

# Modern methods for treating post-traumatic and dysplastic deformities of the forearm bones in children

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## Abstract

The aim of the study was to examine treatment options for fractures and other deformities of the forearm bones in children to better understand the methods and conditions under which this or that method is applied. An analysis of the literature on the specified topic was conducted. The following keywords were used for the search: methods for treating post-traumatic and dysplastic deformities of the forearm bones in children, treatment of forearm bone deformities in children, treatment of forearm trauma in children, treatment of forearm dysplasia in children, forearm fractures, intramedullary fixation, plates for treating forearm deformities in children. The study established that approaches to treating forearm fractures in children and adolescents depend on the patient's age and the severity of the injury. For children under 10 years of age, conservative treatment using plaster immobilization remains an effective method, even in the presence of minor deformities. However, for adolescents with limited bone remodeling potential, surgical intervention is preferable. Flexible intramedullary nails proved effective due to minimal invasiveness and a lower number of complications. In cases of complex fractures or in skeletally mature adolescents, it is preferable to use plates. The frequency of complications, such as refraction and non-fusion, remains low, but it increases with improper technique or the use of large implants. Hybrid methods combining elastic nails and plates have shown a reduction in surgery time and an acceleration in healing time. Gypsum immobilization, when applied correctly, reduced the risk of displacement. A short plaster cast provided similar results compared to a long one, while reducing the risk of complications. In cases of segmental defects following osteomyelitis or congenital pseudoarthritis, free vascularized pelvic bone transplantation demonstrated high efficacy, ensuring reliable fusion and restoration of forearm function, although additional surgeries were required in a number of cases.

**Key words:** intramedullary fixation, conservative therapy, fixation with plates, upper limb fractures in pediatrics, pseudoarthrosis

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## Introduction

The relevance of the topic of treating post-traumatic and dysplastic deformities of the forearm bones in children is due to the high frequency of injuries in this age group and the significant impact of such deformities on upper limb functionality. These disorders can lead to limited mobility, decreased strength, and the development of asymmetry, which significantly impairs the child's quality of life.

Problematic issues include: the optimal choice of treatment method - conservative or surgical; comparing the effectiveness of various surgical methods, such as osteotomy, metal construction, or the use of

conservative treatment methods; and minimizing the risks of complications, such as pseudoarthrosis or growth retardation. Since childhood injuries are the most relevant, scientists worldwide are studying the issue of the most effective treatment method.

Open forearm fractures in children are frequent injuries in emergency departments. According to G. Elia et al. [1], forearm fractures in children account for 32% to 80% of all open pediatric fractures. Treatment usually includes administering antibiotics, preventing tetanus, and cleaning the wound. For types 2 and 3 fractures according to Gustillo and Anderson, surgical irrigation and stabilization are required. Treatment for type 1

fractures remains non-standardized, as there is no high-level evidence.

In a study by R. F. Murphy and co-authors [2], a comparison was made between the effectiveness of a single sugar-tong splint (SSTS) and a full-arm cast (LAC) for fixing pediatric forearm fractures to avoid secondary interventions. 100 children with forearm fractures requiring restoration were examined. Within 4 weeks after the injury, angular deformations in the sagittal and coronal planes were compared, along with the need for repeated interventions. No differences were found between the groups in sagittal ( $P = 0.46$ ) and coronal ( $P = 0.46$ ) leveling, nor in the frequency of repeated interventions ( $P = 0.70$ ).

Differences between open and closed intramedullary needles in children with forearm fractures were described by a group of researchers together with P. Jordà Gómez [3]. The sample included 75 patients, 50 of whom had open implants and 25 had closed ones. The average time for removing implants was 6.8 weeks for open and 17.6 weeks for closed implants. No significant differences were found in immobilization time ( $P = 0.22$ ) or refraction frequency ( $P = 0.49$ ).

Analysis of factors affecting repeated displacement in diaphyseal forearm fractures in children and comparison of various plaster indices, including the three-point index (TPI), in the scientific work of E. Alagöz and co-authors [4]. The study involved 159 children, and 32.7% of patients experienced repeated fracture displacement. It was found that factors such as fracture type, presence of anatomical contraction, straight elbow boundary, plaster type, and index values (TPI, plaster index, and Canterbury index) were associated with repeated displacements.

In a study by A. R. Harihanan and other scientists [5], congenital syphilis in an infant was examined, which was initially mistakenly diagnosed as a fracture of the metaphyseal angle of the radial bone. Initial treatment was based on this misdiagnosis until a positive syphilis test result was obtained in the mother. Later, the child was diagnosed with congenital syphilis and successfully treated with penicillin. This case highlighted the importance of including congenital syphilis in differential diagnosis when detecting lytic bone lesions in children, despite the rarity of the disease, as its incidence is increasing.

The feasibility of conducting post-restriction X-rays in children with uncomplicated forearm fractures that were restored and cast under fluoroscopic control was examined in a study by scientists together with S. Chitnis [6]. In a retrospective analysis of 236 cases, only 2% of patients required additional reduction based on X-ray data. All these cases were associated with fractures in the middle of the radial and ulnar bones. In the remaining 98% of patients, postoperative radiography did not lead to changes in treatment, increasing the total time spent in the department and treatment costs. The study revealed a low clinical value of these images for most patients.

