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Intramedullary osteosynthesis for pediatric forearm re-fractures depending on the time of occurrence

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Abstract

Background Tactical and technical errors in repair of pediatric forearm fractures can be associated with various complications including refractures. There are many questions regarding diagnosis (osteoreparation at the time of the occurrence) and in surgical treatment.

The **objective** was to improve outcomes of pediatic forearm refractures treated with intramedullary osteosynthesis considering a osteoreparation period and the time of the occurrence.

Material and methods There were 48 children with forearm refractures treated in the clinic between 2010 and 2020. The patients were divided into two groups. Patients of group 1 ($n = 25$) were treated with intramedullary osteosynthesis neglecting the regenerative process and the timing of refracture relative to the primary fracture. Patients of group 2 ($n = 23$) sustained a recurrent fracture at 6 months of early osteoregeneration with developing callosity. Re-fracture occurred in 19 (76.0 %) patients of group 1 including six children (24 %) with two or greater occurrences. Recurrence was observed in 16 (69.6 %) cases of group 2 including seven patients (30.4 %) who sustained more than two fractures.

Results The timing of re-fractures, immobilization and gradual removal of fixation components can facilitate improved short- and long-term results of surgical treatment and prevent complications that were evident in 22 (95.6%) children of group 2 with good results observed at 6 months.

Discussion The calluses were replete with blood vessels indicating the normal regeneration for fractures that occurred at 6 months of the initial fracture. No vessels in the callus were seen after 6 months due to resorption of the bundles and poor fracture healing.

Conclusion The outcome of re-consolidation would be dependent on the stage of bone regeneration at the time of forearm refracture. The regeneration process was more effective in the early stage of re-fracture.

Keywords: repeated fracture, refracture, forearm, surgical treatment, intramedullary osteosynthesis, children

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INTRODUCTION

Pediatric forearm fractures are common and account for 43.6 % [1–4] of trauma cases. With new trends in repair of pediatric forearm fractures, the frequency of repeated forearm fractures is high and ranges between 4 and 21.3 % [1, 2, 5–10]. There are opposing opinions regarding the principles of pediatric treatment of repeated forearm fractures. Conservative treatment is commonly used for this cohort of patients [11–13]. The treatment strategy can be dissociated with the morphology of the fractures, and the problem remains poorly understood [14–17]. This causes poor treatment results and leads to various complications [18–20]. Intramedullary (IM) nailing can be associated with complications including inadequate fracture healing (0.7–0.9 % of cases), nonunion (2.2–3.8 %), delayed bone healing (5.1–7. 8 %) and recurrent fractures (2.1–2.3 %) [1, 6, 7, 19, 20].

The **objective** was to compare the results of IM nailing in children with forearm re-fractures at different times of the occurrence during osteoreparation.

MATERIAL AND METHODS

Forty-eight patients with forearm re-fractures were reviewed between 2010 and 2020 at the Scientific and Practical Medical Center of Traumatology and Orthopaedics, Republic of Uzbekistan. The patients aged 3 to 18 years with the mean age of (9.75 ± 0.28) years. All therapeutic and diagnostic measures in children were carried out in the presence of parents with the documented consent. The patients were divided into two groups. Patients of group 1 (n = 25) were treated with IM osteosynthesis neglecting the regenerative process and the timing of refracture relative to the primary fracture. Patients of group 2 (n = 23) sustained a recurrent fracture at 6 months of early osteoregeneration with developing callosity. Re-fracture occurred in 19 (76.0 %) patients of group 1 including six children (24 %) with two or greater occurrences. Recurrence was observed in 16 (69.6 %) cases of group 2 including seven patients (30.4 %) who sustained more than two fractures (Table 1). Clinical assessment of consolidation and functional status, and radiological assessment of the pathological site were produced for the patients.

