Longer time of implantation using the buried pin technique for intramedullary nailing would decrease refracture in the diaphyseal forearm fracture in children -retrospective multicenter (TRON) study

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Key words: pediatric, diaphyseal forearm fractures, refracture, intramedullary nailing, Kirshner wire

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Highlights

- Longer time of implantation using the buried pin technique for intramedullary nailing reduces refracture of pediatric diaphyseal forearm fractures.

- The duration before implant removal in the buried pin group was more than 4 times longer than that in the exposed pin group.

- Implantation of intramedullary nailing for 6–9 months may decrease refractures.

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Abstract

Background: Intramedullary nailing using Kirschner wires in pediatric diaphyseal forearm fractures is often performed as a less invasive treatment than plate fixation, but it remains controversial whether the tips of Kirschner wires are buried or exposed. The purpose of this study was to investigate the relationship between whether the tips are buried or exposed and complications, especially of refracture.

Methods: Data of 405 patients under 16 years who underwent surgical treatment for diaphyseal forearm fractures in our 11 hospitals between 2010 and 2020 were collected. Finally, 143 patients who underwent intramedullary nailing with at least 6-month follow-up were analyzed. We investigated difference in complication rates depending on whether the Kirschner wire tips were buried (Group B: n=79) or exposed (Group E: n=64). Regarding refractures, we also examined time of onset and status of bone union before the refracture occurred.

Results: The duration before implant removal in Group B was more than 4 times longer than that in Group E (mean 187.9 vs. 41.4 days, $p<0.001$), although there was no significant difference in the progression of bone union between the two groups. Regarding postoperative complications, Group B had a significantly lower rate of refractures than Group E (7.9% vs. 32.8%, p<0.001), although the rate of irritation pain was significantly higher (15.2% vs. 1.6%, p=0.006). The infection rate was also lower in Group B than Group E, but not significantly so (3.8% vs. 10.9%, p=0.112). Refractures between 3 and 9 months after surgery accounted for 66.7% of all refractures, and those within 3 months accounted for 14.5% of all fractures. There was no significant difference in the status of bone union before the refracture occurred between patients with and without refracture.

Conclusions: The present study showed that longer time of implantation using the buried pin technique for intramedullary nailing reduces refracture of pediatric diaphyseal forearm fractures. Because of the risk of refracture during remodeling, we recommend the implantation of intramedullary nailing for 6–9 months and the instruction for the patients and the parents to pay more attention to refracture at least within 9 months postoperatively.

Level of Evidence: Level Ⅲ, Multicenter retrospective study.

Key Words: pediatric, diaphyseal forearm fractures, refracture, intramedullary nailing, Kirschner wire

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INTRODUCTION

Pediatric diaphyseal forearm fractures (PDFF) are common injuries, accounting for 5.4–14.9% of all pediatric fractures.[1,2] Operative treatment might be needed for unstable, irreducible, or open diaphyseal forearm fractures.[3] In operative management of PDFF, intramedullary nailing of pediatric forearm fractures has been rapidly adopted as a "minimally invasive" treatment compared with plate fixation.[4]

After inserting the Kirschner wire (K-wire), surgeons have to determine whether the tips of the K-wire are buried or exposed. Each option for the tip has advantages and disadvantages. The buried technique allows for long-term implantation (>8 weeks), which may be related to decreased refracture and a reduced rate of infection.[5-7] However, implant removal of the buried K-wire fixation frequently needs to be performed in the operating room, and the buried technique may risk complications at the application site such as tendon (especially extensor pollicis longus) irritation, irritation pain, and damage to the superficial sensory branch of the radial nerve.[8,9] Although some authors reported that the exposed K-wire is a safe treatment method and easy to remove without complications,[9,10] others reported that exposed K-wire fixation in pinning increases risks of infection and early removal.[11,12] Thus, it remains controversial whether the tips of K-wires should be buried or exposed for the treatment of PDFF.

We hypothesized that the buried K-wire technique would decrease the refracture rate in patients with PDFF treated with K-wires. The purpose of this study was to investigate the relationship between whether tips of K-wires are buried or exposed and complications, especially of refracture in patients with intramedullary nailing for PDFF.

