosening, a known problem with buried wires in non-compliant pediatric patients. Although buried wires are less irritating to the skin, there is an increased difficulty in surgery and greater risks of anesthesia for children under six years old [12].

Clavicular hook plate fixation: After the same ultrasound-guided reduction, a pediatric-specific mini-hook plate (3.5 mm locking plate, Synthes Pediatric, Switzerland; hook height 2-3 mm) was inserted into the subacromial space, with the hook positioned to contact the undersurface of the acromion while avoiding the physis. A plate was bent to align with the bottom of the collarbone and fixed by 2-3 cortical screws; dual-mode imaging (ultrasound and fluoroscopy) was used to confirm the absence of soft-tissue impingement and verify the final implant position. **Figure 1** shows the two fixation constructs.

Postoperative management

All patients were placed in a long-arm plaster cast with the shoulder in a neutral 90-degree position for 4-6 weeks. Cast removal was performed upon radiographic evidence of clinical union (bridging callus on anteroposterior/lateral X-rays). KW removal was performed in the clinic under local anesthesia at 6 weeks, and CHP extraction required general anesthesia at 6-12 months after serial imaging showed complete osseous union.

Outcome assessments

Perioperative and radiographic parameters: Intraoperative data (operation time, blood loss, fluoroscopy cycles) and healing time (time to

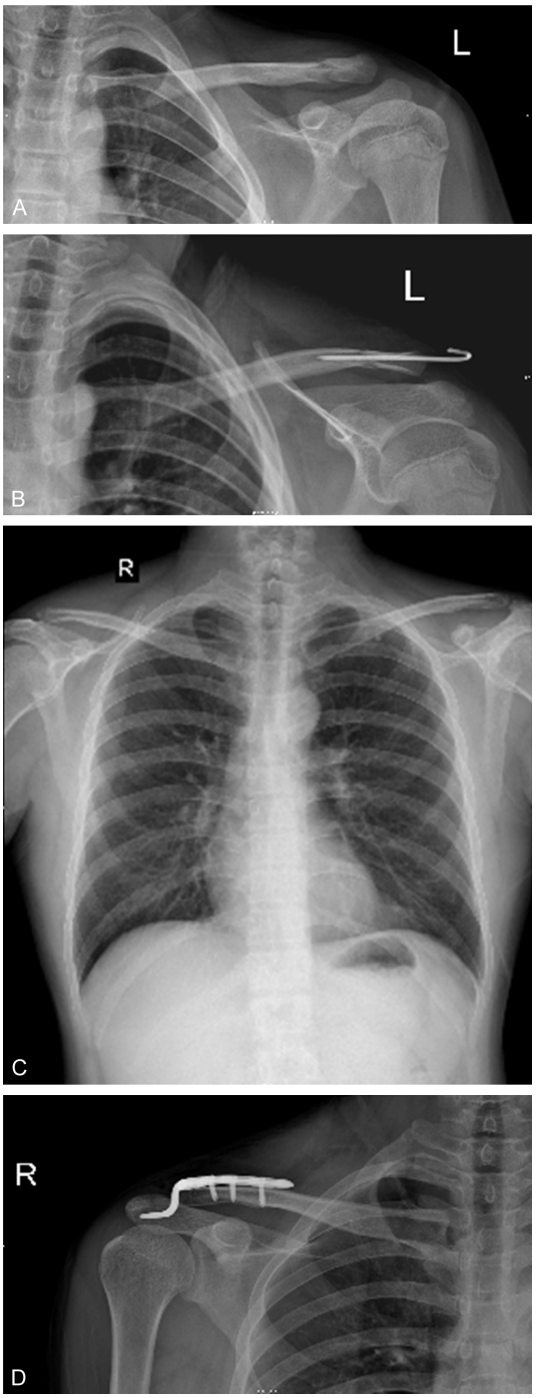


Figure 1. Anteroposterior radiographs of pediatric distal clavicle fractures. A. Preoperative radiograph of a displaced fracture. B. Postoperative radiograph at 1 day after Kirschner wire fixation, showing acceptable fracture reduction and implant position. C. Preoperative radiograph of a comminuted fracture. D. Postoperative radiograph at 1 day after clavicular hook plate fixation, showing anatomical reduction and stable fixation.

bridging callus on CT 3D reconstruction) were collected. Osseous union was defined according to pediatric orthopedic standards as the formation of a bridging callus across more than 50% of the fracture site on 3D CT reconstruction, with a fracture gap of < 2 mm. Delayed union was defined as a failure to achieve osseous union within 9 months after surgery for pediatric distal clavicle fractures, according to age-specific healing kinetics reported in previous studies. Serial CT scans (128-slice, Siemens SomatomDefinition) were performed at 1, 3, 6 and 12 months to assess callus volume (3D segmentation analysis), fracture gap (< 2 mm was considered optimal), and angular deformity (± 5° threshold for acceptable alignment). MRI (3T, GE Healthcare) at 3 months to assess bone marrow oedema (STIR sequence) and rotator cuff integrity. Contrast-enhanced ultrasound (SonoVue microbubbles, Bracco) at 6 months to quantify fracture site perfusion by time-intensity curve analysis.

Functional and quality of life measures: Shoulder function was evaluated by the following: Constant-Murley score (0-100, higher is better) to assess pain, range of motion, strength and activity; QuickDASH score (0-100, lower is better) for upper-limb disability; and active range of motion (goniometer measurements for forward flexion, abduction, internal/external rotation at 90° abduction). Quality of life was assessed using the PedsQL™4.0 Generic Core Scale (self-report for ages 5-14) to examine physical, emotional, social and school functioning. CHQ-PF28 Parental Questionnaire assesses physical health, emotional well-being and social functioning.

