RESEARCH ARTICLE

Single Bone Intramedullary Fixation of the Radius in Pediatric Both Bone Forearm Fractures Using Straight Stainless Steel Kirschner Wire: A Cross-sectional Study on Radiological and Clinical Feature

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Received: 5 April 2023 *Accepted: 30 December 2023*

Abstract

Objectives: We aimed to report radiological and clinical features of single bone intramedullary fixation of the radius in pediatric both bone forearm fractures using straight stainless steel Kirschner (K) wire.

Methods: Fifty-eight children (42 boys and 16 girls) referred to our hospital with both bone diaphyseal forearm fractures were operated on by using the single bone rigid K-wire intramedullary fixation and mini-open technique. The mean follow-up time was 8.9 months (6-12).

Results: The mean age of the patients was 7.4 years (4-12). More than 2/3 of the fractures were in the right hand. Around 63% of the fractures were in the middle third, 28% in the distal third, and 9% in the proximal third. Moreover, 12% were open type I Gustilo-Anderson fractures. The mean time from injury to surgery was two days (1-4), and the mean length of hospital stay was 2.8 days (2-5). The mean duration of surgery was 24.7 minutes (18-38), and the mean follow-up time was 8.9 months (6-12). All fractures united within 4-16 weeks (mean: 7.62). The cast and implant were removed simultaneously as the radiographic fracture union. There was no serious complication. Superficial infection of the pin track and loosening of the pin occurred in three cases (5%), all controlled by antibiotics and timely removal of the pins. Mild restriction of elbow extension (less than 20 degrees) was observed in three cases, which returned to normal at the last follow-up. Limitation of dorsiflexion of the wrist by more than 20° occurred in two patients (35° and 45°), which reverted to 25° and 25°, respectively, at the last follow-up.

Conclusion: In both bone forearm fractures in children, open reduction and internal fixation of only the radius with a stainless steel straight Kirschner wire could be a promising method with good results. This retrograde technique of intramedullary fixation is a simple and cost-effective method with minimal complications and acceptable outcomes in children aged 4-12 years.

Level of evidence: IV

Keywords: Both bones, Forearm, Intramedullary fixation, Kirschner wire, Radius

Introduction

In children, diaphyseal fractures of the forearm are the third most common upper extremity fractures, accounting for nearly 13% of all pediatric fractures.[1, 2] Most pediatric radial and ulnar shaft fractures can be treated with non-surgical methods.[3] For minimally displaced and stable fractures, immobilization with a well-formed forearm cast (three-point cast) can be considered.[4] If posttraumatic tissue swelling is a concern, a noncircumferential splint immobilization (e.g., a sugar tong splint) may be used initially.[5] If closed reduction is not possible, surgeons usually fix the fracture fragments after closed or open reduction to prevent future functional limitations. Various approaches and instruments such as Kirschner (K) wires, plates and screws, rush pins, titanium elastic nails (TEN), and elastic stable intramedullary nails (ESIN) are commonly used to fix fractures. Compared with

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fixation with plates and screws, intramedullary fixation has several advantages, such as less dissection of deep soft tissues, resulting in a lower risk of synostosis, shorter operative time, easy removal of hardware, and a more acceptable cosmetic result.[6] Fixation of only the radius or ulna has been reported as a substitute for fixation of both bones. Fixation of a single bone is safer, less invasive, and technically challenging.[7] The radius is thought to have a more complex function. Therefore, when the radius is reduced and fixed, the alignment of the ulnar fracture improves. The ulnar fracture site becomes more anatomic after the reduction and fixation of the radius.[8] The stainless steel K-wire has been successfully used for intramedullary fixation of radius and ulnar fractures in children and provides biomechanically stable and elastic fixation of forearm fractures.[9,10] We aimed to report radiological and clinical features of single bone intramedullary fixation of the radius in pediatric both bone forearm fractures using straight stainless steel K-wire.

