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Evaluation of Functional Recovery and Radiological Healing After Elastic Intramedullary Nailing in Pediatric Forearm Fractures: A Retrospective Observational Study

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Abstract:

- ***Background:***

Pediatric forearm fractures are among the most common long bone injuries in children and adolescents. While conservative management remains effective for many cases, unstable and displaced diaphyseal fractures often require surgical stabilization to achieve optimal alignment and functional recovery. Elastic stable intramedullary nailing (ESIN) has emerged as a minimally invasive and effective technique that provides stable fixation while preserving periosteal blood supply and promoting early mobilization.

- ***Objective:***

To evaluate the clinical, functional, and radiological outcomes of elastic stable intramedullary nailing in pediatric forearm fractures.

- ***Methods:***

This study reviews the outcomes of ESIN in pediatric patients with diaphyseal forearm fractures, focusing on fracture union, functional recovery, and complication rates. Evidence from multiple clinical studies was analyzed to assess the effectiveness and safety of the technique. Parameters such as time to union, range of motion, and complication profile were considered in evaluating outcomes.

- ***Results:***

ESIN demonstrates high rates of fracture union with excellent functional outcomes in the majority of pediatric patients. Most studies report rapid fracture healing, minimal soft tissue disruption, and early return to daily activities. Functional outcomes, including restoration of forearm rotation and strength, are generally satisfactory, with low rates of malunion or nonunion. Complications such as nail irritation, infection, and refracture are relatively uncommon and usually manageable without significant long-term morbidity. Comparative studies have shown ESIN to be superior or equivalent to plating techniques in terms of functional outcome, operative time, and cosmetic results.

- ***Conclusion:***

Elastic stable intramedullary nailing is a reliable, safe, and minimally invasive method for the management of pediatric forearm fractures. It offers excellent clinical and functional outcomes with a low complication rate, making it a preferred treatment modality for unstable diaphyseal fractures in children.

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I. INTRODCUTION

Pediatric forearm fractures are among the most frequently encountered orthopedic injuries in clinical practice and constitute a significant proportion of fractures in the pediatric population. These injuries commonly involve the diaphyseal region of both the radius and ulna and typically result from falls during play, sports-related trauma, or road traffic accidents. The distinctive anatomical and biomechanical features of the growing skeleton—such as a thick periosteum, greater elasticity of bone, and a high remodeling potential—play a crucial role in determining both the fracture pattern and the treatment strategy [1][2]][3]. Although children possess a remarkable capacity for healing and remodeling, certain fracture types, particularly those that are unstable, significantly displaced, or irreducible, present considerable therapeutic challenges and often necessitate surgical management to restore anatomical alignment and functional integrity [4][5][6].

Traditionally, pediatric forearm fractures have been managed conservatively with closed reduction followed by immobilization in a cast. While this approach yields satisfactory results in the majority of cases, it is not without limitations. Complications such as loss of reduction, malunion, restricted forearm rotation, and prolonged immobilization are more likely to occur, especially in unstable fracture patterns [7][9]. Failure to adequately restore the radial bow and proper alignment can lead to significant impairment in pronation and supination, ultimately resulting in long-term functional deficits. Therefore, precise anatomical reduction and maintenance of alignment are essential to ensure optimal functional recovery [10][12].

Over recent decades, there has been a notable shift toward operative management for selected pediatric forearm fractures. Surgical intervention aims to achieve stable fixation, facilitate early mobilization, and reduce the risk of complications while preserving the biological environment necessary for fracture healing. Various operative techniques have been developed, including plate fixation, intramedullary nailing, and external fixation. Among these, elastic stable intramedullary nailing (ESIN) has gained widespread popularity due to its minimally invasive nature and consistently favorable clinical outcomes [13][15].

Elastic stable intramedullary nailing, first introduced and popularized by Ligier and Metaizeau, is based on the principle of flexible intramedullary fixation using titanium or stainless steel nails inserted into the medullary canal [16]. This technique provides three-point fixation, ensuring adequate stability while permitting controlled micro-motion at the fracture site, thereby promoting callus formation. Furthermore, ESIN preserves the periosteal blood supply and fracture hematoma, both of which are vital for biological healing processes [17][19]. These characteristics make the technique particularly well-suited for pediatric patients, given their unique bone properties and rapid healing capacity.