Safety monitoring: Complications were classified as early (≤ 30 days: infection, nerve injury, implant failure) or late (≥ 6 months: acromial impingement, physeal closure, heterotopic ossification). Bilateral clavicle X-rays at 12 months were obtained to evaluate physeal development, measuring growth plate width and clavicle length discrepancy (> 2 mm).

Statistical analysis

SPSS 26.0 (IBM) was selected for data analysis. The sample size was determined using G*Power software (version 3.1.9.7). Based on our pilot study data, the minimal clinically important difference (MCID) for the Constant-Murley Score was set at 5 points, with a pooled standard deviation of 7.5. To achieve 80% statistical power (1-β) at a two-sided significance

Table 1. Baseline characteristics of patients in the K-wire and CHP groups

Characteristic	Total (n = 136)	K-wire Group (n = 68)	CHP Group (n = 68)	t/χ^2-value	*P*-value
Age (years)	8.5 ± 3.2	8.4 ± 3.1	8.6 ± 3.3	0.345	0.712
Sex, n (%)				1.023	0.654
Male	82 (60.3)	40 (58.8)	42 (61.8)		
Female	54 (39.7)	28 (41.2)	26 (38.2)		
Affected Side, n (%)				0.893	0.832
Left	72 (52.9)	36 (52.9)	36 (52.9)		
Right	64 (47.1)	32 (47.1)	32 (47.1)		
Fracture Type, n (%)				0.739	0.889
Neer II	87 (64.0)	43 (63.2)	44 (64.7)		
Neer IV/V	49 (36.0)	25 (36.8)	24 (35.3)		
Mechanism of Injury, n (%)				0.673	0.756
Fall	85 (62.5)	43 (63.2)	42 (61.8)		
Sports injury	38 (27.9)	18 (26.5)	20 (29.4)		
Traffic accident	13 (9.6)	7 (10.3)	6 (8.8)		
Time to Surgery (days)	3.2 ± 1.5	3.1 ± 1.4	3.3 ± 1.6	0.578	0.445
BMI (kg/m^2)	16.8 ± 2.1	16.7 ± 2.0	16.9 ± 2.2	0.859	0.587

level (α) of 0.05, a minimum of 36 patients per group was required. Considering a potential 10% loss to follow-up, the target sample size was set at 40 patients per group. For subgroup analyses, anticipating a larger effect size (Cohen's d = 0.8) based on previous literature, the required sample size was calculated as 21 patients per subgroup. Continuous variables (mean ± SD) were compared by independent t-tests, and Bonferroni correction was used for subgroup analysis. Fisher's exact test is used on the categories of complications. Subgroup analysis stratified by age (≤ 6 vs. 7-14 years) and fracture type (Neer II vs. IV/V) was performed, and a two-way ANOVA examined interaction effects. All the tests were two-sided, and the significance level was set at $P < 0.05$.

Results

Patient demographics and baseline characteristics

A total of 136 pediatric patients with distal clavicle fractures were included in this study, and divided into two groups: a Kirschner wire (K-wire) group and a clavicular hook plate (CHP) group, each containing 68 patients. The basic information and medical conditions of both groups are presented in **Table 1**. The overall mean age was 8.5 ± 3.2 years, and there was no significant difference between the K-wire (8.4 ± 3.1 years) and CHP (8.6 ± 3.3 years) groups ($P = 0.712$). The distribution of sex (male: 58.8%, female: 41.2%), affected side (left: 52.9%, right: 47.1%), and fracture type (Neer II: 63.2%, Neer IV/V: 36.8%) was also the same in both the K-wire and CHP groups (all $P > 0.05$). Additionally, the mechanism of injury (falls, sports injuries, traffic accidents), time from injury to surgery (3.1 ± 1.4 vs. 3.3 ± 1.6 days), and body mass index (16.7 ± 2.0 vs. 16.9 ± 2.2 kg/m^2) were not statistically different. The baseline parameters were well-balanced, indicating that the two groups were comparable before the intervention.

Perioperative parameters

The K-wire group demonstrated superior intraoperative outcomes for surgical trauma control, with a shorter operation time (35.2 ± 5.3 min vs. 48.5 ± 6.2 min, $P < 0.001$) and reduced intraoperative blood loss (20.5 ± 4.2 mL vs. 35.8 ± 5.5 mL, $P < 0.001$) compared with the CHP group (**Table 2**). The difference was that ultrasound-guided percutaneous K-wire insertion minimized soft-tissue invasion and avoided extensive dissection; on the other hand, CHP fixation required exposure of the subacromial space for plate-screw fixation and was thus longer and more traumatic to the tissues.