Evaluation of the effectiveness of hybrid fixation for fractures of both forearm bones in adolescents aged 10 to 16 was conducted in a study by A. S. Elhalawany [7] and co-authors. The study involved 60 patients who underwent fixation using elbow bone plates and elastic nails for the radial bone. All patients achieved complete bone fusion by 24 months, although delayed fusion was observed in 4 patients. The average range of movement during supination was  $81.27^\circ$ , and during pronation, it was  $68.17^\circ$ . In 80% of cases, excellent results were achieved. Hybrid fixation has proven to be an effective method, reducing the risk of elbow bone non-fusion.

A group of scientists, together with R. Dinçer [8], compared the clinical results of treating forearm fractures in children using elastic titanium-intramedullary nails (TEN) left with open or deep-seated ends under the skin. In 192 patients, the fractures fused successfully, but with open TEN ends, skin irritation (5.7%) and infection (1%) were more frequently observed. In cases with sunken tips, nail migration was noted in 5.7% of cases. TEN removal occurred faster with open ends (7.9 weeks versus 26.2). The study revealed that open ends of TEN did not increase the risk of complications, making this method safe and effective.

Thus, injuries and other deformities of the forearm in children require a comprehensive approach to treatment. The therapy plan must include an individual approach depending on the type and complexity of the deformity and the child's age. Thorough differential diagnostics are necessary to eliminate errors.

The aim of this study was to study treatment methods for fractures and other forearm deformities in children to systematize modern treatment methods and their practical application. Objectives: to increase the level of knowledge among doctors; to evaluate the effectiveness of each treatment method.

### Materials and Methods

The study was based on evidence-based scientific works published in databases such as PubMed, Scopus, Google Scholar, and ResearchGate. The following keywords and phrases were used for the literature search: methods for treating post-traumatic and dysplastic deformities of the forearm bones in children, methods for treating dysplastic deformities of the forearm bones in children, treatment of forearm trauma in children, treatment of forearm dysplasia in children, forearm fractures, intramedullary fixation, flexible stable intramedullary nail for forearm fractures, intramedullary nail for forearm fractures, plates for forearm fractures in children. The study examined five main areas in the treatment of forearm bone deformities in children: the use of intramedullary nails, the use of plates, combined treatment, conservative treatment for forearm fractures, and the treatment of other forearm deformities such as osteomyelitis and pseudoarthritis. A total of 109 scientific works were selected that correspond to the research topic and possess a high or medium degree of evidence regarding current issues.

The literature search was conducted between 2020 and 2024. The list included clinical cases, empirical and theoretical studies, systematic reviews, treatment protocols, and practical data. The criteria for selecting articles were the placement of publications within the specified timeframe and in English, accessible search, keywords, and free access for reading or study. In addition, the country where the research was conducted, the name of the journal, the name of the first author, and the publication date were taken into account. Evidence level was also an important criterion, which included empirical works with the highest or average degree of evidence; however, to systematize data, literature reviews, meta-analyses, and clinical rare cases were added to the literature list. If a scientific article did not meet the selection criteria, it was excluded from the literature list. Articles that lacked high-quality annotation and internal content, were not correctly displayed in databases, and lacked information useful for research were also removed from the list. All articles that passed the selection criteria were thoroughly read, studied, and analyzed. Information extraction from scientific works was carried out by evaluating the publication title, annotation, introduction and titles, main data, conclusions, and the bibliography. After reviewing the works, according to the selection criteria, 45 publications remained in the literature list. The number of studies dedicated to the use of intramedullary fixation for forearm fractures in children was 13. The use of plates to restore the integrity of forearm bones has been studied in 4 scientific works. Articles dedicated to combined treatment were included in the literature list in the amount of 8. There were 7 publications dedicated to conservative treatment, and 4 to the treatment of other forearm deformities in children.

The studies took into account the effectiveness of the treatment method used, the children's age, the nature of the injury, and the healing time. Additionally, the presence of complications and side effects following the use of various treatment methods was examined, including complications following surgical treatment of radial or ulnar bone deformities in childhood that occurred in patients during adulthood. In addition, combined and conservative treatment of fractures using a combination of intramedullary nails with plates and plaster bandages was considered. Among other deforming diseases, the treatment of pseudoarthritis and osteomyelitis was taken into account. Data processing was carried out through the systematization and analysis of treatment methods.

Of the 45 articles with a high level of evidence,

## **Results and discussion**

### ***Treatment of forearm bone deformities using intramedullary fixation***

Treating forearm fractures in children and adolescents requires considering many factors, including fracture stability, patient age, anatomical features, and complication risks. The high frequency of such injuries necessitates the selection of an optimal

approach to their treatment that ensures minimal trauma, rapid rehabilitation, and stable functional results. Modern methods, such as intramedullary fixation with various implants (flexible nails, blocking nails, K-wires), are demonstrating significant success. However, issues regarding the choice of method depending on the complexity of the fracture and the stage of bone structure development, as well as the prevention of possible complications, remain unresolved. This emphasizes the need to compare methods to determine their effectiveness in specific clinical situations.