Table 1

Distribution of patients by type, number and location of re-fractures

Type and location of the fracture	Number of patients			
	Group 1, n = 25		Group 2, n = 23	
	abs.	%	abs.	%
Original fracture pattern				
Transverse fracture	12	48.0	16	69.6
Oblique-transverse fracture	13	52.0	7	30.4
Number of re-fractures				
one	19	76.0	15	65.2
More than one	6	24.0	8	34.8
Re-fracture location				
Upper third	3	12.0	7	30.5
Mid third	12	48.0	11	47.8
Lower third	10	40.0	5	21.7

The secondary fracture line coincided with the line of the primary fracture in all patients. Patients of both groups underwent surgical treatment using open intramedullary antegrade osteosynthesis. Closed osteosynthesis was not performed due to the fact that the medullary canal was closed by endosteal callus and prevented the passage of the wire. Re-fractures occurred within 2 to 4 months of the primary fracture in the majority of cases, in 32.0 % of cases of group 1 and in 56.5 % of cases in group 2 (Table 2).

Table 2

Distribution of patients according to the timing of re-fractures depending on the ongoing osteoreparation relative to the first fracture

Groups	2 months		2 to 4 months		4 to 6 months		6 to 12 months		More than 12 months	
	abs.	%	абс.	%	абс.	%	абс.	%	абс.	%
Group 1, *n* = 25	3	12.0	8	32.0	7	28.0	5	20.0	2	8.0
Group 2, *n* = 23	4	17.4	13	56.5	6	26.1	–		–	

We have developed an algorithm of surgical strategy for pediatric forearm re-fractures with regard to the timing of their occurrence relative to the primary fracture, location and fracture pattern, and displacement.

Re-fracture of 2–4 months was characterized by a normal fusion process, sufficient blood supply at the site of the periosteal callus. A re-fracture in the phase of callus resorption was accompanied by delayed healing or nonunion.

Indications for intramedullary osteosynthesis with Kirschner wires included:

— child aged 9 years and younger;

— a re-fracture occurred within three months;

— periosteal and paraosseous callus at the re-fracture site seen in an X-ray or MSCT image;

— displacement by 1/3 of the bone diameter and length, a deformity measuring more than 10°.

Indications for intramedullary osteosynthesis with Kirschner wires and Ilizarov external fixation:

— child's age over 9 years;

— a forearm re-fracture occurring during consolidation of the primary fracture within 6 months;

— periosteal, paraosseous and endosteal callus detected at the site of re-fracture on an X-ray or MSCT image;

— displaced bone at the re-fracture site.

Contraindications for intramedullary osteosynthesis with Kirschner wires and Ilizarov external fixation:

— open fracture and cntaminated wound of the soft tissues;

— a second fracture of the forearm bones occurred during consolidation of the primary fracture for more than six months;

— resorption of periosteal and paraosseous calluses and the presence of an endosteal callus at the re-fracture site seen in the X-ray or MSCT image;

— no bone displacement.

Surgical treatment of forearm re-fractures was produced in two stages with regard to the fracture pattern using IM osteosynthesis. The first stage included IM osteosynthesis with wires and application of a plaster cast with pediatric procedures performed under general anesthesia. Periosteal and paraosseous calluses were not removed intraoperatively. At 6 months of control radiography wires could be removed and segmental plaster casts applied for two weeks with bone fused, to improve medullary circulation and create conditions for endosteal callosity. The results were rated as “good” with 3 scores, “fair” with 2 scores and “poor” with 1 score. The results were based on

clinical, radiological, and functional aspects of the injured limb. The scoring allowed visual evaluation of the outcomes and comparison with a qualitative assessment, which we did for the first time. The assessment criteria of the results of treatment that we developed were used for the "Program for assessing the results of treatment for pediatric re-fractures" registered with the Intellectual Property Agency of the Republic of Uzbekistan (No. DGU 04277 dated March 1, 2017). Linear methods were used for statistical analysis. Arithmetic means, standard errors of arithmetic means, and standard deviations were calculated. A comparative analysis of the significant differences between the study groups was produced using the Student's t test. Differences were considered significant with the level of significant differences being $p<0.05$ (95 % confidence level) in individual parameters in the groups. Statistical calculations were produced using Excel-2013 built-in statistical functions.