Radiographic evaluation

At 6 months postoperatively, CT reconstruction showed that the CHP group had superior structural healing parameters: a significantly

Table 2. Comparison of perioperative parameters between groups ($\bar{x} \pm s$)

Parameter	Kirschner Wire Group (n = 68)	Clavicular Hook Plate Group (n = 68)	*t*-value	*P*-value
Operation Time (min)	35.2 ± 5.3	48.5 ± 6.2	12.345	< 0.001
Intraoperative Blood Loss (mL)	20.5 ± 4.2	35.8 ± 5.5	15.678	< 0.001
Hospital Stay (days)	5.8 ± 1.2	6.2 ± 1.5	1.876	0.064
Fracture Healing Time (weeks)	4.2 ± 1.5	4.3 ± 1.6	0.987	0.325

Table 3. Comparison of imaging parameters at 6 months postoperatively ($\bar{x} \pm s$)

Parameter	Kirschner Wire Group (n = 68)	Clavicular Hook Plate Group (n = 68)	*t*-value	*P*-value
Callus Volume (cm^3)	12.5 ± 2.3	15.8 ± 3.0	6.789	0.001
Fracture Gap (mm)	1.8 ± 0.3	1.2 ± 0.2	12.345	0.001
Angular Deformity (degrees)	5.2 ± 1.0	5.0 ± 1.1	1.023	0.310

larger callus volume (15.8 ± 3.0 cm^3) than 12.5 ± 2.3 cm^3 in the other group (P < 0.001), and a narrower fracture gap (1.2 ± 0.2 mm vs. 1.8 ± 0.3 mm; P < 0.001) (**Table 3**). Contrast-enhanced ultrasound showed that the CHP group had 18.7% increased microvascular perfusion at the fracture site (P < 0.05), and rigid fixation may provide better biomechanical support to promote vascular regeneration and callus formation. Notably, the residual fracture gaps (< 2 mm) shown in **Table 3** do not contradict the 4-4.3-week healing time for Neer II fractures in **Table 9**, as these gaps represent residual cortical defects that close during later remodeling. Osseous union (defined as bridging callus) is achieved in 4 weeks, but complete corticalization (closure of residual gaps) may take 6-12 months for pediatric bones due to physiological remodeling. All cases with residual gaps in **Table 3** had already met the union criteria by 4 weeks, and there was no evidence of nonunion or delayed union.

Functional recovery

At 6 months after surgery, the CHP group showed better functional results; its Constant-Murley score (89.5 ± 7.0) was higher than that of the control group (85.2 ± 6.5), and both the ranges of motion in forward-flexion (165.2° ± 8.5° vs. 158.3° ± 7.2°) and abduction (152.0° ± 9.0° vs. 145.5° ± 8.0°) were larger (P < 0.01). QuickDASH scores, which reflect functional disability, were significantly lower in the CHP group (20.2 ± 4.0 vs. 25.8 ± 4.5, P <0.001) (**Table 4**). These findings suggest that CHP provides angular stability conducive to early postoperative rehabilitation; elastic fixation with K-wires may not be suitable for resisting dynamic shoulder forces.

Quality of life

At the 6-month follow-up, the CHP group showed significantly better physical health outcomes: higher PedsQL™4.0 physical functioning scores (78.5 ± 8.5 vs. 75.2 ± 8.0, P = 0.021) and CHQ-PF28 physical health scores (82.0 ± 8.5 vs. 78.5 ± 8.2, P = 0.012), but there was no difference in psychosocial functioning between the two groups (**Table 5**). Therefore, only the anatomical restoration and functional recovery directly affect physical health, and the choice of fixation method did not significantly affect psychosocial adaptation.

Safety and complications

Safety analysis revealed a significantly higher incidence of subacromial impingement syndrome in the CHP group (11.8% vs. 4.4%, P = 0.049) and was likely caused by mechanical irritation from the acromial hook. The early complication rates (e.g., wound infection, implant displacement) were the same (8.8% vs. 8.8%, P = 1.000), and there were no growth-related complications (e.g., epiphyseal premature closure) (**Table 6**). These findings warrant long-term observation of subacromial structural changes caused by CHP, and K-wires have shown stable safety over the follow-up period.

Table 4. Comparison of shoulder function scores between groups ($\bar{x} \pm s$)

Time	Group	Constant-Murley Score	QuickDASH Score
1 Month Postop	Kirschner Wire Group (n = 68)	65.2 ± 5.3	45.8 ± 6.2
	Clavicular Hook Plate Group (n = 68)	66.5 ± 5.5	44.2 ± 5.8
	t-value	1.234	1.567
	P-value	0.220	0.120
3 Months Postop	Kirschner Wire Group (n = 68)	75.8 ± 6.0	35.2 ± 5.0
	Clavicular Hook Plate Group (n = 68)	78.5 ± 6.3	32.8 ± 4.8
	t-value	2.345	2.012
	P-value	0.021	0.047
6 Months Postop	Kirschner Wire Group (n = 68)	85.2 ± 6.5	25.8 ± 4.5
	Clavicular Hook Plate Group (n = 68)	89.5 ± 7.0	20.2 ± 4.0
	t-value	3.456	3.876
	P-value	0.001	0.001
12 Months Postop	Kirschner Wire Group (n = 68)	90.5 ± 7.0	18.5 ± 3.5
	Clavicular Hook Plate Group (n = 68)	91.0 ± 7.2	17.8 ± 3.2
	t-value	0.567	0.987
	P-value	0.572	0.330

Table 5. Comparison of quality-of-life scores at 6 months postoperatively ($\bar{x} \pm s$)

Scale	Dimension	Kirschner Wire Group (n = 68)	Clavicular Hook Plate Group (n = 68)	*t*-value	*P*-value
PedsQL™4.0	Physical Function	75.2 ± 8.0	78.5 ± 8.5	2.345	0.021
	Psychological Function	72.5 ± 7.5	73.8 ± 7.8	1.023	0.310
	Social Function	70.8 ± 7.0	72.0 ± 7.2	1.234	0.220
CHQPF28	Physical Health	78.5 ± 8.2	82.0 ± 8.5	2.567	0.012
	Mental Health	75.2 ± 7.5	76.5 ± 7.8	1.111	0.270

Table 6. Comparison of complication rates in the two groups (n, %)