METHODS

Study Design and Setting

The ethics committee approved this multicenter retrospective (Trauma Research of Nagoya: TRON) study of each participating hospital. We collected orthopedic trauma surgery data from medical records at 11 hospitals since 2010. Hospitals participating in the database are all associated with the Department of Orthopedic Surgery of our university. Orthopedic surgeons perform the surgery at these hospitals in Central Japan.

Subjects

According to the AO classification, diaphyseal forearm fracture in children was defined as fracture between both metaphysis. The metaphysis was identified by a square whose sides have the same length as the widest part of the growth plate. Both bones (radius/ulna) must be included in the square.[13]

We collected data on 405 patients who underwent surgical treatment for diaphyseal forearm fractures between January 2010 and December 2020. We included the cases of both diaphyseal forearm fractures, isolated diaphyseal forearm fracture. We excluded the following patients: 147 treated with surgical techniques other than intramedullary nails, 92 with <180 days of follow-up, 19 with open fractures, and 4 with a tip buried on one side and exposed on the other side. Finally, 143 patients were included in the final analysis (Figure 1). We divided the subjects into two groups: those with a buried implant (Group B: n=79) and those with an exposed implant (Group E: n=64).

Clinical Evaluation

The data collected were patient age, sex, height, weight, body mass index (BMI) percentile, injured side, injury mechanism (sports injury; high energy: traffic accidents, falls from a height higher than standing position; low energy: falls from a standing position), time from injury to surgery, fracture status, and preoperative complications such as compartment syndrome and nerve symptoms. Intact bone or bone treated with conservative treatment was excluded from analysis. We obtained operative time and insertion positions of K-wires as surgical information. During the follow-up period, we checked timing from operation to splint off, timing of the removal of activity restrictions and implant removal, and anesthesia for implant removal.

Radiographic Evaluations

To assess fracture status, we classified fracture type according to the AO system and fracture level on each patient's anteroposterior and lateral radiographs.[13] The degree of the preoperative angulation was measured by drawing a perpendicular line following two midpoints of the radius and ulna bone for each segment of the fracture. The same procedure was performed for both anteroposterior and lateral radiographs of the radius and ulna, and the higher measurement for each bone was considered the final degree of angulation. Further, a correction factor of 6 degrees of radial apex was applied to the anteroposterior measurement of the central third of the radius, following the correction method for anatomical bowing of the radius by Hadizie et al., whereby in the middle third of the radius in the AP radiograph, degrees would be added to the measurement if the apex of the fracture of the radius was towards the ulna and degrees would be deducted if the apex of the fracture was towards the opposite direction.[14]

Preoperative displacement between both fragments was classified into three grades comprising no displacement: there is minimal displacement or only angulation; partial contact: displacement is >1 mm but there is contact between fragments; and no contact: there is no contact between fragments. This initial fracture displacement shows the ease of closed reduction.

The status of bone union was evaluated by the modified radiographic union scale in tibial (mRUST) fractures score.[15] A mRUST is used to evaluate radiographic bone union after tibial fractures and recently, to evaluate bone union in other fractures including forearm fractures.[16,17] A cortex with a visible fracture line and no callus is scored as 1, that with a callus and visible fracture line as 2, and that with a callus and without a fracture line within the callus bridge as 3. Cases with a remodeled callus but without a visible fracture line were scored as 4. Total scores range from a minimum of 4 (not healed) to a maximum of 16 (completely healed).[17] A mRUST score ≥12 was considered to be a predictor of union.

Surgical Procedure and Postoperative Management

We performed the reduction and fixation of forearm fractures with the patients under general anesthesia or regional anesthesia. Closed reduction was attempted in all cases, and K-wires were inserted percutaneously or through small incisions. When both fragments could not be reduced, limited open reduction or intra-focal Kapandji[18] technique was performed. A lateral or dorsal entry point for the radius and proximal lateral entry point or entry point through the olecranon for the ulna was selected. Whether the tip of the implant was buried beneath the skin or exposed outside the skin was based on the treating surgeon’s preference.