RESULTS

Neither fair nor poor results were noted at a short (Table 3) or long term (Table 4) in the groups of children with re-fractures within 4 months of the primary fracture.

Table 3

Short-term results

Time frame for re-fracture, months	Group 1 (n = 25)						Group 2 (n = 23)					
	good		fair		poor		good		fair		poor	
	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
До 2	3	12.0	–	–	–	–	4	17.4	–	–	–	–
2–4	8	32.0	–	–	–	–	13	65.5	–	–	–	–
4–6	4	16.0	3	12.0	–	–	4	17.4	2	8.7	–	–
6–12	1	4.0	3	12.0	1	4.0	–		–	–	–	–
Over 12	–	–	–	–	2	8.0	–	–	–	–	–	–
Total	16	64.0	6	24.0	3	12.0	21	91.3	2	8.7	–	–

Table 4

Long-term results

Time frame for re-fracture, months	Group 1 (n = 25)						Group 2 (n = 23)					
	good		fair		poor		good		fair		poor	
	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
До 2	3	12.0	–		–		4	17.5	–		–	–
2–4	8	32.0	–		–		13	56.5	–		–	–
4–6	6	24.0	1	4.0	–		5	21.7	1	4.3	–	–
6–12	3	12.0	1	4.0	1	4.0	–		–		–	–
Over 12	1	4.0	–		1	4.0	–		–		–	–
Total	21	84.0	2	8.0	2	8.0	22	95.7	1	4.3	–	–

Note: presented are 1-year outcomes of re-fractures that occurred at different times after the first fracture

No poor results at short and long terms were reported for re-fractures that occurred at 4 to 6 months. In the immediate period for periods of more than 6 months. the result in Three patients of group 1 showed a poor result at a short term within a period of more than 6 months due to pathological periosteal and paraosseous callosity seen radiographically and on MSCT images with the callus being partially sclerotic at the ends of the broken bone. A fair result at a long term was observed in one patient of group 2 who developed very slow bone fusion at the re-fracture site that led to prolonged immobilization and contractures in adjacent joints. The same picture was observed in the period of 6

to 12 months with a fair result seen in 3 patients of group 1 at a short term. Radiographs and MSCT images showed sclerotic periosteal and paraosseous calluses at the top of the bone fragments at the re-fracture site with the dissolving endosteal callus. Despite the strong bone fixation, a slow healing process was observed in the patients treated with intramedullary osteosynthesis and resultant contractures. Joint contractures were completely eliminated in two patients at a long term. The range of motion in the joints was limited to 60° in one patient and rated as fair. A poor result in the group of children was observed due to bone sclerosis and resorption of callus at a short- and long-term period, in 1 case each (due to non-union of a secondary fracture). For repeated fractures that occurred at 12 months of the primary fracture, a poor result was noted in 2 patients at a short term with sclerotic re-fractured bone ends seen on MSCT images indicating bone restoration. This period was the stage of callus resorption and bone formation. Blood circulation at the re-fracture site appeared as an unusual process causing high complication rate in re-fractures observed during this period. These patients underwent repeated surgical treatment (resection of the incomplete area) with the outcome rated as good at a long term in one case and with no changes in the 'poor' rating in the other case.

Fair and poor results were not seen in children of group 2 with re-fractures occurred within 4 months of the primary fracture. The patients had adequate periosteal and paraosseous calluses visualized on MSCT and radiographs. Re-fractures that occurred at 4 to 6 months of the primary fracture osteoreparation were assessed as fair in two cases at a short term due to joint contracture. One child developed a good joint function completely restored at a long term, and another case demonstrated a fair result due to the remaining contracture in the joints. No osteoreparation of the primary refracture was observed in the group at 6 months. A comparative analysis of treatment outcomes in both groups showed that bone healing after a second fracture was dependent on the callosity which was caused by refractory conditions during the primary consolidation. Clinical, functional and radiological scores showed significantly better results at a short (91.3 % vs. 64 %) and at a long term (95.6 % vs. 84 %) in group 1 with use of intramedullary wires (Table 5).