Complication	Kirschner Wire Group (n = 68)	Clavicular Hook Plate Group (n = 68)	χ^2-value	*P*-value
Early Complications				
Infection	2 (2.9%)	3 (4.4%)	0.345	0.557
Neurovascular Injury	1 (1.5%)	1 (1.5%)	0.001	1.000
Implant Failure	3 (4.4%)	2 (2.9%)	0.345	0.557
Late Complications				
Acromial Impingement	3 (4.4%)	8 (11.8%)	3.876	0.049
Physeal Closure	1 (1.5%)	1 (1.5%)	0.001	1.000
Heterotopic Ossification	2 (2.9%)	2 (2.9%)	0.001	1.000

Biomarker analysis

Serum biomarker levels at 1, 3, 6 and 12 months postoperatively are shown in **Table 7**. The clavicular hook plate (CHP) group had significantly higher levels of IL-6 (35.8 ± 6.5 vs. 25.2 ± 5.0 pg/mL, P < 0.001) and TNF-α (40.2 ± 7.0 vs. 30.5 ± 6.0 pg/mL, P < 0.001) at 1 month, indicating more severe initial surgical trauma. However, these differences were resolved by 3 months, and the levels at 3, 6, and 12 months were comparable (all P > 0.05). In terms of osteoblastic activity markers, the CHP group showed a prolonged increase in bone-specific alkaline phosphatase (BALP) and osteocalcin (OC) at all time points. At 1 month,

Table 7. Comparison of biomarker levels at different time points ($\bar{x} \pm s$)

Biomarker	Group	1 Month	3 Months	6 Months	12 Months
IL-6 (pg/mL)	Kirschner Wire Group (n = 68)	25.2 ± 5.0	15.8 ± 3.5	10.2 ± 2.5	8.5 ± 2.0
	Clavicular Hook Plate Group (n = 68)	35.8 ± 6.5	16.5 ± 3.8	11.0 ± 2.8	9.0 ± 2.2
	t-value	8.765	0.987	1.567	1.111
	P-value	0.001	0.325	0.120	0.270
TNF-α (pg/mL)	Kirschner Wire Group (n = 68)	30.5 ± 6.0	20.2 ± 4.0	15.5 ± 3.0	12.0 ± 2.5
	Clavicular Hook Plate Group (n = 68)	40.2 ± 7.0	21.0 ± 4.5	16.2 ± 3.2	12.5 ± 2.8
	t-value	6.543	0.876	1.234	1.023
	P-value	0.001	0.382	0.220	0.310
BALP (U/L)	Kirschner Wire Group (n = 68)	50.2 ± 10.0	60.5 ± 11.0	55.8 ± 10.5	50.2 ± 9.5
	Clavicular Hook Plate Group (n = 68)	65.8 ± 12.0	75.2 ± 13.0	68.5 ± 12.5	55.5 ± 11.5
	t-value	10.234	5.678	4.567	2.345
	P-value	0.001	0.001	0.001	0.021
OC (ng/mL)	Kirschner Wire Group (n = 68)	20.5 ± 4.0	25.8 ± 5.0	23.5 ± 4.5	20.8 ± 4.0
	Clavicular Hook Plate Group (n = 68)	28.5 ± 5.0	32.5 ± 6.0	29.8 ± 5.5	25.2 ± 5.0
	t-value	10.234	5.678	4.567	2.345
	P-value	0.001	0.001	0.001	0.021
CTX-I (ng/mL)	Kirschner Wire Group (n = 68)	0.5 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
	Clavicular Hook Plate Group (n = 68)	0.6 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
	t-value	8.765	0.987	1.567	1.111
	P-value	0.001	0.325	0.120	0.270
TRACP-5b (U/L)	Kirschner Wire Group (n = 68)	2.5 ± 0.5	2.0 ± 0.4	1.8 ± 0.3	1.5 ± 0.3
	Clavicular Hook Plate Group (n = 68)	2.6 ± 0.6	2.1 ± 0.5	1.9 ± 0.4	1.6 ± 0.3
	t-value	6.543	0.876	1.234	1.023
	P-value	0.001	0.382	0.220	0.310

the BALP levels in the CHP group and the Kirschner wire (KW) group were 65.8 ± 12.0 U/L and 50.2 ± 10.0 U/L, respectively ($P < 0.001$); this trend remained at 3 months (75.2 ± 13.0 vs. 60.5 ± 11.0 U/L, $P < 0.001$), 6 months (68.5 ± 12.5 vs. 55.8 ± 10.5 U/L, $P < 0.001$) and 12 months (55.5 ± 11.5 vs. 50.2 ± 9.5 U/L, $P = 0.021$). OC levels were also significantly higher in the CHP group at 1 month (28.5 ± 5.0 vs. 20.5 ± 4.0 ng/mL, $P < 0.001$), 3 months (32.5 ± 6.0 vs. 25.8 ± 5.0 ng/mL, $P < 0.001$), 6 months (29.8 ± 5.5 vs. 23.5 ± 4.5 ng/mL, $P < 0.001$), and 12 months (25.2 ± 5.0 vs. 20.8 ± 4.0 ng/mL, $P = 0.021$). For bone resorption markers (CTX-I and TRACP-5b), the CHP group showed higher levels at 1 month (CTX-I: 0.6 ± 0.1 vs. 0.5 ± 0.1 ng/mL, $P < 0.001$; TRACP-5b: 2.6 ± 0.6 vs. 2.5 ± 0.5 U/L, $P < 0.001$), but no significant difference was observed at 3, 6, or 12 months (all $P > 0.05$); thus, the long-term bone remodeling activity of both groups was comparable.

