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Comparative analysis of different modifications of elastic nail osteosynthesis in the treatment of children with extra-articular proximal humeral fractures

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Abstract

Introduction The relevance of studying the treatment of proximal humeral fractures in children stems from the high incidence of fractures in this anatomical region and the absence of a standardized treatment approach. This highlights the need for further research to develop treatment protocols that account for the unique characteristics of the pediatric body and the specific features of these fracture types.

Objective of the study was to analyze and compare the outcomes of treating children with extra-articular proximal humeral fractures using double-nail versus single-nail modifications of intramedullary osteosynthesis with elastic nails.

Materials and Methods Patients were divided into two groups. The study group (n = 39) patients underwent surgical treatment with a single elastic rod while patients in the control group (n = 32) received treatment using a double-nail modification of osteosynthesis. Treatment efficacy was analyzed in both inpatient and outpatient settings with clinical, radiological, and sociological assessment methods.

Results Postoperative parameters (duration of pain syndrome, hospitalization period, return to school, and fracture consolidation time) were comparable in both groups, indicating similar efficacy of the treatment methods in these studied parameters. Statistically significant differences were observed only in operative time, directly linked to the specific surgical techniques employed in each group. The proposed method in the main study group allowed for faster surgery and did not significantly affect other key parameters of anatomical and functional recovery. Patients in both groups were satisfied with the treatment outcomes.

Discussion Unlike the conventional two-nail configuration, the single-rod approach significantly reduces operative time, thereby lowering the risks associated with anesthesia, and slightly reduces the duration of pain syndrome. The study had limitations, including a short follow-up period (no more than 12 months post-injury and 1 month post-implant removal) and a lack of differentiation between fracture configurations (metaphyseal vs. epiphyseal fractures).

Conclusion The single elastic nail osteosynthesis method provides functional recovery of the injured segment and restoration of the child's overall activity comparable to the double-nail technique. Fracture consolidation occurs with correct fragment alignment within standard timeframes.

Keywords: proximal humeral fracture, children, osteosynthesis, intramedullary osteosynthesis

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INTRODUCTION

The relevance of the problem of treating children with fractures of the proximal humerus is associated not only with the high incidence of the injuries to this location, which accounts for 14 % of injuries to the upper limbs and 1.45–2 % of all skeletal injuries [1, 2], but also with long-term impairment of the upper limb function after treatment, especially in late childhood age group [3].

The growth in the number of musculoskeletal injuries, including multiple and combined injuries, as well as the growing demands of patients for quality of life, necessitate the introduction of modern minimally invasive surgical methods in the treatment of children with proximal humerus fractures. Minimally invasive technologies allow for early rehabilitation and maximum restoration of the upper limb functional abilities [4].

Treatment of children with fractures of the proximal humerus is associated with a number of difficulties related to the anatomical and biomechanical characteristics of this segment. The main factors complicating its treatment are: small size of the proximal fragment, which complicates its stabilization and fixation; high mobility of bone fragments due to muscle action and biomechanical load on the shoulder joint; location of the fracture in the area of the epiphyseal plates, which increases the risk of disturbances in bone development [5]. These features require the use of specialized techniques to minimize complications and restore the functional activity of the limb.

Minimally invasive technologies that reduce the risk of complications are preferable among the surgical methods of humeral fractures repair. One of these methods is FIN (Flexible Intramedullary Nailing), which provides stable fixation of fragments due to flexible intramedullary rods, reduces the rehabilitation term, and ensures early activation of patients and return to daily activities [6–8].

Purpose of the study was to compare the outcomes of treating children with extra-articular proximal humeral fractures using two-nail versus single-nail modification of intramedullary elastic osteosynthesis.

MATERIALS AND METHODS

An analysis of surgical treatment of children (n = 71) with proximal humerus fractures who underwent surgical treatment at the Red Cross Regional Children's Clinical Hospital (Kurgan) from 2016 to 2023 was conducted. The control group included patients (n = 32) operated on using the double-nail technology; their medical records were analyzed retrospectively. The study group included patients of a prospective study (n = 39) operated on using the single-nail intramedullary osteosynthesis technology.

Exclusion criteria for both groups were patients with severe traumatic brain injury (SBI), angioneurological complications of the fracture, pathological fractures of the humerus, refusal of the patient/legal representative of the patient to participate in the study.

This study was conducted in accordance with the World Medical Association Declaration of Helsinki "Ethical principles for medical research involving human subjects" as amended in 2000.

Patients' data were analyzed for the following parameters: age, gender, injury location, injury mechanism, fracture type according to the AO PCCF (Pediatric Comprehensive Classification of Long-Bone Fractures) [9], presence of concomitant injuries, condition of peripheral nerves and vessels, postoperative complications, hospitalization time, and implant removal time. Duration of pain was assessed based on the need for analgesics. The location of bone fragments, fixation devices, and fracture healing stages were analyzed using standard radiographic views.