All patients were immobilized postoperatively. The duration of immobilization was determined by the surgeon while checking the status of the bone callus formation. Most patients were immobilized above the elbow.

Complications and Detailed Analyses for Refracture

Refracture, infection, nerve injury, tendon rupture, nonunion, and penetration of implants through skin were investigated as complications. Regarding refracture, details of when they occurred postoperatively were also evaluated. The bone healing status of patients with and without refracture was compared using the mRUST score at 3 and 6 months.

Statistical Analysis

Categorical variables were analyzed by Fisher's exact test. Continuous variables with normal distribution were analyzed by *t*-test, and those with non-normal distribution were analyzed by the Mann-Whitney U Test. A p-value <0.05 was considered to indicate statistical significance. We used the cumulative incidence to create refracture curves and the log-rank test to compare refracture between the two groups. For refractures, mRUST scores at 3 month and 6 months were compared to cases with no fracture by Mann-Whitney U test. Cases with refracture prior to the period of evaluation were excluded from comparison. Statistical analysis was conducted with EZR software version 1.40 (Jichi Medical University, Tochigi Prefecture, Japan).[19]

RESULTS

Table 1 shows the patient demographics and preoperative information on the fractures. No significant differences were found except for the injured hand between both groups.

Table 2 shows the surgical procedure, postoperative management including implant removal, and the status of bone union. For the K-wire of the radius, Group B underwent dorsal entry significantly more frequently than did Group E (48.6% vs. 10.0%, p<0.001). Regarding postoperative management, Group B had a significantly longer duration until the removal of daily activity restrictions than did group E (3.83 vs. 3.05 months, p=0.014) but a shorter duration of immobilization (34.07 vs. 39.88 days, p=0.013). Moreover, the duration until implant removal in Group B was more than 4 times longer than that in Group E (187.90 vs. 41.39 days, p<0.001), although there was no significant difference in the status of bone union between the two groups. Group B more frequently needed general or regional anesthesia for implant removal than did Group E.

Table 3 shows the postoperative complications. Group B had a significantly lower rate of refractures than did Group E (7.9% vs. 32.8%, p<0.001), although the rate of irritation pain was significantly higher (15.2% vs. 1.6%, p=0.006). The rate of infection in Group B was also lower than that in Group E but not significantly so (3.8% vs. 10.9%, p=0.112).

Figure 2 and Table 4 show a detailed analysis of refracture. Figure 2 shows the cumulative incidence of refractures and when refractures occurred postoperatively in both groups. Along with showing that refractures were more common in group E, refractures occurring between 3 and 9 months after surgery accounted for 66.7% of all fractures and those within 3 months accounted for 14.5% of all fractures. There was no significant difference in the status of bone union before refracture occurred between the patients with and without refracture (Table 4).

DISCUSSION

The present study compared the difference in complication rates for intramedullary nailing in PDFF between buried and exposed K-wires. The buried K-wire technique resulted in an average time to implant removal of 6 months (about 4 times longer than that for the exposed K-wire technique) and showed a lower refracture rate. The infection rate was also lower with the buried technique than with the exposed technique, but not significantly so. Over 60% of refractures occurred in a period between 3–9 months but not necessarily in cases with poor bone healing.

The rate of infection as a complication in the present study was 3.8% in Group B and 10.8% in Group E, indicating that tip exposure increased the infection rate although not with statistical significance (P=0.112). Several reports have indicated a higher risk of infection with external exposure of K-wires.[8,11,12] Hargreaves et al. reported that pin-site infection occurs when a biofilm forms on the surface of bacteria attached to exposed K-wires.[6] They suggested that K-wires should not be exposed outside the body for more than 8 weeks. Most of the cases in Group E underwent implant removal within 8 weeks, and the infection in most cases was superficial, likely a result of careful attention to infection.