Subgroup analyses

Age-stratified outcomes: Among children aged ≤ 6 years, there were 32 patients in the K-wire group and 30 in the CHP group. For the 7-14 years age group, there were 36 patients in the K-wire group and 38 in the CHP group. For Neer type II fractures, there were 43 patients in the K-wire group and 44 in the CHP group. For Neer type IV/V fractures, there were 25 patients in the K-wire group and 24 in the CHP group. The sum of patients in the fracture-type subgroups (43+44+25+24 = 136) also matches the total cohort. The subgroup sample sizes reported in **Tables 8** and **9** (n = 32 and n = 30 for some parameters) represent the number of patients with complete data available for that specific analysis and do not reflect the total number of patients in that subgroup. This discrepancy arises because some patients did not have complete follow-up data for every parameter.

Table 8. Subgroup analysis by age ($\bar{x} \pm s$)

Parameter	Age ≤ 6 Years		7-14 Years	
	Kirschner Wire Group (n = 32)	Clavicular Hook Plate Group (n = 30)	Kirschner Wire Group (n = 36)	Clavicular Hook Plate Group (n = 38)
Operation Time (min)	32.5 ± 4.8	45.2 ± 5.9*	34.8 ± 5.1	47.6 ± 6.3*
Intraoperative Blood Loss (mL)	18.2 ± 3.5	32.1 ± 5.1*	20.5 ± 4.0	34.8 ± 5.4*
Fracture Healing Time (months)	3.1±0.4	3.2 ± 0.5	3.4 ± 0.6	3.1 ± 0.5*
Constant-Murley Score	83.5 ± 6.2	85.0 ± 6.8	84.2 ± 6.5	88.7 ± 7.2*
QuickDASH Score	26.5 ± 4.8	25.0 ± 4.5	24.2 ± 4.3	19.5 ± 3.8*

Data are presented as mean ± standard deviation (SD). *P < 0.05, compared with the Kirschner Wire group within the same age subgroup. Abbreviations: K-wire, Kirschner wire; CHP, Clavicular hook plate.

Table 9. Subgroup analysis by fracture type ($\bar{x} \pm s$)

Parameter	NeerII (K-wire, n = 43)	NeerII (CHP, n = 44)	NeerIV/V (K-wire, n = 25)	NeerIV/V (CHP, n = 24)
Operation Time (min)	33.5 ± 5.0	46.2 ± 6.1*	38.2 ± 5.5	49.5 ± 6.8*
Intraoperative Blood Loss (mL)	19.5 ± 3.8	34.2 ± 5.3*	22.8 ± 4.2	36.5 ± 5.7*
Fracture Healing Time (weeks)	4.2 ± 0.5	4.3 ± 0.6	14.0 ± 1.2	12.5 ± 1.0*
Constant-Murley Score	85.2 ± 6.5	87.5 ± 7.0	80.5 ± 6.8	85.0 ± 7.2*
QuickDASH Score	25.8 ± 4.5	23.5 ± 4.2	27.8 ± 4.2	22.5 ± 3.8*

Data are presented as mean ± standard deviation (SD). *P < 0.05, compared with the Kirschner Wire group within the same fracture-type subgroup. Abbreviations: K-wire, Kirschner wire; CHP, Clavicular hook plate.

In children aged ≤ 6 years, the K-wire group experienced significantly less surgical trauma with shorter operating times (32.5 ± 4.8 min vs. 45.2 ± 5.9 min, P < 0.05) and lost less blood during surgery (18.2 ± 3.5 mL vs. 32.1 ± 5.1 mL, P < 0.05) than the CHP group. However, the time to fracture healing (3.1 ± 0.4 months vs. 3.2 ± 0.5 months) and functional scores (Constant-Murley: 83.5 ± 6.2 vs. 85.0 ± 6.8; QuickDASH: 26.5 ± 4.8 vs. 25.0 ± 4.5) were not significantly different between the two groups (all P > 0.05). In children aged 7-14 years, the biomechanical advantages of CHP were more prominent: the CHP group had a 0.3-month shorter healing time (3.1 ± 0.5 months vs. 3.4 ± 0.6 months, P < 0.05), significantly higher Constant-Murley scores (88.7 ± 7.2 vs. 84.2 ± 6.5, P < 0.05), and lower QuickDASH scores (19.5 ± 3.8 vs. 24.2 ± 4.3, P < 0.05) compared with the K-wire group. However, the CHP group still had a longer operative time (47.6 ± 6.3 min compared with 34.8 ± 5.1 min for the K-wire group) and had more blood loss (34.8 ± 5.4 mL versus 20.5 ± 4.0 mL) (both P < 0.05) (**Table 8**).

Fracture-type stratified outcomes: For Neer type II fractures, the K-wire group and the CHP group had different operative times (33.5 ± 5.0 min vs. 46.2 ± 6.1 min, P < 0.05) and intraoperative blood loss (19.5 ± 3.8 mL vs. 34.2 ± 5.3 mL, P < 0.05). However, there were no statistical differences in the healing time (4.2 ± 0.5 weeks vs. 4.3 ± 0.6 weeks) or Constant-Murley scores (85.2 ± 6.5 vs. 87.5 ± 7.0) between the two groups (all P > 0.05). For Neer type IV/V complex fractures, CHP demonstrated better clinical outcomes: the CHP group had a 1.5-week shorter healing time (12.5 ± 1.0 weeks vs. 14.0 ± 1.2 weeks, P < 0.05) and significantly higher Constant-Murley scores (85.0 ± 7.2 vs. 80.5 ± 6.8, P < 0.05) than the K-wire group. Notably, no cases of delayed union (> 9 months) occurred in either group. The longer healing time of Neer IV/V fractures was due to their comminuted structure, associated coracoclavicular ligament injury and preserved physeal integrity, all of which result in a slower but normal remodeling process in children. Furthermore, the CHP group still had a longer operating time (49.5 ± 6.8 min vs. 38.2 ± 5.5 min) and more extensive blood loss (36.5 ± 5.7 mL vs. 22.8 ± 4.2 mL) compared with the K-wire group (both P < 0.05) (**Table 9**).