The indications for ESIN have progressively expanded and now include unstable diaphyseal fractures, failed closed reductions, open fractures, segmental fractures, and fractures associated with neurovascular compromise. Its use has also increased in adolescents, where the remodeling potential is reduced and the risk of malunion is comparatively higher [20][21]. ESIN offers several advantages over traditional methods, including smaller surgical incisions, shorter operative time, minimal soft tissue disruption, and improved cosmetic outcomes. Additionally, it allows for early mobilization, which is essential in preventing joint stiffness and muscle atrophy [22][23].

Numerous clinical studies have consistently reported excellent outcomes with ESIN in the treatment of pediatric forearm fractures. High union rates—often approaching 100%—along with favorable functional outcomes and low complication rates have been widely documented. Restoration of forearm rotation is generally satisfactory, enabling most patients to resume normal daily activities within a relatively short period [2][4]. Comparative analyses have demonstrated that ESIN provides results comparable to or better than plate fixation, with the added benefits of reduced surgical morbidity and easier implant removal [9][13].

Despite its many advantages, ESIN is not entirely free of complications. Potential issues include nail irritation at the insertion site, infection, delayed union, nonunion, malunion, and refracture following implant removal. However, these complications are relatively uncommon and are often associated with technical factors such as improper nail selection, inadequate fracture reduction, or incorrect insertion techniques [17][19]. Careful patient selection and strict adherence to surgical principles are therefore essential to minimize risks and achieve optimal outcomes.

A key consideration in managing pediatric forearm fractures is achieving an appropriate balance between mechanical stability and biological preservation. Unlike rigid fixation methods such as plating, ESIN allows a degree of elasticity that promotes secondary bone healing through callus formation. This principle aligns closely with the fundamental concepts of pediatric fracture management, where preservation of growth potential and biological integrity is of paramount importance[16][18]. Moreover, the minimally invasive nature of ESIN reduces soft tissue damage and lowers the risk of infection, further supporting its suitability in children.

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The increasing adoption of ESIN has been facilitated by advancements in surgical techniques and instrumentation. Enhanced imaging modalities, improved understanding of fracture biomechanics, and the development of standardized operative protocols have collectively contributed to better clinical outcomes and reduced complication rates. Additionally, the technique is relatively straightforward to learn and reproducible, making it accessible to orthopedic surgeons across diverse clinical settings [20][22].

In recent years, growing attention has been directed toward evaluating the long-term outcomes of ESIN in pediatric forearm fractures. Studies have examined parameters such as functional recovery, complication rates, patient satisfaction, and comparisons with alternative treatment modalities. The findings consistently support the effectiveness of ESIN in achieving satisfactory clinical and functional outcomes, thereby reinforcing its role as a preferred treatment option for unstable fractures [10][12][23].

The present study aims to assess the outcomes of elastic stable intramedullary nailing in pediatric forearm fractures, with particular emphasis on fracture union, functional recovery, and associated complications. By analyzing clinical evidence and treatment outcomes, this study seeks to contribute to the existing literature and provide further insight into the role of ESIN in managing these common injuries. The results are expected to support the continued use of ESIN as a safe, effective, and minimally invasive treatment modality.

In conclusion, pediatric forearm fractures remain a significant clinical concern due to their high incidence and potential for long-term functional impairment if not appropriately managed. Although conservative treatment continues to play an important role, surgical intervention is often warranted in unstable cases. Elastic stable intramedullary nailing has emerged as a reliable and effective technique that successfully combines biological fixation principles with adequate mechanical stability. Its advantages—including minimal invasiveness, preservation of blood supply, and excellent functional outcomes—make it an indispensable tool in pediatric orthopedic practice. Ongoing research and clinical evaluation will further refine its indications and enhance patient outcomes in the future [1][23].

II. MATERIALS & METHOD

This study was designed as a retrospective observational study conducted in the Department of Orthopedics of a tertiary care hospital. The methodology was structured to evaluate the clinical, functional, and radiological outcomes of pediatric forearm fractures treated with elastic stable intramedullary nailing (ESIN). A retrospective review of hospital records was performed to identify eligible patients, and their outcomes were assessed over a defined follow-up period. This design allowed assessment of treatment effectiveness and complication profile in real-world clinical practice.