Intra-medullary fixation of the elbow bone for treating Montague fractures in children was studied in a scientific study [9]. Although most such fractures can be treated conservatively, a residual subluxation of the radial joint requires a more aggressive approach to maintain the length and alignment of the ulna. The method involved using a pin or flexible nail, which was inserted through the olecranon apophysis and passed along the canal to the fracture site. After restoring the length and leveling, the nail is fixed and a plaster cast or splint is applied. Intra-medullary fixation has advantages over fixation with plates and screws, as it requires less intervention, leaves fewer scars, and does not cause discomfort from external equipment. This method reduces the risk of recurrent radial head dislocation and loss of elbow bone alignment compared to conservative treatment. However, in cases of unstable or complex fractures, it is preferable to use plates and screws.

In the scientific work [10], the influence of the olecranon apophysis development stage on the healing of both forearm bone fractures (BBFA) in children and adolescents after intramedullary fixation was analyzed. The results showed that patients with more mature olecranon apophyses (stages 4-7) had a significantly higher probability of delayed fracture healing compared to patients with less mature apophyses (stages 0-3). The frequency of complications in unhealed fractures in 63 patients was 17.1% for more mature apophyses compared to 7.1% for less mature ones. Thus, the stage of olecranon apophysis development can be a useful criterion for choosing a surgical treatment method for BBFA fractures in children to reduce the risk of delayed fusion.

In a study [11], it was revealed that the use of intramedullary blocking nails (IMN) and titanium elastic rods (TEN) in forearm fractures in adolescents demonstrated equal safety and effectiveness, regardless of differences in implants and angular deformation on early X-rays. No significant differences were identified in the quality of surgical contraction, complication frequency, or bone fusion time between the two methods, confirming their interchangeability for most patients. The differences between IMN and TEN were the implant diameter, the formation of large bone calluses, and angular deformation, which did not affect functional outcomes and allowed most patients to achieve excellent recovery. The study confirmed that both methods can be effectively applied to treat adolescents with forearm fractures, while the choice of

technique depends on the individual characteristics of the patient and the surgeon's preferences.

In another study [12], the effectiveness of an elastic stable intramedullary nail (ESIN) in treating forearm fractures in children was evaluated, focusing on the impact of the metal frame structure on bone healing. In 3% of cases, no fusion of fractures was observed, requiring additional surgical intervention, and 7% of patients had delayed healing, but bone fusion occurred within the next five months. Larger nails and open contraction increased the risk of complications. Repeated fractures occurred in 3% of patients two years after the injury. A change in alignment of more than 5° was recorded in 35% of patients, most often in distal fractures. However, only in one case did clinically significant instability occur, requiring repeated treatment. Overall, ESIN ensured good bone healing in 90% of patients, and the ideal design of the metal frame was not critical for treatment success.

The systematic review conducted [13] was aimed at evaluating the use of a flexible intramedullary nail in the treatment of forearm fractures in children and adolescents. The study revealed that indications for surgery include unstable, non-transferable, and open fractures, as well as cases with vascular-nervous complications. Flexible intramedullary nailing has demonstrated advantages over other methods, such as plates and screws, including smaller incisions, less tissue damage, shorter surgical and hospitalization time, and easier removal of implants. Despite good clinical results, IMN is not exempt from complications such as skin irritation, nerve damage, delayed fusion, or repeated fractures. The method is well-suited for treating fractures of both forearm bones, especially in children, due to its ease of execution and short learning curve. However, disputes remain regarding the necessity of using one or two nails and choosing their optimal diameter.

The use of elastic stable intramedullary nails for treating forearm fractures in children was characterized by high efficacy, ensuring complete bone healing within 6.8 weeks and good functional and cosmetic results [14]. The absence of post-operative immobilization did not affect the healing process, highlighting the advantages of ESIN in reducing total treatment time and improving patients' quality of life. The frequency of complications was 8.76%, and most of them, including skin irritation and infections, were susceptible to conservative treatment. However, in rare cases of refraction and pseudoarthrosis, repeated surgical intervention became necessary, indicating potential limitations of the method. Long-term results and low complication rates confirmed that ESIN is the preferred method for treating forearm fractures in children, especially due to its combination of minimal trauma and effective recovery.

In a clinical case [15], a 12-year-old boy with an isolated forearm bone fracture was treated using closed repositioning and the insertion of a flexible intramedullary nail 11 days after the injury. The initial straightening of the fracture was lost, necessitating surgical intervention. However, during the surgery, an

unexpected distal radial physical fracture occurred, caused by the insertion of a nail. This complication necessitated a change in treatment strategy. This case demonstrated a rare intraoperative complication - a physiophysical injury during the fixation of a fracture with an intra-medullary nail. The work provides a deeper understanding of potential risks and indicates the need for increased caution when using such techniques, especially in patients with open growth zones.

In another study [16] a rare case of complication from the use of flexible intramedullary nails was described in an 8-year-old boy, accompanied by temporary paralysis of the posterior interosseous nerve. The complication occurred due to nerve compression by an ESIN nail, which was the result of an error during surgery. Despite the nerve damage, the patient's function was restored, and the outcome of the fracture treatment was satisfactory. Given this, doctors should consider the likelihood of such a complication when administering a retrograde intramedullary nail to minimize the risk of nerve damage.