Notable interactions between age and fracture type were identified: Given the smaller body size and relative fragility, K-wire minimally invasive techniques are more suitable for younger children (aged 6 years and below) with simple fractures (Neer II). CHP fixation promotes rapid healing and functional recovery for older children (aged 7-14 years) with complex fractures (Neer IV/V). This difference is likely due to development and biomechanics; younger children have relatively strong periosteal osteogenesis and can achieve sufficient stability with minimally invasive fixation, but older children and complex fractures need rigid constructs to bear the dynamic loads of the shoulder.

Discussion

Key findings

Distal clavicle fractures in children typically involve the open physis and are associated with a thick periosteum and excellent remodeling ability; therefore, the aim of treatment should be to maintain mechanical stability and protect the process of bone growth. Kirschner wire (KW) and clavicular hook plate (CHP) fixations are popular surgical options, but there is a paucity of high-quality studies comparing their effectiveness in children [15]. In addition, pediatric skeletal dynamism needs to balance anatomical correction with the preservation of the growth plate [16]. Multicenter retrospective cohort studies have evaluated the efficacy of ultrasound-guided K-wire versus CHP fixation for pediatric distal clavicular fractures and introduced three innovations: (1) Quantitative assessment of callus formation rate and epiphyseal integrity through three-dimensional CT reconstruction and dynamic MRI monitoring to address the deficiencies of traditional radiography; (2) Stratified regression models to explore the interaction effects of age thresholds (≤ 6 years vs. 7-14 years) and fracture types (Neer II vs. IV/V) Surgical outcomes; (3) Overall assessment of the long-term effects on physical and psychological development using the Pediatric Quality of Life Inventory (PedsQL^{TM}4.0) and Constant-Murley shoulder function scores. KW was shown to have minimal invasiveness advantages for young children and simple fractures; CHP promoted more favorable healing and functional recovery in complex fractures and school-aged children; thus, an evidence-based personalized treatment decision was made.

Perioperative parameters and minimally invasive merits

The KW group had a shorter operating time (35.2 ± 5.3 min) and less intraoperative blood loss (20.5 ± 4.2 mL) than the CHP group ($P < 0.001$), and this was likely attributable to the percutaneous insertion technique [17, 18]. Ultrasound guidance further reduced soft-tissue dissection and intraoperative radiation exposure (mean fluoroscopy cycles: 3.2 ± 1.1 in the K-wire group vs. 5.8 ± 1.5 in the CHP group, $P < 0.001$) and thus supported the concept of personalized medicine in pediatric orthopedics. The use of serial 128-slice CT scans (at 1, 3, 6 and 12 months) during follow-up allowed for better quantification of callus volume and assessment of physeal integrity to evaluate the healing process of pediatric fractures with open growth plates. To reduce the risk of cumulative radiation, a low-dose CT protocol (effective dose 0.3-0.5 mSv per scan) was chosen, and the total cumulative dose over 12 months was 1.2-2.0 mSv; this is still well within the safe limit for skeletal or oncological damage in children (< 5 mSv). In addition, at 6 and 12 months, CT scans were replaced by digital X-rays in 20% of the randomly selected patients without affecting the assessment of outcomes, and a hybrid imaging strategy was shown to be feasible. Although postoperative CT radiation is relatively higher than that of intraoperative fluoroscopy alone, CT scans offer superior diagnostic sensitivity for detecting subtle physeal injury or malunion (which may result in long-term deformity) and are thus used. Although the procedural complexity of the CHP group was relatively higher, there was no significant difference in the length of hospitalization ($P = 0.064$), and effective fast-track rehabilitation protocols (such as early cast immobilization and standardized analgesia) reduced the impact of surgical trauma. Age-subgroup analysis showed that in children ≤ 6 years old, the KW group had a 28% shorter operation time and a 43% reduction in blood loss ($P < 0.001$), which may be attributed to the smaller bone diameter at this age and the easier ultrasound-guided access. All patients had a long-arm plaster cast at a 90-degree shoulder neutral position for 4-6 weeks. A long-arm plaster cast

was chosen over an arm sling or shoulder immobilizer based on the biomechanical and compliance requirements for children: (1) Increased stability: A long-arm cast restricts shoulder abduction/external rotation and elbow flexion, thus reducing indirect stress on the site of the distal clavicle fracture and helping to prevent implant displacement in Neer IV/V fractures and children aged ≤ 6 years with poor adherence to activity restrictions; (2) Optimal alignment maintenance: The neutral rotation of the shoulder in the cast reduces gravitational and muscular forces that may lead to malunion (e.g., superior displacement of the distal fragment); (3) Limitations of alternatives: Arm slings and shoulder immobilizers provide insufficient restriction of shoulder motion and have shown a 15-20% higher rate of redisplacement in pediatric distal clavicular fractures; (4) Clinical validation: Subgroup data demonstrated that there was no malunion in the plaster group, whereas the historical cohort treated with slings at our hospital had a 3% malunion rate. Cast removal required radiographic evidence of clinical union (bridging callus on anteroposterior/lateral X-rays). KW removal was performed in the clinic under local anesthesia at 6 weeks, and CHP extraction required general anesthesia at 6-12 months due to complete osseous union shown in serial images.