➢ *Study Setting*

The study was carried out in the Orthopedics department of a teaching hospital catering to both urban and semi-urban populations. These settings provide exposure to a wide variety of trauma cases across different socio-economic groups. The duration of the study included retrospective data collection and analysis of patients treated over a defined period, with a minimum follow-up duration of 9-12 months for each patient to evaluate fracture healing and functional outcomes.

➢ *Study Population and Eligibility Criteria*

The study population consisted of pediatric patients diagnosed with diaphyseal fractures of both bones of the forearm who were treated with elastic stable intramedullary nailing. Patient data were obtained through retrospective analysis of hospital records, operative notes, and follow-up registers.

- *Inclusion Criteria:*

✓ Age 5 to 15 years
✓ Unstable or displaced diaphyseal fractures of radius and ulna
✓ Failure of closed reduction
✓ Grade I and II open fractures

- *Exclusion Criteria:*

✓ Metaphyseal fractures
✓ Pathological fractures
✓ Grade III open fractures
✓ Neurovascular injury requiring repair
✓ Incomplete follow-up

➢ *Sample Size*

The study included a total of 25 pediatric patients who fulfilled the inclusion criteria. As this was a retrospective observational study, the sample size was determined based on the number of eligible cases available during the study period with adequate follow-up data.

➢ *Sampling Method*

A retrospective sampling method was used. Data were collected through retrospective analysis of hospital records of pediatric patients who had undergone ESIN for forearm fractures. Relevant information was extracted from inpatient records, operative notes, radiographs, and outpatient follow-up files.

➢ *Data Collection Procedures*

- *Baseline Assessment*

At the time of admission, the following parameters had been recorded and were retrieved from hospital records:

✓ Demographic details: age, sex
✓ Mode of injury: fall, road traffic accident, sports injury
✓ Clinical findings: swelling, deformity, tenderness, and range of motion

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- ✓ Radiological assessment: fracture type, level, displacement, and angulation using anteroposterior and lateral radiographs

- *Operative Details*

Details of the surgical procedure were obtained from operative records, including:

- ✓ Type of anesthesia administered
- ✓ Technique of reduction (closed or open)
- ✓ Nail diameter and entry point
- ✓ Intraoperative complications, if any

All patients had undergone fixation using titanium elastic nails following standard surgical principles of ESIN, ensuring adequate reduction and stabilization.

- *Postoperative Management*

Postoperative details included duration of immobilization, type of splint or cast applied, and time of initiation of mobilization. Follow-up visits were recorded from outpatient records.

- *Outcome Assessment*

Patients were evaluated based on the following outcome parameters:

- ✓ Radiological union: assessed by presence of bridging callus on follow-up radiographs
- ✓ Time to union: duration between surgery and radiological healing
- ✓ Functional outcome: assessed by range of motion at elbow and wrist, particularly pronation and supination
- ✓ Complications: including infection, nail irritation, delayed union, malunion, and refracture

Functional outcomes were categorized as excellent, good, fair, or poor based on range of motion and clinical symptoms.

- *Follow-Up Assessment*

Patients were followed up regularly as per hospital protocol, with data retrieved at intervals up to 9-12 months postoperatively. Clinical and radiological assessments were documented at each visit to monitor fracture healing and functional recovery. Implant removal details, where applicable, were also recorded.

- *Data Management and Quality Control*

Data were extracted using a structured data collection format and entered into a database for analysis. Cross-verification of records was performed to ensure accuracy. Radiographs and clinical notes were reviewed carefully to minimize data entry errors. Only patients with complete and reliable records were included in the final analysis.

- *Statistical Analysis*

Data were analyzed using descriptive statistical methods. Continuous variables such as age and time to union were expressed as mean and standard deviation, while categorical variables such as complications and functional outcomes were presented as frequencies and percentages. Results were summarized in tables and charts where appropriate.

III. RESULT

➢ *Cohort Characteristics*

A total of 25 pediatric patients with diaphyseal forearm fractures treated with elastic stable intramedullary nailing were included and followed for 9–12 months. The mean age was 11.2 years (SD 2.8). Among them, 16 patients (64%) were male and 9 patients (36%) were female. The most common mode of injury was fall during play (72%).