Patients were examined at least once a month at the outpatient stage. To assess functional recovery and patient satisfaction with the treatment, the QuickDASH questionnaire [10] was used. This questionnaire has been validated for children aged 8 to 18 years and is a brief variant of the original questionnaire "Disorders of the Arm, Shoulder, and Hand" (DASH).

The average age of patients at the time of injury was (11.28 ± 2.78) years (range, 7 to 15) in the main study group and (11.15 ± 2.45) years (range, 6 to 16) in the control group. The duration of injury at the time of surgery was from 16 hours to 7 days in the main study group and from 14 hours to 11 days in the control group. There was no significant difference in age and gender between the groups.

The most common mechanism of injury was a fall from height in a domestic setting, recorded in 22 (69 %) cases in the control group and in 26 (67 %) cases in the study group. Other mechanisms included falling from a bicycle or scooter (four patients in both groups), injuries during sport activities including martial arts (three cases in both groups), and high-energy injuries (three patients in the control group and six patients in the study group).

In three children of the control group and five children of the main group, the humerus fracture was accompanied by a closed SBI of the concussion type. In one case, a 7-year old patient of the control group, who was injured in a traffic accident, was diagnosed with a combination of a humerus fracture, SBI, and femur fracture.

In all cases of both groups, fractures were closed. The distribution of fractures according to the AO PCCF is presented in Table 1.

Table 1

Distribution of patients by AO PCCF fracture types

Fracture	Control group (*n* = 32)		Study group (*n* = 39)	
	No	%	No	%
11E/1.1	9	28.1	9	23.1
11E/2.1	12	37.5	12	30.8
11M/3.1	11	34.4	18	46.2

Statistical analysis of the study data was performed using Statistica 12.0 software (StatSoft Inc.). The results are presented as the arithmetic mean (M) and standard error of the mean (± m) for quantitative indicators. To compare mean values between the groups, Student's t-test was used, which is effective when for samples corresponding to the normal distribution. To check the compliance of the distribution of qualitative features with the expected one under the null hypothesis, the Pearson criterion (χ^2) was used. Differences were considered statistically significant at $p \leqslant 0.05$.

Surgical technique

In a single-nail configuration of intramedullary osteosynthesis, the operation is performed under general anesthesia. The patient was placed on the operating table in a supine position with the possibility of giving the "greeting pose", abduction of the shoulder joint to a right angle with flexion of the elbow joint at 90°.

The entry hole in the distal part of the lateral column is formed using a bone awl 10–20 mm proximal to the lateral epicondyle through a preliminary skin incision. A titanium nail with a pre-curved end is inserted into the medullary canal using a T-handle. Reduction is achieved by gentle

traction and usually requires abduction and internal rotation to eliminate displacement. It is important to remember that the center of rotation of the humerus in fractures of the proximal part, the capsuloperiosteal flap, is located posteromedially. The quality of reduction is checked using radiography in the anteroposterior, lateral projections and Neer's projection [11].

If the reduction is satisfactory, the rod is driven into the proximal epiphysis. In cases of poor reduction due to soft tissue interposition in the fracture zone, it is recommended to increase the deformity in both planes, advance the rod until it reaches the fracture zone and rotate it in the fracture zone with simultaneous traction to release the clamped tissues. Next, the proximal fragment is fixed with a pre-curved rod and rotated to eliminate residual displacement. Upon achieving satisfactory reduction, the rod is impacted into the subchondral bone through the growth plate to ensure maximum fixation stability and prevent rod migration. The stability of the fracture fixation is checked radiographically by rotating the humerus.

RESULTS

The groups were comparable in all preoperative characteristics. In both groups, the rod was pre-bent by 10° to optimize reduction. The nail diameter was selected based on preoperative radiography, considering the ratio of the nail diameter to the diameter of the medullary canal in its narrowest part. For the double-nail configuration, this ratio was 0.3, for the single-rod configuration 0.4 (to improve the stability of fixation). The nail diameter ranged from 2.0 to 3.5 mm. In the control group, a 2.0-mm titanium nail was used in eight cases, a 2.5-mm one in 17 cases, and a 3.0-mm one in seven cases. In main study group patients, 2.0-mm nails were used in four cases, 2.5-mm ones in nine cases, 3.0-mm ones in 21 cases, and 3.5-mm ones in five cases (Table 2).