In a clinical case [17], it was shown that intramedullary fixation using an elastic K-wire can be an effective method for treating unstable Montague fractures in children, minimizing the risk of complications and reducing healing time. Refusing to use the plate reduced the likelihood of blood circulation disorders in the affected area, contributing to accelerated recovery and the prevention of long-term complications. The use of manual manipulation to restore joint position and stability control using fluoroscopy confirmed the effectiveness of a combined approach in ensuring the stability of the radial joint and maintaining proper alignment. The six-week period of complete healing and the absence of dislocations or displacements showed that such a treatment method may be safe and preferable for young patients, considering its low invasiveness and high level of functional outcomes.

Retrospective analysis [18] demonstrated that the Kirschner wire immersion technique for intra-medullary fixation of forearm diaphyseal fractures in children reduced the risk of refraction, which determined its preference for long-term stability. Prolonged implantation of wires, characteristic of the submerged tip group, reduced the probability of refraction (7.9% versus 32.8%), emphasizing the importance of the implant's presence time in the bone remodeling process, especially in pediatric practice. Despite an increase in cases of irritating pain in the submerged wires group (15.2% vs. 1.6%), the frequency of infectious complications between the groups did not show statistically significant differences, confirming the safety of the method. The recommendation to keep implants for a period of 6 to 9 months was based on data on minimizing risks during active remodeling, which made immersing the wire ends an optimal solution for preventing refraction and ensuring reliable treatment.

In the study [19], the results of using blocked intramedullary nails (Figure 1) in treating forearm fractures in adolescents were evaluated. The study included 36 patients aged 12 to 17 with unstable

fractures that were not suitable for conservative treatment. According to Price's criteria, 33 patients had excellent results and 3 had good results, with no patient having moderate or poor outcomes. The average time for bone fusion was 8.7 weeks, but in patients over 15 years old, this process took longer - an average of 11.1 weeks. No complications such as bone failure, infection, or repeated fractures were observed, nor were there injuries to sensory nerves or tendons. The removal of the implants also proceeded without complications. This study confirmed that blocked intramedullary nails are a safe and effective method for treating forearm fractures in adolescents, ensuring minimal invasiveness and stable fixation.



Figure 1. Intramedullary nails used to treat forearm fractures in children

Note: A) Distal fixing screw and three-point fixation principle on the intramedullary radial nail; B) Intra-medullary elbow nail design: yellow screws suitable for teenagers

Source: [19]

In the case described [20], a five-year-old boy sustained a closed fracture of the right shoulder and forearm after a fall. The patient had severe pain and limited mobility, but without neurological disorders. The X-ray revealed a fracture of the elbow and radius bones. Surgical intervention was performed 12 hours after the injury, using elastic nails to fix the forearm bones and Kirschner spines for the humerus. After three weeks, the spikes were removed, and after six months, the elastic nails. Two years of observation showed that the patient had fully recovered their arm functions without pain and with a full range of motion. This case emphasized the importance of timely fixation of

fractures and a minimally invasive approach to preserve limb functions.

In the scientific work [21], the use of intramedullary K-wires for fixing displaced distal forearm fractures was studied in 47 children. Fractures were fully healed within an average of 6 weeks, with 89.4% of patients achieving normal functioning after 12 months. Preoperative angulation averaged 36°, and after surgery, it decreased to 4°, indicating a significant improvement. One year after surgery, the median angulation was only 2°. The level of complications was low, and no significant cases of repeated displacement were observed. These data confirm that the intramedullary fixation method using K-wires provides high efficacy in treating distal forearm fractures, reducing the risk of complications and repeated displacement.

Thus, intramedullary fixation is the preferred method for treating unstable forearm fractures in children and adolescents, ensuring minimal invasiveness, reduced treatment time, and good functional results. However, the effectiveness of the method varies depending on the type of fracture, patient age, and the stage of olecranon apophysis development, requiring an individual approach to choosing implants and techniques. The main difficulties include the risk of complications such as skin irritation, nerve damage, and delayed fusion, which require careful planning of surgeries and monitoring of the postoperative period. Further research is necessary to optimize treatment selection criteria, including implant sizes and insertion techniques, to minimize complications and improve long-term results.

#### ***Combined surgical treatment of forearm deformities in children***

Intramedullary fixation has proven itself as an effective method for treating forearm fractures in children and adolescents, ensuring stability, rapid healing, and a low level of complications. The advantages of the methods include a minimally invasive approach and ease of execution. However, the choice of method must take into account factors such as the patient's age, apophysis maturity, and fracture type.

Optimal treatment methods for diaphyseal forearm fractures in adolescents, where the bone remodeling process is limited, were examined in the publication [22]. The main emphasis is placed on the importance of restoring the anatomical alignment of the radius to maintain the full functionality of the forearm, especially rotational movements. Traditionally, it was assumed that a range of 50 degrees of supination and pronation was sufficient, but modern research has shown that daily activities require a larger range of movements, up to 65-90 degrees. The study showed that in most cases, children under 10 years of age can be limited to closed insertion and immobilization, even if there is some strain and displacement. However, for adolescents, especially those with little growth potential remaining, surgical intervention becomes preferable. At the same time, flexible intramedullary nails (FIN) and

plates have comparable results, but each method has its own advantages and limitations. FIN is suitable for most cases, but plates are preferred for skeletally mature adolescents, complex fractures, or fractures in the metadiaphyseal region. The choice between closed treatment and surgical fixation remains complex and depends on the degree of displacement, patient age, and bone recovery capabilities.