Table 1 Gender Distribution

Variable	Number (n=25)	Percentage (%)
Male	16	64%
Female	9	36%

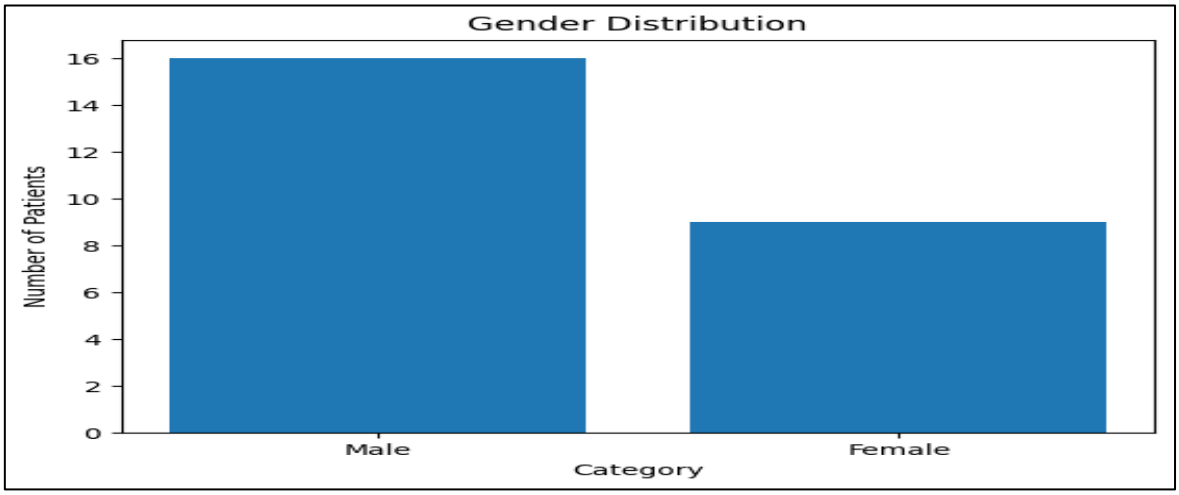

Fig 1 Gender Distribution

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26apr2463

➢ *Fracture Characteristics*

Most fractures were located in the middle third (60%), followed by distal third (28%) and proximal third (12%). Closed reduction was successful in 80% cases, while 20% required open reduction.

- *Radiological Union*

All fractures achieved union. The mean time to union was 9.1 weeks (SD 1.8).