Materials and Methods

We report the results of retrograde nailing of the radius with K-wire in children with diaphyseal fractures of both forearm bones. Fifty-eight patients were included in our study. All patients underwent mini-open reduction and retrograde intramedullary fixation of the radius only with stainless steel K-wire. The mean follow-up time was 8.9 months (6-12 months).One surgeon (S.K.) performed surgeries from March 2012 to March 2020.

Inclusion criteria

Closed or open fractures of type I Gustilo and Anderson were included in our study. Displaced diaphyseal forearm fractures of both bones in children between 4 and 12 years of age; the acceptable anteroposterior angulations were 20 degrees for shaft fractures of the distal third of the radius and ulna, 15 degrees at the level of the middle shaft, and 10 degrees in the proximal third (provided the child had at least two years of growth remaining).[11] If the shortening was less than one cm, 100% translation was acceptable.[12]

Exclusion criteria

Patients with nondisplaced fractures, acceptable closed reduction, Monteggia and Galeazzi fractures-dislocations, and metaphyseal fractures were excluded from the study.

Approach

After ensuring that informed consent was obtained, all included patients with displaced diaphyseal forearm fractures of both bones underwent surgery [Figure 1]. Under general anesthesia, a mini-open anterior Henry approach (five cm) was used [Figure 2]. Protecting the sensory branch of the radial nerve, a sharp and straight stainless steel K-wire was inserted into the distal end of the radius through the dorsal side of the wrist while the wrist was flexed. The K-wire was then driven upward just distal to the proximal radial growth plate until proximal resistance was felt and fracture compression and anatomic reduction were observed [Figure 3]. The choice of the diameter of the K-wire was based on the width of the medullary canal of the radius, which was usually 2-3 mm. The K-wire filled 60% of the medullary canal. The length of the K-wire was chosen according to the distance between the styloid process of the radius and the radial head above the skin. Finally, the distal sharp end of the K-wire was bent at the level of the wrist and cut outside the skin [Figure 4]. The forearm was fixed in supination with a splint above the elbow to avoid contracture of the interosseous membrane or ligaments. After surgery, an antibiotic was prescribed intravenously for 24 hours. Patients were discharged on the first day after surgery unless restricted due to another injury. The sutures were removed after 10-14 days, and a cast was applied above the elbow to protect the reduction for 4-8 weeks. After radiological union was achieved (3 of 4 cortices on AP and lat radiographs) [Figure 5], the cast and K-wire were removed [Figure 6].

Figure 1. Left both bones forearm fractures in an 8-year-old boy

Figure 2. Five cm incision in the path of Henry's approach

Figure 3. Only radius fixation of both bones forearm fracture with steel Kirschner wire