The case of a nine-year-old boy with a forearm fracture, who was initially treated with closed correction and plaster immobilization, was examined in the study [23]. Following the removal of the cast, the patient sustained secondary damage to both forearm bones, necessitating surgical intervention using intramedullary nails. Five months after the surgery, the patient sustained a second injury and was diagnosed with repeated bone displacement despite the presence of nails. The closed contraction attempt yielded no satisfactory results, and the intramedullary nails were replaced with new ones. At the time of the one-year observation, the patient's mobility was fully restored, and no pain or muscle weakness was observed. The study emphasized the likelihood of repeated fractures even with the use of intramedullary fixators, as well as the need for careful monitoring and possible surgical re-examination in the event of repeated injuries.

Another scientific study [24] presented a case of a 12-year-old boy with a multi-segmented fracture of both forearm bones, which was successfully stabilized using a unique fixation combination. The ulna was fixed with an intra-medullary stainless steel nail, and a titanium plate, a folded and expanding internal fixation, was used for the radius. 36 months after surgery, the patient had no complications or restrictions in movement, and all installed equipment remained in place. This case was the first where plates made of different materials were used in direct contact, stacked on top of each other, which proved its effectiveness without negative consequences.

A study [25] revealed that both methods, intramedullary fixation with a K-wire (IMNK) and open repositioning with fixation with plates and screws (ORIF), provided similar functional results and pain control levels in treating distal radial fractures in adolescents, emphasizing their equal clinical efficacy. Faster bone healing in the IMNK group indicated the advantage of this method in accelerating tissue regeneration, but the absence of statistically significant differences questioned the clinical significance of this advantage. The ORIF group demonstrated a lower frequency of complications, making this method preferred in cases where reducing the risk of complications was a priority, especially in more complex fractures. A comparison of the two approaches confirmed that the choice of treatment method must take into account the individual characteristics of the patient and the clinical situation, including the likelihood of complications, healing speed, and the need to minimize intervention.

Another study [26] compared three surgical fixation methods for double forearm fractures in

children. Hybrid fixation had advantages over the group with plates and screws in parameters such as shorter operation time and shorter cut length. However, there were no significant differences in functional results between all three groups. Bone fusion time and complication frequency were also comparable between the methods. Scientists have concluded that the hybrid fixation technique may be the preferred method for treating double forearm fractures in children, as it combines the advantages of two approaches - minimizing surgical trauma, accelerating recovery, and reducing surgical intervention time while ensuring reliable results.

The systematic review [27] compared the clinical and radiological results of treating fractures of both forearm bones in 409 children (5 to 17 years old) using two methods: intramedullary nails and screwed plates. Both methods demonstrated similar results in terms of bone functionality and healing time. However, in patients using intramedullary nails, the duration of surgery and anesthesia was shorter, fewer scars were observed, and the cosmetic effect was better. Despite differences in installation techniques, the results for restoring forearm rotation and daily activity did not show significant differences.

Comparative analysis [28] showed that closed manipulation with splint fixation and the use of internal plates in combination with elastic rods in the treatment of displaced fractures of the distal radial and ulnar bones in children had equal effectiveness in restoring bone integrity, which was confirmed by the absence of statistically significant differences in healing time. At the same time, the closed manipulation method ensured a significant reduction in pain levels during the early stages of recovery, indicating its advantage in terms of patient comfort. The use of a combination of tires and elastic rods was associated with a shorter hospital stay, which allowed for accelerated rehabilitation, reduced financial costs, and reduced the risk of complications. These results emphasized the importance of an individual approach to choosing a treatment method that considers not only clinical but also economic and social aspects to achieve optimal results.



Figure 2. Ropes used for manual fixation.  
Source: [28]

Diametaphyseal fractures of the forearm are difficult to treat due to the transient nature of the injury zone, where standard stabilization methods are less effective. In a study [29], which included 132 children with diametaphyseal forearm fractures, an analysis was

conducted on the results of various types of stabilization, including ESIN, K-wire fixation, and open reduction with plate osteosynthesis. Complications and the need for repeated intervention were comparable both with conservative treatment and with surgical interventions. Repeated fragment displacement was the most frequent complication requiring intervention, observed in 13 out of 15 patients. None of the complications resulted in permanent injuries. The exposure time of X-ray radiation was lower with conservative treatment compared to surgical methods, but the differences between ESIN and K-wire fixation were minimal.

Long-term observation of treatment for forearm fractures in adolescents using plate fixation confirmed the effectiveness of the method in achieving bone fusion and restoring preoperative activity in the majority of patients [30]. However, a significant number of patients retained residual symptoms such as pain and discomfort, indicating a potential impact on quality of life in the long term. The presence of complications in 12% of cases, including infection and compartment syndrome, emphasized the need for careful observation and timely treatment in the postoperative period. The removal of equipment in one-third of patients reflected the importance of assessing the need for repeated interventions when planning treatment. Despite its high effectiveness, plate fixation is associated with the risk of long-term symptoms, which requires informing patients and their families about possible consequences to improve the quality of medical care.

In the clinical case [31] a rare case of complication was described in a 26-year-old man who underwent open repositioning and internal fixation of both forearm bones at the age of 13 after an injury. After 13 years, the patient sought medical attention complaining of pain, soft tissue erosion, and the migration of the fixing plate. These complications occurred due to bone growth, in which the plate shifted proximal, resulting in pressure on the skin and its damage. The patient refused to remove the equipment at the age of 17, but subsequently developed inflammation and the threat of exposing the metal. At the age of 26, the patient sought medical assistance again and underwent surgery to remove the plate, which led to the elimination of pain and improved mobility.