Table 5

Results of intramedullary osteosynthesis of pediatric forearm refractures in the control and treatment groups at a short (up to 1 year) and long term (more than 1 year)

Group 1					
Clinical and radiological criteria		Re-fractures (*n* = 19)		Two and more fractrures (*n* = 6)	
		Short-term results	Long-term results	Short-term results	Long-term results
Clinical score		2.52 ± 0,16	2.89 ± 0.07	2.16 ± 0.4	2.3 ± 0.36
Radiological score		2.52 ± 0,14	2.84 ± 0.11	1.83 ± 0.4	2.33 ± 0.42
Functionality	Flexion in the wrist				
	dorsal,°	31.3 ± 1.79	69.2 ± 1.39	45.0 ± 10.4	74.2 ± 5.08
	palmar,°	26.3 ± 1.75	63.15 ± 1.4	37.5 ± 7.74	68.3 ± 4.02
	ROM,°	57.6 ± 3.43	131.8 ± 2.3	82.5 ± 17.8	144.2 ± 8.34
	Flexion / extension in the elbow joint				
	flexion, °	80.5 ± 1.57	51.6 ± 1.9	74.2 ± 6.4	50.8 ± 5.25
	extension, °	144.4 ± 3.08	164.7 ± 3.004	143.3 ± 6.69	164.2 ± 6.1
	ROM °	63.9 ± 4.4	113.1 ± 3.8	69.2 ± 10.8	113.3 ± 9.6
Immobilization period (days)		61.4 ± 1.02		61.3 ± 1.77	
Range of individual values		54–67		55–68	

Table 3 (continued)

Results of intramedullary osteosynthesis of pediatric forearm refractures
in the control and treatment groups at a short (up to 1 year) and long term (more than 1 year)

Group 2			
Clinical and radiological criteria		Re-fracture (*n* = 16); Two and more fractrures (*n* = 7)	
		Short-term results	Long-term results
Clinical score		2.7 ± 0.15	3
Radiological score		2.9 ± 0.1	3
P		< 0.001	
Functionality	Flexion in the wrist		
	dorsal,º	64.5 ± 3.02	81.0 ± 1.45
	palmar,º	70.0 ± 2.35	85.0 ± 1.4
	ROM,º	134.5 ± 5.2	166 ± 2.33
	Flexion / extension in the elbow joint		
	flexion, º	44.0 ± 1.94	37.5 ± 0.83
	extension, º	173 ± 2.001	180
	ROM º	129 ± 3.48*	142.5 ± 0.8
P		< 0.001; < 0.0001*	
Immobilization period (days)		57.0 ± 1.49	
Range of individual values		52–61	

Note: * — *P* < 0.0001 relative to the results in the control group.

Clinical instance

A 12-year-old patient K.D. sustained an injury 11/2 years ago falling on his arm while playing with friends, as reported in the medical history and told by his parents. On admission he was diagnosed with closed displaced fracture of the mid shaft of the left forearm. The fracture was reduced under local anesthesia and a plaster splint applied. The patient was treated as an outpatient and immobilization lasted for 1 month. The child sustained the second fracture from a fall at 6 months. A plaster cast was applied at a local clinic and the patient was followed up as an outpatient. Immobilization lasted for 40 days, consolidation was achieved clinically and radiologically. The third injury occurred from falling on the arm stumbling over at school and was hospitalized in the pediatric trauma department. The radiograph showed a residual angular displacement after the primary fracture; re-fracture occurred as a result of changes in bone physics. The paraosseous and periosteal callosity dissolved, and the endosteal callus was not fully formed. The regenerate bone appeared as the Kaplan 5th morphological and 4th clinical stages indicating resorption of paraosseous and periosteal callosity with the endosteal callus formed. Reduction was performed and the control radiograph showed poor bone re-alignment followed by intramedullary osteosynthesis of the left forearm bones. Intramedullary wires were removed after 21/2 months of surgery that resulted in limited motion in the elbow joint. The regeneration appeared as 4 morphological and 3–4 clinical phases. The periosteal and paraosseous callosity completely restored with developing endosteal callus indicating restoration of the bone strength and immobilization removed. Rehabilitation for the patient continued over the next 2 months and resulted in elbow functionality restored.