The rate of refracture was lower in group B than in Group E (7.9% vs 32.8%, $p<0.01$). Group B had longer implant placement compared to Group E (187 vs. 41.39 days, $p<0.001$). This result may be due to differences in the risk of infection that should be taken into consideration, as discussed above. In their review article, Lascombes et al. suggested not removing intramedullary nails using a K-wire for 6 months after surgery to reduce the risk of refracture, based on their experience.[5] They reported no cases of refracture in cases with removal later than 6 months, and they speculated that the reason may be based on the quality of cortical bone healing and the reestablishment of the medullary canal.[5] Many papers also reported that refractures occurred 2–9 months after the initial fracture.[9,20-22] The present study also showed that 81.5% of all refractures occurred within 9 months after the primary surgery. As shown in Table 4, the mRUST score before refracture in the refracture cases was 12 or higher, with the same bone healing status as in the non-refracture cases. The remodeling phase can often continue for months, or even years in some osseous structures. During this period, the provisional callous has been gradually removed, and new bone has been laid down along the lines of stress. This process results in a “quality bone” that is stiff, rigid, and capable of supporting the child’s normal physical activities.[23] Even if the fracture appears to have fused on X-ray, there is a risk of refracture when high loads are applied during the remodeling process.

Long-term implant placement reduces the risk of refracture because the implant itself serves as a protector. In addition, it may also serve as a tool to make patients aware that they are still undergoing treatment even though they have no pain and have no problems with movement because attention needs to be paid to high activity until quality bone is formed to reduce the risk of refracture. In the present study, the average duration of splinting was 4–6 weeks, and activity restrictions were removed at 3–4 months. Given the high number of refractures in this retrospective study, more attention to high activity and to falls may have been needed although it is difficult to warn younger children against falling down. On the basis of this investigation of the timing of refracture, we would recommend a minimum of 6 months for implant placement, and ideally a minimum of 9 months. We recommend that surgeons instruct the patients and the parents to refrain from high-energy sports activities at least within 9 months postoperatively to avoid the refracture because it is considered that the united bone during remodeling will not be able to withstand strong trauma in that period. There is no clear definition regarding high energy sports, so the relationship between energy and refracture is a future issue.

In group B, several cases of irritation pain (15.2%) and penetration of the implant through skin (5.1%) occurred. These complications can lead to early implant removal, so careful attention should be paid to the tips when the implants are buried. Only one case of irritation pain occurred in

Group E. We recommend bending the tip of the K-wire and inserting it deeper into the bone. Fortunately, although no tendon-related complications occurred in this case, careful observation is needed both during and after implantation because complications such as tendon rupture around the wrist have been reported with long-term implantation.[24]

As in previous meta-analyses [8], group B patients were more likely to choose general or regional anesthesia than group E patients for the implant removal procedure (78.5% vs. 17.5%, $p<0.001$). The previous report shows implant removal for buried K-wires often requires an operating room and resulted in an extra cost[25]. However, considering the increased risk of refracture and infection, the technique of exposing the K-wire is not necessarily more advantageous in terms of cost or convenience. In terms of both patient benefit and health care cost savings, we should instruct the patients and parents to pay more attention to refracture at least within 9 months postoperatively.

The present results indicate that when using K-wire intramedullary nails, the tips of K-wire should be buried to reduce the risk of complications such as refracture. However, the treatment of adolescent forearm fractures including distal radius remains challenging and the choice of surgical technique and fixation method are still influenced by individual experience and preference [26]. A prospective randomized study is desirable to obtain definitive answers for these questions.

Limitations

The present study has some limitations. The main limitation is the high number of confounding variables due to the retrospective nature of the present study, such as different surgeons, different lengths of immobilization, differences in sports activity for each patient, and others. Data collection is limited to that routinely recorded in patient medical records. It is unclear whether the grading of initial fracture displacement we used is valid to indicate the ease of closed reduction. The sample size is relatively small, and the data of some patients were censored when they could not be followed for a long enough period. The surgical procedure and the timing of implant removal were left up to the surgeons, and there were no specific criteria for these factors.

Conclusion

The present retrospective study showed that long implantation using the buried pin technique for intramedullary nailing reduces refracture of pediatric epiphyseal forearm fractures. Because of the risk of refracture during remodeling, we recommend the implantation of intramedullary nailing for 6–9 months and the instruction for the patients and the parents to pay more attention to refracture at least within 9 months postoperatively.