The effectiveness of single-bone and two-bone plate fixation in 50 children (9 to 15 years old) with unstable fractures of both forearm bones was compared by a group of scientists in the work [32]. All 50 participants achieved fracture healing, and the forearm range of motion was restored in the majority of patients. The average repeated angular displacement was higher in the group with one bone fixation (1) (5.36°), whereas in the group with both bones fixation (2), repeated changes in the angular position of bone fragments were not observed. The time to fusion was similar in both groups, with no significant differences in functional indicators or pain levels. Group 1 showed significantly shorter surgical time, but had a higher risk of repeated angular displacement.

In a randomized controlled study [33], within 12 weeks after transcutaneous fixation of bones with forearm bone fractures, 16 skeletally immature patients were observed, divided into two groups: Group 1 received fixation of only the radial bone, and Group 2 - fixation of both bones. The results showed that fixing both bones increased fluoroscopy time ( $p = 0.011$ ) and surgery duration ( $p = 0.014$ ). However, this group showed a significant decrease in postoperative pain ( $p < 0.001$ ) and returned to studies faster than group 1 ( $p < 0.001$ ).

A clinical case of Folkman's contracture treatment following an epigastric fracture of the humerus confirmed the importance of timely identification and correction of complications associated with nerve compression [34]. Comprehensive treatment, including intensive physiotherapy, psychological support, and surgical intervention, demonstrated effectiveness in improving arm function, reducing disability, and restoring motor activity. Despite the positive result, the presence of residual impairments in fine motor skills emphasized the need for long-term observation and rehabilitation to minimize functional limitations. This case illustrated the importance of an individualized approach and multidisciplinary interaction in the treatment of Folkman's contractures in children, as well as the timely identification and elimination of factors contributing to the development of this condition.

Thus, the most effective methods for treating diaphyseal forearm fractures in children remain flexible intra-medullary nails (ESIN) and plate fixation, the choice of which depends on the patient's age, fracture nature, and degree of displacement. The main difficulties are associated with the risk of repeated displacements, the need for repeated interventions, and possible long-term symptoms such as pain and discomfort. For adolescents with limited growth potential, surgical treatment is preferred, while for young children, closed repositioning with immobilization is often sufficient. Combined methods, such as hybrid fixation, minimize surgical trauma, accelerate recovery, and ensure reliable functional results. Further research is necessary to develop treatment standards for diaphyseal fractures and to optimize methods depending on age and the degree of skeletal maturity.

#### ***Conservative treatment of forearm deformities in children***

Brachial fractures in children are among the most common injuries requiring treatment, necessitating the selection of optimal treatment methods that account for the characteristics of the growing organism, the risk of complications, and the need to preserve limb functionality. Many researchers have focused on comparing various approaches to immobilization and fixation to reduce displacement risks and accelerate recovery. Despite a significant volume of research, universal approaches have not yet been defined, especially in cases of complex fractures. This requires

further analysis of the effectiveness of existing methods, their advantages, limitations, and application depending on the patient's age and the nature of the injury.

In the scientific work [35], various radiological indices were evaluated to predict the movement of distal forearm fractures in 124 children (5-18 years old) treated with plaster casts. Patients with fractures of both forearm bones had a higher risk of displacement compared to patients with fractures of only the radial bone. The relationship between the gap index and displacement was confirmed in both the rear and side projections. In radial bone fractures, a high plaster cast index was also associated with increased displacement. At the same time, the three-point index and the second angle of the metacarpus did not show a connection with displacements. Thus, the proper shape and density of the plaster cast can reduce the risk of displacement.

A protocol for a randomized controlled trial to compare two approaches to treating distal radius torus fractures in children (aged 4 to 15) was published in [36]. Participants were randomly assigned to either a soft bandage with immediate discharge or rigid immobilization with further observation. The primary objective was to assess pain using the Wong-Baker FACES scale three days after randomization. Additionally, limb function, quality of life, resource utilization, and complications after three and six weeks were studied. Data were collected using electronic questionnaires filled out by participants and their parents. This study aimed to establish the equivalence of soft dressings and rigid immobilization in treating fractures, which could optimize the approach to their treatment.

The influence of various limb immobilization positions in the conservative treatment of distal radial fractures (DRF) on complication frequency and functional outcomes was studied in a systematic review of 786 patients [37]. Immobilization of the wrist in the extended position led to an improvement in both functional and radiographic results, reducing the risk of complications such as pain and the need for repeated correction or surgery. Comparing forearm positions (pronation or supination) yielded contradictory results. Meta-analysis did not reveal statistically significant differences in the indicators of contraction loss or the need for re-casting of the orthosis. Thus, extending the wrist during immobilization is preferable for improving DRF treatment results, while the ideal position of the forearm remains unclear.

In another systematic review and meta-analysis [38], scientists studied the effectiveness of immobilization below or above the elbow in the conservative treatment of distal radial fractures. The analysis included ten randomized controlled trials involving 909 patients. In the short term, there was no significant difference in the indicators of arm, shoulder, and hand disability between lower and higher arm immobilization (difference 4.99 lower, 95% CI: from 10.45 lower to 0.46 higher). In the long term, a small difference was identified in favor of lower arm immobilization (difference 0.83 lower, 95% CI: from

1.64 lower to 0.03 lower), but this difference was clinically irrelevant. There were also no significant differences in the indicators of secondary outcomes, such as X-ray results and pain assessment.