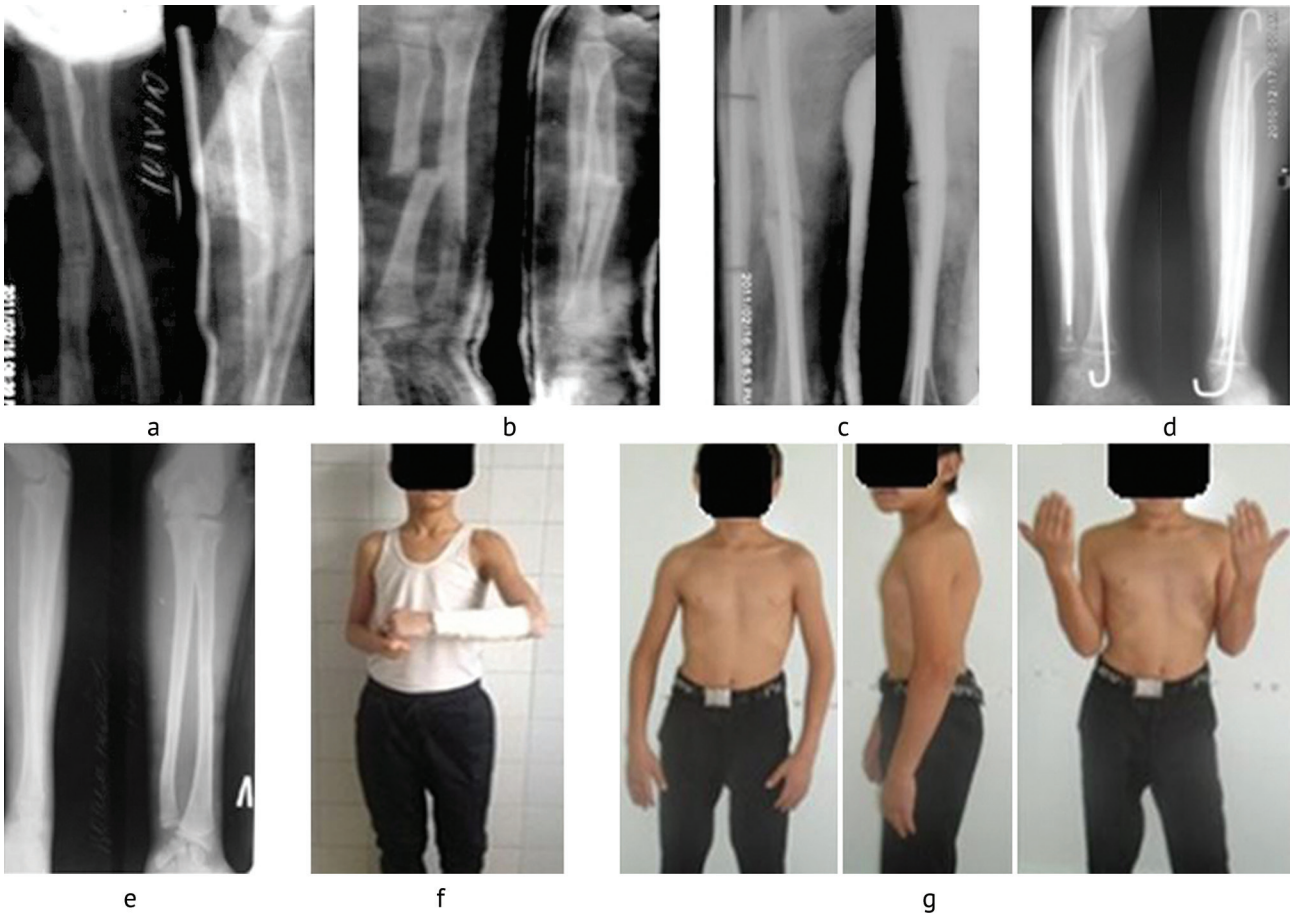

Fig. 1 Radiographs showing (*a*) primary fracture; (*b*) re-fracture; (*c*) re-fracture following intramedullary osteosynthesis; (*d*) bone regeneration at a month; (*e*) bone regeneration at 9 months of surgery. Photo of the patient showing (*f*) appearance of the patient with a segmental plaster cast applied; (*g*) functionality of the joint

DISCUSSION

Flexible intramedullary nailing (FIN) is reported as the method of choice for the surgical treatment of pediatric forearm re-fractures [11, 13]. FIN has important advantages of minimal invasiveness, stable fixation, the possibility of early limb function, good cosmetic results, low risk of complications [4], shorter inpatient period and more rapid return to everyday life. Intramedullary osteosynthesis with a wire is difficult to perform in a closed manner for a re-fracture case due to the closure of the bone marrow canal providing no opportunity for stability during bone reduction. Thin wires can be used for re-fractured bones with a narrow medullary canal [10], but wires with a smaller diameter can cause a bone re-fracture or instability of the fracture during surgical treatment [7]. Wires with a larger diameter were suggested [3]. Wires with a diameter 2/3 of the diameter of the medullary canal were used in closed reduction. They believed that fractures treated with FIN can be associated with bone re-fractures. FIN is recommended to be used for 10–12 months to minimize the risk of re-fractures [12, 16]. Re-fractures can occur with wires, therefore, there is little benefit from leaving the wires longer for complete fracture healing. Pinning can be associated with skin perforation, requiring additional intervention, subcutaneous hematoma and joint contracture, incomplete elimination of diastasis between bone fragments at the fracture site, and limited forearm rotation [2, 8, 11, 19].

Morphological examination of re-fractures and primary fractures were experimentally conducted in laboratory animals [15]. A re-fracture occurred in the early period of consolidation with the callosity of the primary fracture heals well in the callus and in the cortex of the