Figure 4. Kirschner wire was bent at the wrist level and cut outside the skin

Figure 5. Union

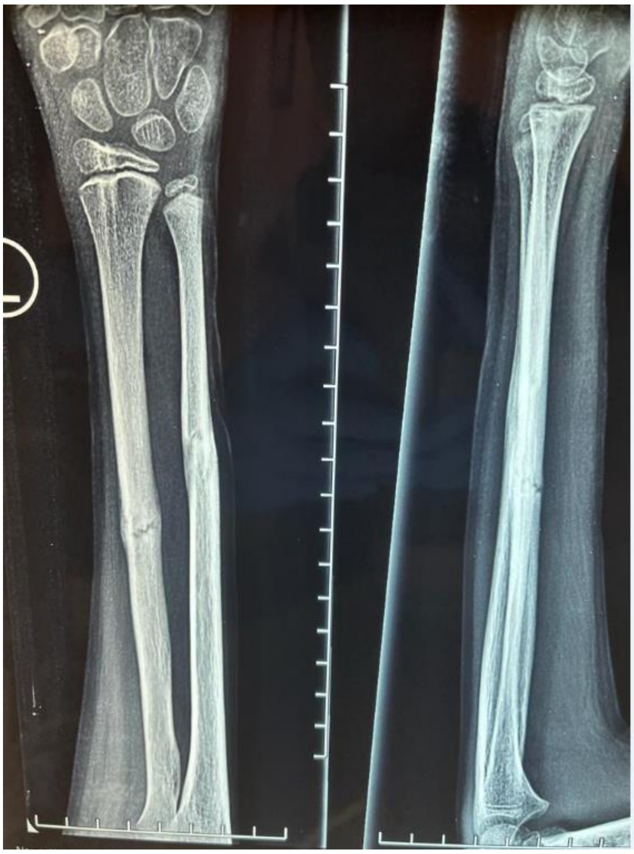

Figure 6. After K-wire removal

Angulation and range of motion were measured with a goniometer and compared with the uninjured arm. We accepted no more than 10 degrees of angulation in any direction.[13] Patients were evaluated at 2, 4, 6, 8, and 12 weeks after surgery and then at 4, 6, 9, and 12 months postoperatively.

Patients were evaluated for possible complications, including compartment syndrome, hematoma formation, pin loosening, neurovascular and tendon damage, delayed union, nonunion, ulnar malunion, limitation of wrist and forearm motion, premature closure of growth plates, heterotopic ossification, and synostosis. The study was carried out in agreement with the Helsinki Declaration of Research.

Results

A total of 42 (72.4%) boys and 16 (27.6%) girls underwent surgery with a mean age of 7.4 years (range: 4-12) [Tables 1 and 2]. The mean time from injury to surgery was two days (range: 1-4), and the mean time of hospitalization was 2.7 days (range: 2-5). The mean duration of surgery was 24.7 minutes (18-38), and the mean follow-up time was 8.9 months (range: 6-12).

All fractures united within 4-16 weeks (mean: 7.62). Mild restriction of elbow extension (less than 20°) was observed in three cases, which returned to normal at the last follow-up. Limitation of dorsiflexion of the wrist by more than 20° occurred in two patients (35° and 45°), which reverted to 25° and 25°, respectively, at the last follow-up [Table 1].

Table 1. Patients information

Number	Age (years)	Sex	Side	Closed or Open	Location	Injury to Surgery	Duration of the	Hospitalization (days)	Cast off (weeks)	Union Time (weeks)	Implant Removal (week)	Follow Up (month)	Final Ulnar Angulation(degree) AP-Lat		Elbow Limition>20	Forearm Limition>20	Wrist Limition>20	Other Complications
1	4	M[1]	R[2]	C[3]	M[4]	2	20	2	6	6	6	6	4	4	-	-	-	-
2	7	F[5]	R	O[6]	D[7]	1	22	3	8	8	8	6	5	10	-	-	-	-
3	12	F	R	C	M	2	25	2	10	12	12	12	7	12	-	supination	dorsiflexion	Pin Track Infection
4	11	M	L[8]	C	D	2	20	4	10	12	12	12	3	9	-	-	-	-
5	4	M	L	C	M	4	21	2	4	4	4	6	0	0	-	-	-	-
6	5	M	R	C	M	3	20	2	6	6	6	6	0	2	-	-	-	-
7	6	M	R	C	M	2	27	3	8	8	8	6	3	0	-	-	-	-
8	10	F	R	C	M	3	30	5	10	10	10	12	6	10	-	-	-	-
9	5	M	R	C	D	2	25	4	6	6	6	6	0	5	-	-	-	-
10	6	F	L	C	D	4	26	3	6	6	6	6	2	2	-	-	-	-
11	7	M	R	C	M	2	27	4	8	8	8	6	0	2	-	-	-	-
12	8	M	R	C	P[9]	1	23	3	10	10	10	9	3	6	-	-	-	-
13	11	M	L	C	M	2	25	5	10	10	10	12	4	13	-	-	dorsiflexion	Pin Track Infection
14	12	M	R	O	M	1	38	5	10	16	16	12	2	4	-	-	-	Pin Track Infection

[1] Male
[2] Right
[3] Closed fracture
[4] Middle part
[5] Female
[6] Open fracture
[7] Distal part
[8] Left
[9] Proximal part