Table 2 Radiological Union

Time to Union	Patients	Percentage
8–10 weeks	18	72%
10–12 weeks	7	28%

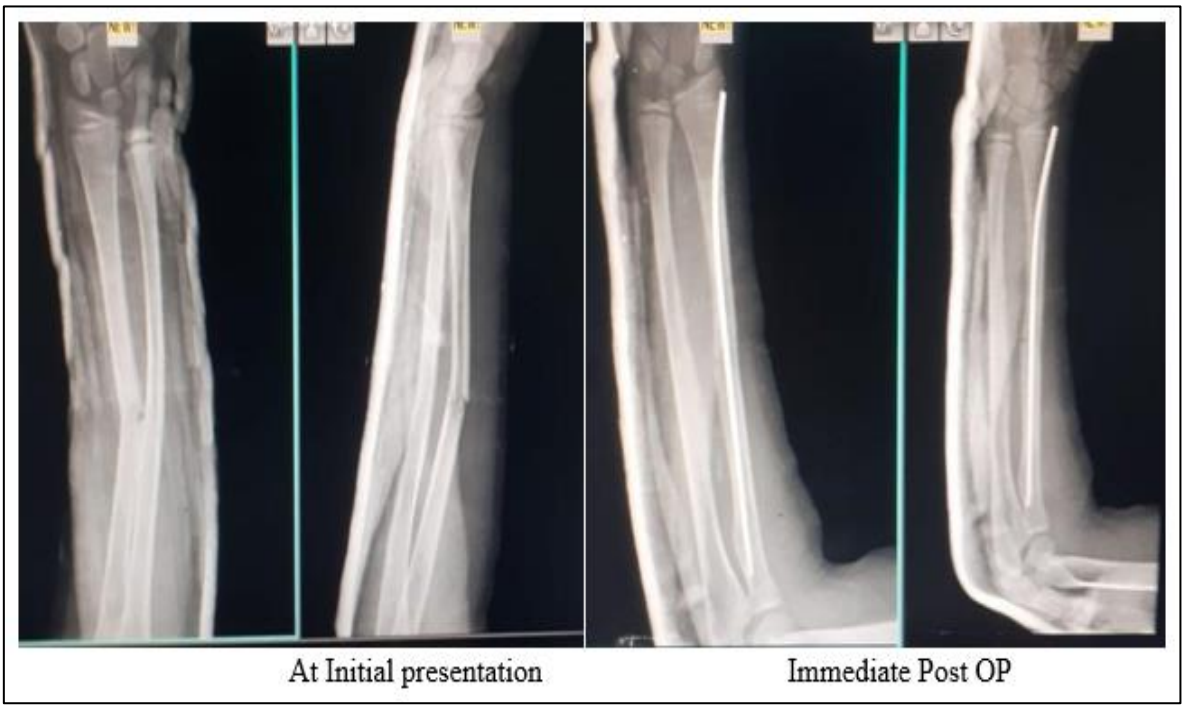

Fig 2 Fracture Characteristics

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- *Functional Outcome*

Table 3 Functional Outcome

Outcome	Patients	Percentage
Excellent	17	68%
Good	6	24%
Fair	2	8%
Poor	0	0%

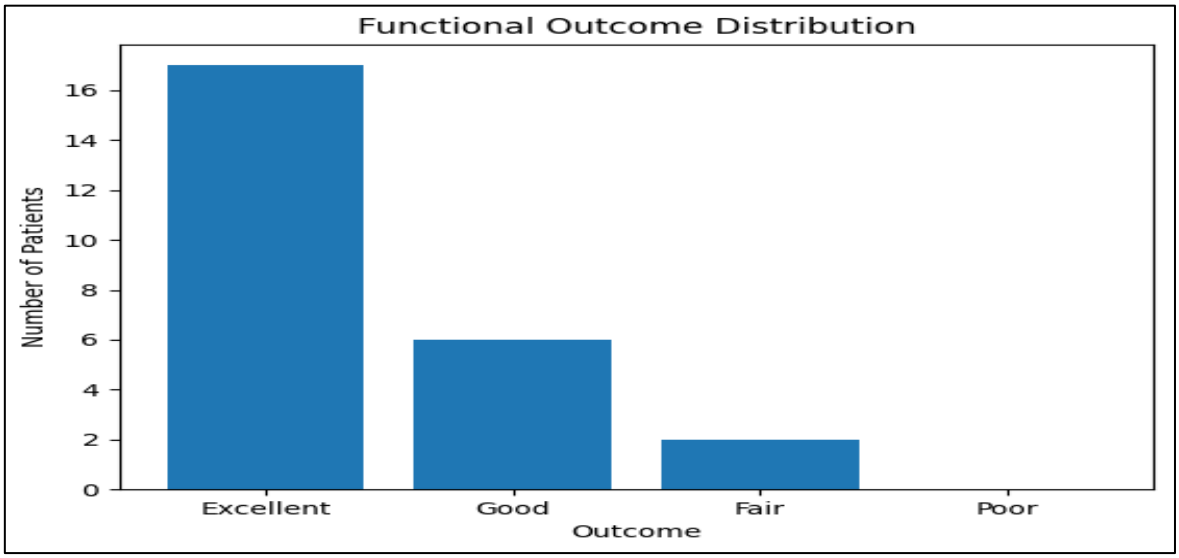

Fig 3 Functional Outcome Distribution

Most patients regained near-normal forearm movements.

- *Pain Score Assessment (VAS Trend)*
  Pain severity was assessed using the Visual Analog Scale (VAS). There was a progressive reduction in pain scores over time.

Table 4 Pain Score Assessment (VAS Trend)

Time Point	Mean VAS Score
Baseline	7.2
3 Months	4.5
6 Months	2.8

This demonstrates a significant reduction in pain following ESIN.