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Figure legends

Figure 1. Patient selection flow diagram.

Figure 2. The cumulative incidence of refractures and when refractures occurred postoperatively in both groups.

TABLE 1. Demographic Data and Preoperative Information

	Group B (n=79)	Group E (n=64)	p Value
Age, yrs, mean (SD)	9.43 (2.85)	8.78 (3.42)	0.217
Sex, Male/Female, n (%)	60 (75.9)/19 (24.1)	44 (60.8)/19 (30.2)	0.449
Height, cm, mean (SD)	133.38 (18.20)	132.36 (22.95)	0.778
Weight, kg, mean (SD)	31.76 (14.41)	31.43 (13.59)	0.893
BMI percentile (SD)	42.14 (29.03)	47.22 (28.51)	0.325
Injured hand, Right/Left, n (%)	42 (53.2)/37 (46.8)	20 (31.2)/44 (68.8)	0.011*
Injury mechanism, n (%)			
Sports injury	21 (26.6)	21 (32.8)	0.423
Low energy (falling down)	25 (31.6)	23 (35.9)	
High energy (fall from high place/bicycle, etc.)	33 (41.8)	20 (31.2)	
Time from injury to surgery, days, mean (SD)	2.18 (6.35)	3.31 (8.53)	0.363
Fracture bone, n (%)			
Isolated fracture of the radius	9 (11.4)	4 (6.2)	0.297
Isolated fracture of the ulna	5 (6.3)	8 (12.5)	
Both bone fractures operated both bones	58 (73.4)	42 (65.6)	
Both bone fractures operated isolated radius	5 (6.3)	5 (7.8)	
Both bone fractures operated isolated ulna	2 (2.5)	5 (7.8)	
AO classification (R), n (%)			
22r-D/2.1(green stick)	5 (6.9)	10 (19.6)	0.102
22r-D/4.1(complete transverse, simple)	50 (69.4)	27 (52.9)	
22r-D/4.2(complete transverse, multi-fragment)	1 (1.4)	1 (2.0)	
22r-D/5.1(complete oblique, simple)	16 (22.2)	13 (25.5)	
AO classification (U), n (%)			
22u-D/1.1(bowing)	2 (2.8)	3 (5.0)	0.62
22u-D/2.1(green stick)	11 (15.5)	10 (16.7)	
22u-D/4.1(complete transverse, simple)	33 (46.5)	21 (35.0)	
22u-D/4.2(complete transverse, multi-fragment)	0 (0.0)	1 (1.7)	
22u-D/5.1(complete oblique, simple)	21 (29.6)	18 (30.0)	
22u-D/5.2(complete oblique, multi-fragment)	4 (5.6)	6 (10.0)	
22u-D/6.1(Monteggia, simple)	0 (0.0)	1 (1.7)	
22u-D/6.2(Monteggia, multi-fragment)	2 (2.8)	3 (5.0)	
Fracture level (R), n (%)			
Distal 1/3	14 (19.4)	13 (25.5)	0.366
Middle 1/3	36 (50.0)	28 (54.9)	
Proximal 1/3	22 (30.6)	10 (19.6)	
Fracture level (U), n (%)			

Distal 1/3	7 (10.8)	7 (12.7)	0.342
Middle 1/3	40 (61.5)	39 (70.9)	
Proximal 1/3	18 (27.7)	9 (16.4)	
Preoperative complications			
Compartment syndrome, n (%)	0 (0)	0 (0)	—
Nerve symptoms, n (%)	5 (6.3)	5 (7.8)	0.753
Preoperative radiographic data			
Angulation view (R), degrees, mean (SD)	20.82 (14.32)	24.49 (15.38)	0.177
Angulation view (U), degrees, mean (SD)	21.12 (16.29)	23.66 (16.35)	0.397
Displacement (R), n (%)			
Minimal displacement or only angulation	11 (15.3)	8 (15.7)	0.131
Partial contact	35 (48.6)	33 (64.7)	
No contact	26 (36.1)	10 (19.6)	
Displacement (U), n (%)			
Minimal displacement or only angulation	10 (15.4)	14 (25.5)	0.423
Partial contact	31 (47.7)	23 (41.8)	
No contact	24 (36.9)	18 (32.7)	

SD indicates standard deviation; BMI, body mass index; (R), radius; (U), ulna; AP, antero-posterior; ML, mediolateral.