Table 1. Continued

15	8	M	L	C	P	2	29	4	6	6	6	6	0	0	-	-	-	-
16	7	M	R	O	D	1	19	3	6	6	6	6	2	8	-	-	-	-
17	6	F	R	C	M	2	22	2	8	8	8	6	0	0	-	-	-	-
18	9	M	R	O	M	1	24	3	10	10	10	9	3	6	-	-	-	-
19	5	F	R	C	M	1	23	2	6	6	6	6	0	5	-	-	-	-
20	10	M	R	C	M	2	22	4	8	8	8	9	5	8	-	-	-	-
21	6	M	R	C	D	3	24	3	8	8	8	12	5	0	-	-	-	-
22	7	M	L	C	M	2	25	3	6	6	6	6	0	5	-	-	-	-
23	9	M	R	C	D	2	26	3	10	10	10	12	0	0	-	-	-	-
24	4	M	L	C	M	2	20	2	6	6	6	6	0	0	-	-	-	-
25	5	M	L	C	M	2	18	2	6	6	6	6	2	6	-	-	-	-
26	5	M	R	C	M	2	28	2	6	6	6	6	0	5	-	-	-	-
27	9	M	R	C	M	2	22	2	8	8	8	9	0	10	-	supination	-	-
28	5	M	L	C	P	3	19	3	6	8	8	9	0	0	-	-	-	-
29	4	F	L	C	D	2	25	2	4	4	4	6	2	8	-	-	-	-
30	7	F	R	C	M	2	23	3	8	8	8	6	4	10	-	-	-	-
31	9	M	R	O	M	1	21	3	10	10	10	12	2	3	-	-	-	-
32	8	M	L	C	M	2	27	2	10	10	10	12	3	7	-	-	-	-
33	8	F	R	C	D	3	24	2	8	8	8	9	0	5	-	-	-	-
34	4	M	R	C	M	1	22	3	4	6	6	12	0	0	-	-	-	-
35	12	M	L	C	D	1	25	4	12	12	12	12	0	10	-	-	-	-
36	7	M	R	C	M	2	31	3	8	8	8	9	2	8	-	-	-	-
37	9	F	R	C	M	2	27	3	8	8	8	9	2	6	-	-	-	-
38	4	F	R	C	P	2	27	2	6	6	6	12	2	7	-	-	-	-
39	7	M	R	C	D	1	28	2	6	6	6	6	3	9	-	-	-	-
40	12	M	L	O	M	1	29	3	12	12	12	9	0	6	-	-	-	-
41	8	M	R	C	M	3	22	2	10	10	10	9	0	10	-	-	-	-
42	9	M	L	C	M	2	26	3	6	8	8	12	2	9	-	-	-	-
43	6	F	R	C	D	2	20	2	6	6	6	12	0	5	-	-	-	-
44	5	M	R	C	M	4	19	2	6	6	6	9	0	7	-	-	-	-
45	11	M	L	C	M	2	26	2	12	12	12	6	3	8	-	-	-	-
46	6	M	R	C	D	2	25	2	8	8	8	9	0	0	-	-	-	-

Table 1. Continued

47	10	M	L	C	D	3	32	3	8	8	8	12	4	11	-	-	-	-
48	8	F	L	C	M	1	24	2	8	8	8	6	0	6	-	-	-	-
49	7	F	R	C	M	1	27	2	8	8	8	12	0	0	-	-	-	-
50	6	M	R	C	M	1	28	3	6	6	6	12	0	0	-	-	-	-
51	11	M	L	C	M	1	22	3	10	10	10	12	4	9	-	-	-	-
52	5	M	R	C	M	2	21	4	6	6	6	6	2	0	-	-	-	-
53	9	M	L	C	D	2	25	2	8	8	8	9	0	0	-	-	-	-
54	5	F	R	C	M	3	24	2	4	6	6	12	5	5	-	-	-	-
55	7	M	R	O	M	1	27	2	8	8	8	12	0	7	-	-	-	-
56	7	M	R	C	P	2	29	3	6	8	8	9	5	5	-	-	-	-
57	10	M	R	C	D	3	24	2	8	8	8	12	0	0	-	-	-	-
58	8	F	R	C	M	2	25	2	6	8	8	6	0	2	-	-	-	-