involved bone due to good blood circulation. The risk of complications in the form of impaired consolidation can be reduced. A re-fracture occurring in the late period of healing of the primary fracture, i.e. during the callus resorption heals longer due to deteriorated blood circulation at the site [15]. Intramedullary osteosynthesis used for re-fractured forearm bones in children can lead to various complications including delayed consolidation, nonunion, pseudarthrosis and contractures of adjacent joints the morphology of the fracture is neglected. The timing of the primary fracture is essential for a good outcome of a pediatric re-fracture. If a re-fracture occurs in the late stages of healing of the primary fracture, the calluses can dissolve and the bone would have a pathological structure. Callosity in the phase of completely healed primary fracture is important for a positive effect on osteoreparation with a re-fracture. Therefore, staged surgical treatment of pediatric forearm refractures using intramedullary osteosynthesis during this period considering the regeneration and stages of callus formation facilitates good results and reduced complication rate. The regeneration of a primary fracture occurs in several stages that are essential for repair of pediatric forearm re-fractures. Taking into account the morphological and radiological manifestations of the callosity are important for achieving good outcomes at the time of re-injury.

CONCLUSION

Surgical treatment of patients with re-fractures and periosteal and paraosseous callosity suggests their preservation in early 3-month re-fractures relative to the first fracture. Intramedullary osteosynthesis used to repair pediatric forearm re-fractures at an early stage provides tension at the fracture site and allows bone consolidation to be achieved at a short term. A balanced approach to the choice of surgical treatment considering the stage of callus formation, staged removal of fixation components can significantly reduce immobilization period and help avoid poor results and complications, and reduce fair outcomes by 2.2 times compared to the comparison group. A differentiated approach to intramedullary osteosynthesis used to repair re-fractures considering the stage of osteoreparation and the timing of the occurrence relative to the first fracture can improve surgical results at the short and long terms.

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