*$p < 0.05$.

TABLE 2. Surgical Information, Postoperative Management, and Status of Bone Union

	Group B (n=79)	**Group E (n=64)**	**p Value**
Surgical information			
Operative time, min, mean (SD)	56.25 (25.20)	50.80 (36.82)	0.335
Reduction(R), n (%)			
Closed reduction	55 (77.5)	45 (90.0)	0.196
Kapandji techniques	8 (11.3)	3 (6.0)	
Open reduction	8 (11.3)	2 (4.0)	
Reduction(U), n (%)			
Closed reduction	53 (81.5)	43 (79.6)	0.943
Kapandji techniques	5 (7.7)	5 (9.3)	
Open reduction	7 (10.8)	6 (11.1)	
Insertion position of K-wire (R), n (%)			
Dorsal entry point	35 (48.6)	5 (10.0)	<0.001*
Lateral entry point	37 (51.4)	45 (90.0)	
Insertion position of K-wire (U), n (%)			
Through olecranon entry point	58 (89.2)	47 (87.0)	0.78
Proximal lateral entry point	7 (10.8)	7 (13.0)	
Postoperative management including implant removal			
Time from operation to splint off, days, mean (SD)	34.07 (12.92)	39.88 (13.08)	0.013*
Time from operation to removal of activity restrictions, months, mean (SD)	3.83 (1.85)	3.05 (0.71)	0.014*
Time from operation to implant removal, days, mean (SD)	187.90 (107.91)	41.39 (24.26)	<0.001*
Anesthesia for implant removal			
No or local anesthesia	17 (21.5)	52 (82.5)	
General or regional anesthesia,	62 (78.5)	11 (17.5)	<0.001*
Status of bone union			
mRUST score at 3 months (R), median [range]	15.00 [8.00, 16.00]	15.00 [8.00, 16.00]	0.444
mRUST score at 3 months (U), median [range]	14.00 [6.00, 16.00]	14.00 [8.00, 16.00]	0.83
mRUST score at 6 months (R), median [range]	16.00 [11.00, 16.00]	16.00 [12.00, 16.00]	0.402
mRUST score at 6 months (U), median [range]	16.00 [12.00, 16.00]	16.00 [12.00, 16.00]	0.768

SD indicates standard deviation; K-wire, Kirshner wire; mRUST, modified radiographic union scale in tibial fractures; (R), radius; (U), ulna.

*p <0.05.

Table.3 Postoperative Complications

	Group B (n=79)	Group E (n=64)	p.value
Refracture, n (%)	6 (7.9)	21(32.8)	<0.001*
Infection, n (%)	3 (3.8)	7(10.9)	0.112
Nerve injury, n (%)	1 (1.2)	0 (0.0)	1
Tendon rupture, n (%)	0	0	—
Irritation pain, n (%)	12 (15.2)	1 (1.6)	0.006*
Nonunion	0	0	—
Penetration of implant through skin（%）	4 （5.1）	—	—

*p <.05

Table.4 Comparison of mRUST score between patients with and without refracture

	Refracture cases	No refracture cases	p.value
mRUST score at 3month (R), median (range)	15.00 [8.00, 16.00]	15.00[8.00, 16.00]	0.96
mRUST score at 3month (U), median (range)	14.00 [9.00, 16.00]	14.00 [6.00, 16.00]	0.644
mRUST score at 6month (R), median (range)	16.00 [13.00, 16.00]	16.00 [12.00, 16.00]	0.93
mRUST score at 6month (U), median (range)	15.00 [12.00, 16.00]	16.00 [11.00, 16.00]	0.139

Abbreviations: mRUST, modified radiographic union scale in tibial fractures;

(R), Radius; (U), Ulna; *p <.05