Table 2. Qualitative variables of patients

Qualitative variables		Male		Female		Total	
		Frequency	%	Frequency	%	Frequency	%
Side	Left	16	38.1	3	18.8	19	32.8
	Right	26	61.9	13	81.2	39	67.2
Closed or Open Fracture	Closed	36	85.7	15	93.8	51	87.9
	Open	7	14.3	1	6.3	7	12.1
Location in Forearm (third)	Distal	11	26.2	5	31.3	16	27.6
	Middle	27	64.3	10	62.5	37	63.8
	Proximal	4	9.5	1	6.3	5	8.6
Age	<5	11	26.2	4	25	15	25.9
	6-10	24	57.1	11	68.8	35	60.3
	11<	7	16.7	1	6.3	8	13.8

The final ulnar angulation in the forearm (anteroposterior view) was 1.74 ± 1.96 (min-max range:0.75-3.9) degrees; this value for the lateral view was 5 ± 3.85 (min-max range:1.1-9.2) degrees [Table 3].Cast and implant removal were performed simultaneously as radiographic fracture unions [Table 3]. No serious complications such as nonunion, deep infection, premature physeal closure, compartment syndrome, heterotopic ossification, synostosis, and neurovascular and tendon damage occurred. Superficial pin track infection and pin loosening occurred in 3 (5%) cases. Antibiotics and timely removal of the pin controlled all.

Discussion

Diaphyseal forearm fractures are common injuries in the pediatric population, and most of them can be treated by closed reduction and plaster casting. The use of intramedullary devices to stabilize forearm fractures is not new. Rush nails, ESIN, and TEN provide three-point fixation micromotion allowed by the elasticity of the fixation promotes external bridging callus.[15]

Typically, surgeons stabilize both radius and ulna in pediatric forearm fractures. However, Flynn and Waters described intramedullary pin fixation of the radius or ulna or to the inner surfaces of the cortices.[14] In these nails, the both bones in fractures with closed reduction. They believed that stabilizing only one bone would bring the other bone to reduction. Their results were uniformly good without using a plate for both bones in adults.[16]

Table 3. Quantitative variables of patients

Quantitative variables	Male		Female		Total	
	Mean	SD	Mean	SD	Mean	SD
Time, from Injury to Surgery (day)	1.95	0.79	2.06	0.85	1.98	0.80
Duration of Surgery (min)	24.54	4.12	24.62	2.44	24.56	3.71
Hospitalization (day)	2.88	0.86	2.43	0.81	2.75	0.86
Casting duration (week)	7.80	2.10	7.12	1.78	7.62	2.03
Union Time (Week)	8.19	2.37	7.5	1.86	8	2.24
Time of Implant Removal (Week)	8.19	2.37	7.5	1.86	8	2.24
Follow Up (Month)	9	2.56	8.62	2.87	8.89	2.63
Final Ulnar Angulation in forearm (AP View) (Degree)	1.57	1.75	2.18	2.45	1.74	1.96
Final Ulnar Angulation in Forearm (Lat View) (Degree)	4.8	3.94	5.81	3.61	5	3.85
Age	7.6	2.44	7	2.16	7.4	2.37

According to the study by Lee et al., 22 of 24 patients with both bone forearm fractures were treated with ulnar fixation only. Recurrence of angulation of the radius occurred in seven patients; two out of the seven patients required additional surgical stabilization of the radius.[17] Myers and Houshian[18] used Nancy Nails and ESIN as single-bone fixators in 25 and 20 children with both bone forearm fractures, respectively, and reported excellent results. Alnaib et al. treated fractures of both forearm bones in 29 children with radius-only intramedullary nailing and achieved excellent functional outcomes and union rates.[19]