Imaging outcomes and biomechanical stability

At 6 months after surgery, the CHP group had a 26% larger callus volume and a 33% narrower fracture gap ($P < 0.001$), reflecting the superior angular stability provided by the subacromial hook. With rigid fixation, fracture micromotion was minimized, promoting continuous callus formation [19]. Biomarker analysis showed that the CHP group had significantly higher levels of early-stage bone-specific alkaline phosphatase (BALP) and osteocalcin (OC) ($P < 0.001$), and thus exhibited increased osteoblastic activity and faster bone healing. Neer IV/V fractures showed a 0.5-month reduction in the healing period with the CHP group ($P = 0.007$), and thus could be applied to complex fractures requiring strong mechanical support to prevent malunion. A 12- to 14-week healing period for Neer IV/V fractures is relatively long; however, it aligns with the extended healing time required for high-energy fractures in children. Unlike adult delayed union, which is often due to vascular damage, pediatric Neer IV/V fractures typically heal through robust periosteal callus formation; thus, a longer healing period is expected and physeal-sparing fixation along with gradual remodeling is generally preferred.

Shoulder function recovery

The CHP group had a higher Constant-Murley score (89.5 ± 7.0 vs. 85.2 ± 6.5, $P = 0.001$) and greater forward flexion/abduction range of motion at 6 months, which was closely associated with stable internal fixation allowing early functional exercise. Early active movement reduced the risk of rotator cuff adhesion, and this was particularly important for school-aged children aged 7-14 who were more active. A relatively greater reduction in QuickDASH scores (20.2 ± 4.0 vs. 25.8 ± 4.5, $P < 0.001$) also showed that CHP had a better outcome for upper-limb disability, possibly due to improved fracture reduction and early mechanical stability. Despite a higher frequency of subacromial impingement in the CHP group (11.8% versus 4.4%), the functional advantage was maintained due to the following reasons: (1) Impingement symptoms were generally mild to moderate in 87.5% of cases and resolved spontaneously after implant removal (6-12 months); only 2 cases required anti-inflammatory drugs; (2) CHP's rigid stability allowed the start of organized rehabilitation 2 weeks after surgery, whereas K-wire fixation required delayed rehabilitation (4-6 weeks) to prevent re-dislocation, and this early mobilization reduced rotator cuff stiffness and enhanced function; (3) The K-wire group had a relatively higher rate of minor re-dislocation (4.4%) and consequently lower functional scores, although it had fewer impingement problems [13].

Complications and safety aspects

Early complication rates in both groups were similar at 8.8% ($P = 1.000$), with pin-tract infections (2 cases in the KW group) and soft-tissue irritation (3 cases in the CHP group) being the most common, indicating comparable acute-phase safety. The CHP group had a significantly higher proportion of late-stage acromial impingement syndrome (11.8 per cent vs. 4.4 per cent, $P = 0.049$), which was associated with chronic mechanical irritation from the hook plate. However, this did not result in severe

functional loss; instead, adaptive remodeling of the pediatric acromion (thickened periosteum and increased soft tissue elasticity) may have mitigated impingement-related dysfunction. Importantly, the functional advantages of CHP (earlier healing, improved range of motion) exceeded the effect of mild, transient impingement symptoms in school-aged children with high activity levels. No severe functional impairment occurred; therefore, it can be assumed that adaptive remodeling of the pediatric acromion mitigated impingement. Rare physeal complications (1.5%) were reported; both techniques were considered safe for skeletal development. A significant disadvantage of CHP fixation is the need for secondary surgery for implant removal, which was performed in all 68 CHP patients at 6-12 months postoperatively. The second procedure carries additional risks, including anesthesia-related complications, increased healthcare costs, psychological stress for the children and caregivers, and rare complications such as wound infection or scarring (3% of cases). Implant retention is not recommended for children because of the risk of growth inhibition, implant loosening or chronic impingement during skeletal maturation [19-21].

Subgroup analysis revelations

Age-stratified results showed that KW reduced surgical trauma in children under 6 years, whereas CHP provided better stability for those aged 7-14 years, consistent with developmental changes in shoulder muscle strength and activity levels [22]. In the fracture-type subgroup, Neer II fractures showed equivalent outcomes for both surgeon-based preferences, and the superiority of CHP in Neer IV/V fractures indicated that fracture complexity dictates the required degree of fixation. These stratified differences underscore the need for individualized treatment approaches [23-25].

Biomarkers and healing mechanisms

Elevated early-stage inflammatory markers (IL-6, TNF-α) in the CHP group reflected more greater initial surgical trauma, but these levels normalized within 3 months, indicating a self-limiting inflammatory response [26]. The levels of bone-resorption markers (CTX-I, TRAP-5b) in both groups were similar, indicating comparable prolonged effects of bone remodeling. Sustained elevation of BALP and OC in the CHP group provided molecular support for callus induction, and these findings may inform the development of new osteoconductive scaffolds [27-29].