Table 2

Distribution of patients by nail diameters

Nail diameter, mm	Control group (n = 32)		Study group (n = 39)	
	No	%	No	%
2.0	8	25.0	4	10.3
2.5	17	53.1	9	23.1
3.0	7	21.9	21	53.8
3.5	0	0	5	12.8

In the early postoperative period, all patients used a sling bandage until pain relieved, this period did not exceed seven days. During the immobilization period, passive exercise therapy was performedж after the end of immobilization, they switched to active exercise therapy. The average duration of hospitalization was (5.8 ± 2.6) days in the control group and (5.3 ± 2.1) days in the main study group ($p > 0.05$). It was due to pain and the patient's desire to be in hospital.

The time of the surgical intervention was significantly different between the groups (Table 3). The reduction in the surgical time was not only due to the smaller number of implants and, consequently, half of the time required for their placement, but also to the technical simplification of the insertion and removal procedures as there was no crossing of nails.

Pain persisted (assessed by the need for analgesic drugs and on the VAS scale) for (3.7 ± 2.0) days in the main study group and for (3.8 ± 2.1) days in the control group. Children in both groups resumed their studies in educational or preschool institutions within six to 15 days.

Table 3

Duration of the intervention

Manipulation	Time, min		*P*-value
	Study group	Control group	
Implant insertion	31.0 ± 9.4 (18–65)	41.0 ± 11.4 (24–70)	< 0.05
Implant removal	18.0 ± 7.8 (14–35)	25.0 ± 9.2 (19–38)	< 0.05
Total time	51.0 ± 17.2 (32–100)	64.0 ± 20.6 (43–108)	< 0.05

At the outpatient stage, children were examined every 4-5 weeks. At each appointment, a clinical test for consolidation was performed, including palpation of the fracture area to exclude pathological mobility and pain during axial loading, as well as an assessment of the restoration of limb function. The functional assessment included the volume of active and passive movements in the joints of the upper limb, muscle tone and trophism. Particular attention was paid to assessing abduction and rotation in the shoulder joint. Besides, consolidation was studied radiographically, including disappearance of the interfragmentary gap, formation of a bone callus of uniform density crossing the fracture line, complete restoration of the cortical bone layer.

Clinical signs of fracture healing were noted in all patients in both groups within one to two months. The decision to remove the implants was made based on a comprehensive clinical and radiological assessment. In the main group, the period before removal of the metal rod was (5.8 ± 1.2) months, in the control group — (5.9 ± 1.4) months.

The results of surgical treatment were evaluated with Flynn system [12]. The criteria for assessing the results included several key parameters that allow one to evaluate both the clinical and functional results of treatment. According to the scale, excellent results were obtained in 37 (95 %) cases in the main group and in 31 (97 %) cases in the control group, sfair results were obtained in two (5 %) and one (3 %) patients, respectively. In all cases in both groups, a fair result was associated with a residual angular deformity of less than 10°. There were no poor outcomes.

Due to the validation of the QuickDASH questionnaire for children aged eight years and older, one child was excluded from the main study group and three children under eight years of age from the control group during the survey. Seven days after the operation, the patients in the main group scored (20.16 ± 1.98) points, while those in the control group scored (20.74 ± 2.21) points; after the rod removal, the main group scored (0.81 ± 0.28) points, while the control group scored (0.74 ± 0.32) points. The scores obtained after the rod removal indicate minimal functional limitations, which corresponds to excellent treatment results according to QuickDASH.

In the control group, four cases of local skin irritation in the area of rod insertion complicated by bursitis were recorded, and five such cases were identified in the main study group. This condition did not require early removal of the implant, stopped after the planned extraction of the fixator within the specified time frame and did not affect the treatment outcome.

Case report

A 12-year-old patient was admitted to the emergency room of the Red Cross Regional Children's Clinical Hospital on March 17, 2022, with a 11E/2.1 humerus fracture falling down the stairs at school on the day of admission to the hospital. Surgical treatment was performed using the single-rod modification of intramedullary osteosynthesis technology (Fig. 1).