The meta-analysis [39] analyzed the results of conservative treatment for distal radius fractures using short (SA) and long (LA) arm immobilization in 9 randomized controlled trials involving 983 patients. There were no significant differences between the SA and LA groups in radiographic data, the need for repeated interventions, or functional indicators. This means that short immobilization is a safe option, providing similar results compared to long-term immobilization, but with lower risks of complications such as mobility limitations and the development of immobilization syndrome. Thus, the benefits of short immobilization may outweigh the theoretical risks associated with limiting forearm rotation, making this method preferable for conservative treatment.

In this scientific work [40], the functional and radiological results of treatment for forearm fractures in 30 children (under 14 years of age) were evaluated using closed reduction and plastering in the extended position of the elbow. Non-severe fractures included both the elbow and radial bones, or one of them at a medium level. A significant reduction in angular deformation was established after surgery: the curvature of the radial bone decreased from  $22.7^\circ$  to  $0.7^\circ$  in the anterior-posterior direction and from  $24.2^\circ$  to  $3.2^\circ$  in the lateral direction. Similar improvements were observed in the ulna. Two weeks after surgery, 83.3% of patients retained undamaged plaster, while 16.7% had weakened plaster. Most patients demonstrated good rotation of movements three and six weeks after treatment. Plaster casting in an extended elbow position is a more effective method for treating forearm fractures in children than traditional plaster casting in a bent position.

In the study [41], the effectiveness of two immobilization methods - long-arm plaster (LAC) and single sugar splint (SSTS) - was compared for the treatment of distal forearm fractures in 186 children (aged 4 to 15). Statistically significant differences were observed only in sagittal curvatures during the first and second weeks (the LAC group showed better results). Additionally, seven cases of repeated interventions were recorded in this group, while three were in the SSTS group. However, this difference was not statistically significant. Both immobilization methods - SSTS and LAC - were effective and comparable in terms of radiological results and the frequency of repeated interventions, making both techniques suitable for treating distal forearm fractures in children.

Thus, the conservative treatment of distal forearm fractures in children included a variety of methods, each with its own advantages and limitations. The most effective method was casting with elbow extension, which improved functional and radiographic results, reducing the risk of complications and the need for repeated interventions. Short immobilization is associated with lower risks but has similar results to long immobilization, making it a preferred option in

most cases. The use of soft and hard dressings for elbow and wrist fractures also demonstrated equivalent results, but preference should be given to soft dressings to optimize rehabilitation and reduce pain. Further study of the ideal position of the forearm and the possible long-term effects of various immobilization methods is necessary to select the most appropriate approach in each clinical case.

#### *Treatment of osteomyelitis and forearm pseudoarthrosis in children*

The reconstruction of segmental defects and the treatment of congenital forearm pseudoarthrosis in children represent complex tasks that require the use of highly effective methods. The rarity of pathologies and the complexity of their treatment necessitate an individual approach to each case. Modern methods, such as free vascularized femoral bone transplantation and the FIBBAG technique, are demonstrating significant success, but issues regarding the optimization of functional outcomes and the minimization of complications remain unresolved. The choice of approach depends on the nature of the pathology, the patient's age, and associated factors, emphasizing the importance of further research to create treatment algorithms that take these aspects into account.

The results of treating segmental bone defects in the forearm after osteomyelitis in 8 children (3 to 12 years old) using a fibular intra-medullary bone grafting and additional grafting (FIBBAG) technique were analyzed in the study [42]. Successful fusion was observed in all patients, and the average defect size was 5.86 cm. The fusion time ranged from 2 to 14 months, with additional transplant procedures in two patients. There were no recurrences of infection, nor were there any signs of fatigue or damage to the graft. However, positive elbow oscillations were noted in three patients, and the shortening of the forearm remained the primary cosmetic limitation. Overall, the FIBBAG methodology has demonstrated high efficiency and a low level of complications in the reconstruction of post-osteomyelic defects in children, offering a viable option for complex cases.

In a scientific study [43], a rare congenital pseudoarthrosis of the elbow bone associated with neurofibromatosis type 1 (NF1) was described in a 12-year-old boy. After a minor injury, the patient developed a non-fusion of the elbow bone. Treatment included microsurgical reconstruction using a vascularized growth plate. More than seven years after the first surgery, the patient maintained a painless condition and full forearm functionality, despite the need for secondary correction of the radial flexure. Additionally, this study [43] analyzed nine publications describing 20 cases of congenital non-fusion of the ulna. In most cases, the use of a vascularized growth plate yielded good results, ensuring bone fusion after primary surgery. Complications requiring repeated interventions were observed in nine cases. The advantage of this method lies in its ability to improve bone fusion and growth, which is especially important for congenital

pathologies. Compared to other methods, such as internal fixation or non-vascularized transplants, the vascularized growth plate showed better long-term results, although additional corrective surgeries may be required in some cases.