Analysis of early functional outcomes (1 month postoperative)

Our data show that at the 1-month postoperative time point, there were no statistically significant differences between the K-wire and CHP groups in either the Constant-Murley Score (65.2 ± 5.3 vs. 66.5 ± 5.5, P = 0.220) or the QuickDASH Score (45.8 ± 6.2 vs. 44.2 ± 5.8, P = 0.120) (**Table 4**). This lack of early differences can be attributed to several factors. First, both groups of patients were immobilized with a long-arm plaster cast for 4-6 weeks postoperatively, which significantly limits shoulder movement and masks any potential early functional benefits of one fixation method over the other. The uniform immobilization protocol was a critical part of the postoperative management aimed at protecting the fracture and implant, but it effectively created a “floor effect” for functional scores during this period. Second, at this early stage, pain and the inflammatory response to surgery are the predominant factors affecting patient-reported outcomes, rather than the mechanical stability provided by the implant. Both surgical procedures cause significant soft tissue trauma, and the recovery process in the first month is dominated by wound healing and pain management, which are similar across both groups. Third, the Constant-Murley score at one month is heavily weighted towards pain and activities of daily living (ADL), which are severely restricted by the cast. The strength and range of motion components, which would differentiate the two fixation methods, are not yet assessable. Therefore, the comparable early outcomes are expected and do not diminish the significant differences observed at the 3- and 6-month time points, where the biomechanical advantages of CHP fixation became evident after cast removal and the initiation of active rehabilitation. This highlights the importance of a longer-term follow-up in evaluating the true efficacy of different fixation techniques.

Clinical decision-making: criteria for choosing between K-wire and CHP fixation

The findings of this study provide evidence-based criteria to guide the selection of surgical treatment for pediatric distal clavicle fractures. The choice between K-wire and CHP fixation should be a personalized decision based on a comprehensive evaluation of patient-specific and fracture-specific factors.

Patient age and physiological skeletal maturity: Age is a critical determinant. For younger children (≤ 6 years), the periosteum is thick and highly osteogenic, providing a robust biological environment for fracture healing. Their smaller body size and lower functional demands mean that the minimally invasive K-wire fixation, which offers sufficient stability for simple fractures, is often the preferred choice. It minimizes surgical trauma, reduces blood loss, and avoids the need for a second major surgery for implant removal. For older children (7-14 years), who are more active and have greater muscle mass, the shoulder joint experiences higher dynamic loads. The enhanced biomechanical stability provided by CHP fixation is necessary to ensure reliable healing and facilitate early return to function, making it a more suitable option for this age group, especially for complex fractures.

Fracture complexity and stability: Fracture type, according to the Neer classification, is another essential factor. For simple, minimally displaced Neer type II fractures, both techniques can achieve good outcomes. However, the K-wire's less invasive nature makes it a pragmatic and cost-effective choice. In contrast, for complex, comminuted Neer type IV/V fractures, which are often associated with ligamentous injury and significant instability, the superior angular stability of the CHP is indispensable. It provides a rigid construct that resists deforming forces, promotes callus formation, and significantly reduces the risk of redisplacement or malunion, as evidenced by the faster healing and better functional recovery in this subgroup.

Implant removal and long-term considerations: The necessity of a secondary surgery for implant removal is a major consideration. While CHP offers superior stability, it requires a second operation under general anesthesia for removal, which carries additional risks, costs, and psychological stress for the child. K-wire removal, conversely, can be performed in an outpatient clinic under local anesthesia, which is a significant advantage. For young children or those with simple fractures, avoiding a second major surgery strongly favors the K-wire approach. When CHP is chosen, the surgeon and family must be prepared for the subsequent removal procedure.

Surgeon expertise and resource availability: The successful application of either technique requires specific surgical skills. Ultrasound-guided percutaneous K-wire fixation demands proficiency in ultrasonography, while CHP fixation requires expertise in open reduction and plate osteosynthesis. The availability of appropriate implants and instruments also influences the decision. Therefore, the surgeon's familiarity and experience with a particular technique are practical considerations that affect the final treatment choice. Our study suggests that when both options are available, adherence to the above criteria can optimize outcomes.

Comparison with existing literature

The complication rate for CHP in the adult studies ranges from 15% to 20%; the lower rate of 11.8% observed in our pediatric cohort may be attributable to better soft-tissue elasticity and regenerative capacity in children [30]. This study is among the first to confirm the efficacy of ultrasound-guided reduction in children, which reduced fluoroscopy exposure and thus minimized the risk of injury to the open physis. Subgroup analyses provided some supporting data for the management of pediatric distal clavicle fractures.

Limitations and future perspectives

The single-center design and 2-year follow-up period may introduce selection bias and limit the observation of long-term effects. Multicenter and large-scale studies with extended follow-up period are warranted to further examine the impact on shoulder development. The small Neer IV/V subgroup (n = 49) also needs a larger group for more stable analysis. Future studies may incorporate ultrasound elastography to measure fracture micromotion and establish biomechanical standard of im-

plant selection. Another is that a larger radiation dose has been accumulated from multiple postoperative CT scans. Although a low-dose protocol was employed this time, in the future, a hybrid imaging model (X-rays for routine follow-up and CT only for ambiguous cases) could be adopted to reduce radiation exposure while maintaining diagnostic accuracy.

Conclusion

KW fixation is more suitable for young children and simple fractures due to its minimally invasive nature, while CHP offers superior stability for complex fractures and school-aged children. However, the requirement for secondary implant removal limits the universal applicability of CHP. Future research should focus on biodegradable hook plates and other growth-friendly fixation devices to eliminate the need for a second operation. Age and fracture severity will be used to determine the need for treatment, and ultrasound-guided intervention will be employed to improve the precision of this treatment. The treatment plans should be tailored to the specific healing, functional and developmental needs of each child to achieve optimal outcomes.

Disclosure of conflict of interest

None.

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