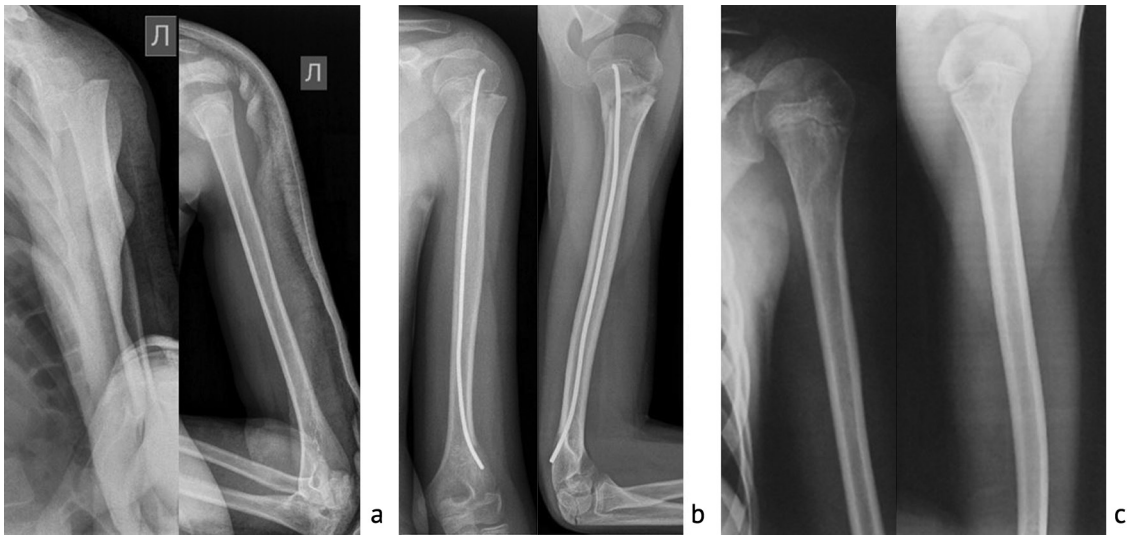

Fig. 1 Patient's radiographs: (a) at admission; (b) one months after surgery; c 12 months after surgery

DISCUSSION

Currently, most pediatric patients with proximal humerus fractures are treated conservatively. The high remodeling potential of this limb segment allows for significant residual displacement [13]. Conservative treatment, despite its popularity and effectiveness, in most cases, especially in complex fractures or in fractures in older children, has a number of limitations and risks: secondary displacement, prolonged immobilization, difficulty in complying with the restrictive regimen [14, 15]. The number of supporters of the surgical method of treatment increase due to high level of demand for quality of life, the need for rapid social reintegration, and the desire to avoid immobilization [16, 17].

Proximal humerus fractures are often unstable, and therefore, the choice of fixation method is critically important and largely determined by the surgeon's skill. Various methods are used to fix proximal humerus fractures in children requiring surgical treatment, including screws, plates, external fixators, percutaneous pin fixation, or elastic intramedullary osteosynthesis [18–20]. Percutaneous Kirschner wire fixation and intramedullary osteosynthesis are the most widely used, and demonstrate similar efficacy and satisfactory clinical outcomes. Kirschner wires are inserted percutaneously and require postoperative limb immobilization. Protruding ends of the wires can cause muscle and soft tissue irritation and are also at risk of migration [21]. In displaced fractures, intramedullary rod osteosynthesis is the method of choice due to excellent functional outcomes, low complication rate and the possibility of early mobilization [22], but it also has its drawbacks. Intramedullary methods, as a rule, are characterized by a long duration of surgical intervention, are associated with increased intra-operative blood loss and the need for subsequent removal of fixaton elements [23, 24].

In order to minimize the duration of surgical intervention, a single-nail modification of intramedullary osteosynthesis was proposed. The first mention of this technique belongs to Chee et al. [25], who confirmed its effectiveness in 11 clinical cases. Samara et al. assessed the effectiveness of one retrograde elastic nail in 19 patients and noted stable fixation and the absence of serious complications [26]. The technique is recommended, including for children over 11 years of age with low remodeling potential. Our data that were obtained in a bigger sample are consistent with those findings.

In all cases of our study, reduction was performed with a closed method, which is at odds with the literature, that describes cases of soft tissue interposition and non-reducible fractures [27]. Interposition of the periosteum, deltoid muscle, or long head of the biceps tendon may be an obstacle to closed reduction [28].

In our opinion, the use of a second rod is not mandatory, although it ensures a more uniform distribution of biomechanical loads due to the divergent effect on the stretching and compression zones. One rod creates a directed compression force along the concavity of the arch and acts as an internal splint, fixing the fragments until fracture consolidation, while the residual remodeling potential of the proximal humerus can correct acceptable radiographic deformities [29]. The refusal to use a second nail to prevent rotation of the proximal segment is justified by the remodeling potential and adaptive capabilities of the shoulder joint, the multiplanar mobility of which eliminates the risks of biomechanical disorders [30].

CONCLUSION

The results of the study indicate the clinical effectiveness of the surgical treatment method using retrograde intramedullary osteosynthesis of a single-nail configuration in children with proximal humeral fractures. All patients achieved radiographic union with restoration of full painless range of motion after implant removal.

The single-rod intramedullary osteosynthesis technique provides functional restoration of the damaged segment and the child's overall activity comparable to the double nail technique; fracture consolidates within the usual time term. The use of one nail reduces the surgery time, reduces costs, and simplifies the installation and removal of the implant compared to the double-nail technique. There is no need for long-term immobilization. Children and their parents were satisfied with the treatment results.

Conflict of interest *None.*

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Ethical standards *This study was conducted in accordance with the World Medical Association Declaration of Helsinki "Ethical principles for medical research involving human subjects" as amended in 2000.*

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