Sheng Hu Du et al. compared the results of single and double ESIN for treating both bone forearm fractures in children. They found that fixation of the radius was as adequate as fixation of both bones for forearm fractures.[20] Crighton et al., who reported in their study a tendency to greater angulation of fractures fixed by Single elastic intramedullary nailing, believed that caution should be considered in the use of single bone fixation for both bone forearm fractures.[21]

Kim et al., in their review, reported that the supination, pronation, and radiographic angulation outcomes were similar in single and both-bone fixation. The pronation and supination limitation and re-angulation rate were comparable for radius-only compared to ulna-only fixation.[22] In addition, Yong et al., in their meta-analysis, reported that single bone fixation in pediatric both bone forearm fracture resulted in acceptable outcomes with no adverse effects on the function of the forearm.[23]

A biomechanical study showed that using intramedullary fixation to stabilize the radial fracture results in a significantly more stable construct than fixation of a fractured ulna.[7] When the radius is reduced and fixed, the alignment of the ulnar fracture is improved.[8] In the early 1980s, Metaizeau et al. [24] described ESIN of pediatric forearm fractures with small-diameter (1.5-2.5 mm) contoured implants.[25] As with other intramedullary nailing techniques, no attempt was made to fill the medullary canal. Too large a nail may result in nail entrapment and distraction at the fracture site, especially in the ulna.[10] Large nails may also increase the stiffness of fixation, which may decrease callus formation, resulting in delayed union and nonunion.[12] Ballal MS et al. used ESIN for displaced forearm fractures in 93 children for ten years; three cases resulted in nonunions of the ulna, possibly due to the disturbed periosteal blood supply with open reduction, use of a very thick nail and overbending of the nail leading to the distraction of the fracture site. [26] Keily[27] and Slongo & Zachariou concluded that pre-bending may not be necessary for a stable fracture configuration.[28] We used a smaller diameter K-wire not to fill the medullary canal with a retrograde method to compress the fracture site. This is a theory, but it may be essential to introduce a curved nail in a straight bone and a straight nail in a curved bone. Maybe introducing straight K-wire in a curved radius also has a three-point fixation property.

The extensor policis longus (EPL) appears to be at particular risk of injury if the dorsal entry point is utilized near the second or third dorsal compartment during either nail insertion or extraction. [12, 29, 30] To avoid erosion of the EPL tendon, the nail must be long enough to extend beyond the tendon either into the subcutaneous tissue or through the external skin nails.[6, 31, 32] If the nail end remains outside the skin, extraction is easier and less likely to result in EPL tendon injury. As with all surgical techniques, careful patient selection is critical for better results.

Limitation

The limitations of this study are that it is retrospective, includes only a small number of patients, and has no control group.

Conclusion

We recommend using a 2-2.5 mm straight steel pin in the curved radius to act as a three-point fixation. We recommend a mini Henry approach for reduction only and passing the pin, which will be safe and less invasive. The brachialis muscle and the radial sensory nerve are retracted to the radial side to approach the bone. The forearm will be immobilized in supination to maintain the longest distance between the two bones and keep the interosseous ligament at its highest tension to avoid motion restriction. The wrist will be in 20-30 degrees of dorsiflexion and the elbow in 90 degrees of flexion, which is considered the functional position and may mitigate the need for future physiotherapy. In summary, this technique, used for failed closed reduction of both bone forearm fractures in children aged 4-12 years, involves open mini-reduction and retrograde fixation of the radius-only with a stainless steel straight Kirshner wire without an image intensifier. This method is inexpensive, easy to perform, and has acceptable outcomes.

Acknowledgement

We would like to thank Dr. Seyyed-Mohsen Hosseininejad, Assistant Professor of Orthopedic Surgery, Golestan University of Medical Sciences, Gorgan, Iran, for his contributions to analyzing the data and editing the manuscript.

Conflict of interest: None

Funding: None

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