Another systematic review [44] was aimed at developing a treatment algorithm for pseudoarthrosis with type 1 neurofibromatosis. 47 studies were analyzed, including 84 cases, to determine the best surgical methods. The procedure with one bone demonstrated the highest level of fusion (92%), but led to a loss of rotational movements of the forearm. Free vascularized femoral bone transplantation showed a high level of fusion (87%) and provided good functional results while maintaining elbow flexion and forearm rotation. Other treatment methods were less successful. The authors recommended using free vascular transplantation as the primary treatment method, and single-bone surgery as a rescue procedure.

Congenital forearm pseudoarthrosis (CPF) is a rare condition often associated with neurofibromatosis (NF) [45]. Achieving bone fusion is significantly more difficult in this disease. Traditional treatment methods, such as plaster casting, internal fixation with or without bone grafting, and electrical stimulation, often prove ineffective. A more successful approach was the use of a free vascularized fibular flap (FVF), which allows for achieving fusion with higher efficiency. This study [45] described three cases of CPF treatment using FVF in patients aged 15 months to 9 years. In two cases, intramedullary wires were used for stabilization, while in the third case, compression plates were used. In all cases, bone fusion was observed an average of 11 months after surgery, and in one case, repeated intervention was required. Vascularized fibular flap is recognized as the preferred treatment method for CPF, as it ensures high adhesion rates and good functional results. However, the surgical intervention is technically complex, and complications may arise that require additional operations.

Thus, the FIBBAG methodology demonstrates high efficacy in treating post-osteomyelic defects due to reliable fusion and a low level of complications, although cosmetic limitations such as forearm shortening remain a problem. Vascularized transplants, particularly those of the fibula, have shown the best results in congenital pathologies, including neurofibromatosis, ensuring both bone fusion and improved bone growth, but require high technical skill of the surgeon and sometimes repeated interventions. The procedure with one bone is effective for complex cases, although it restricts forearm movements, making it a "salvation" option. Traditional methods, such as plaster casting or electrical stimulation, are significantly inferior in efficiency. Further research is required to optimize treatment algorithms, especially regarding the selection of methods for various age groups and the severity of the pathology.

This scientific work examined 11 studies with a high level of evidence, which included systematic reviews, meta-analyses, randomized and retrospective

articles. Additionally, 17 studies with a medium level of evidence were included, which included methodological descriptions, comparative research, and retrospective articles. Scientific works with a low level of evidence were reviewed in the amount of 9 publications, which were represented by rare clinical cases. The relevance of the articles was represented by 30 publications with a high level of relevance and 7 articles with moderate relevance. The subject matter of all studies corresponded to the topic studied in this scientific article.

### Conclusions

The study established that the treatment of forearm fractures in children and adolescents requires an individual approach depending on age, fracture type, and bone growth status. In younger age, up to 10 years, effective conservative treatment with closed reduction and gypsum immobilization is possible, even with minor angulation or displacement. However, in adolescence, when the possibilities for bone remodeling are limited, surgical methods become preferable.

Flexible intramedullary nails and plates have comparable results, but FIN is used more frequently due to minimal invasiveness, fewer complications, and ease of removal. Plates are preferable in complex cases and in skeletally mature adolescents. Complications occur rarely and are associated with incorrect fixation techniques or large implants. Retrograde nail insertion may pose a risk of nerve damage. Intramedullary nails have shown high efficacy with minimal complications, making them preferred for the majority of adolescents with forearm fractures.

Fixation with plates showed good results in bone fusion and function restoration, but long-term complications such as pain, discomfort, and the need to remove the plates were frequent. Cases of metal structure migration in growing patients were also noted, requiring repeated surgeries. Hybrid methods, such as using elastic nails in combination with plates, demonstrated shorter surgical time and lower trauma, which accelerated healing and reduced the risk of complications. In cases of unstable fractures of both forearm bones, transcutaneous fixation of both bones improved results and reduced postoperative pain, emphasizing the need for an individual approach to each patient.

A plaster cast with the correct shape and density (plaster and cast indices) reduced the risk of displacement, especially in patients with fractures of both forearm bones. In the case of conservative treatment, short immobilization was comparable to long one in terms of radiological indicators, although there were no statistically significant differences in complications. Immobilization in the extended position of the wrist demonstrated better functional and radiographic results, which reduced the frequency of repeated interventions. Giving below the elbow showed minimal advantages over immobilization above the elbow, allowing both approaches to be considered acceptable. Short immobilization in the treatment of

distal fractures in children has fewer complications and similar results compared to long immobilization, making it a preferred option.

In the treatment of segmental malformations of the forearm after osteomyelitis and pseudoarthrosis in children, the effectiveness of using fibular grafts and vascularized grafts was demonstrated. The FIBBAG method, which utilizes a calcaneal graft, demonstrated successful bone fusion in all patients with low complications, although in some cases, a shortening of the forearm was observed. Treatment of congenital pseudoarthrosis associated with neurofibromatosis has also proven successful using vascularized femoral bone transplantation. This method ensured good fusion and preservation of forearm functionality, although additional corrective surgeries were sometimes required. Free vascularized transplantation has shown better results compared to other methods, allowing it to be recommended as the primary approach.

The limitation of the study was the lack of data on the use of conservative methods for treating fractures and dysplastic processes of the forearm in children. Further research must be directed toward finding optimal solutions to reduce the number of complications and side effects in the treatment of forearm bone deformities in children.

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