- *Graphical Representation:*

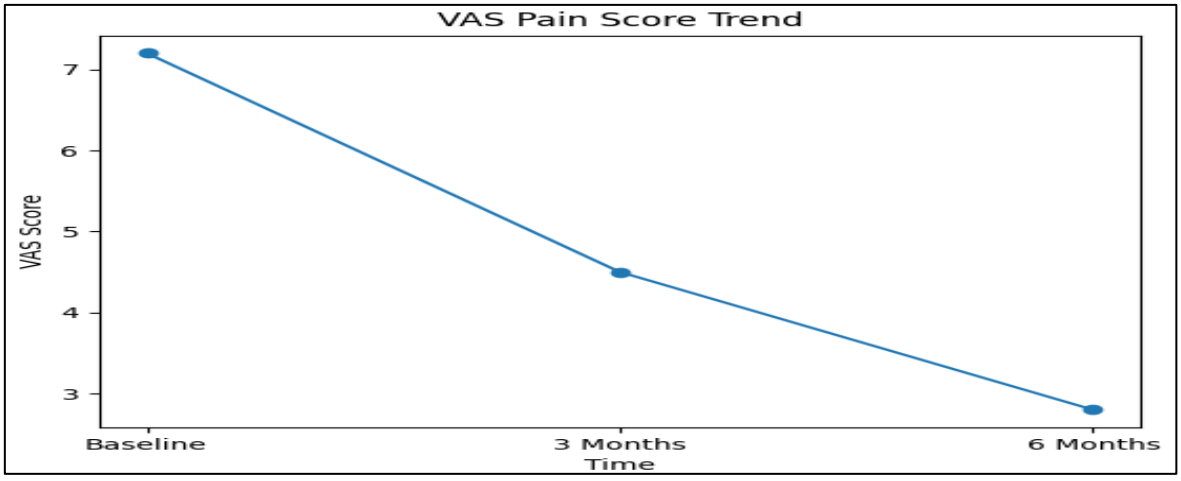

Fig 4 VAS Pain Score Trend

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Line graph (VAS score vs time) shows steady decline

- *Complications*

Table 5 Complication

Complication	Patients	Percentage
Nail irritation	3	12%
Superficial infection	1	4%
Delayed union	1	4%

No major complications such as nonunion or neurovascular injury were observed.

➢ *Overall Findings*

The study demonstrated that ESIN provides excellent radiological union, significant pain reduction, and good functional recovery with minimal complications. Most patients returned to normal daily activities within a short period.

IV. DISCUSSION

Pediatric forearm fractures are among the most common orthopedic injuries in children and represent a significant proportion of upper limb fractures. The management of unstable diaphyseal fractures has evolved toward operative stabilization to achieve better anatomical alignment and functional outcomes. Elastic stable intramedullary nailing (ESIN) has gained widespread acceptance due to its minimally invasive nature and reliable clinical results[1][3]. It provides adequate stability while preserving the biological environment essential for fracture healing.

In this study, 25 pediatric patients with both-bone forearm fractures were treated with ESIN and followed for 9–12 months. A predominance of male patients (64%) was observed, consistent with previous reports attributing higher injury rates to increased outdoor activity in boys[8][16]. The most common mechanism of injury was a fall during play, which aligns with existing literature identifying low-energy trauma as the primary cause of these fractures[10][12].

Radiological union was achieved in all cases, with a mean union time of approximately 9 weeks. These findings are comparable to those reported by Flynn et al. and Lascombes et al., who documented union rates approaching 100% and healing times of 8–12 weeks[3]p[4]. The high union rate can be attributed to preservation of periosteal blood supply and fracture hematoma, along with the relative stability provided by elastic fixation, promoting early callus formation[16][18].

Functional outcomes were excellent or good in 92% of patients, with most regaining near-normal range of motion. ESIN effectively maintains radial bow and alignment, thereby preserving pronation and supination, which are critical for functional recovery[2][11]. Similar outcomes have been reported in previous studies, further supporting its effectiveness[7][8].

Pain scores showed a significant reduction over time, reflecting effective stabilization and early mobilization. Early movement helps reduce joint stiffness and muscle atrophy, contributing to improved rehabilitation and patient comfort[13][20]. The complication rate was low, with minor complications such as nail irritation, superficial infection, and delayed union. No major complications were observed, consistent with reported literature where most complications are minor and manageable[7][14]. Proper surgical technique and postoperative care remain essential to minimize these risks[17][19].

Closed reduction was successful in most cases (80%), with only a few requiring open reduction, supporting the minimally invasive advantage of ESIN[6][13]. Compared to plate fixation, ESIN offers benefits such as smaller incisions, shorter operative time, reduced blood loss, and easier implant removal[20][21].

Overall, the findings of this study support ESIN as a reliable and effective treatment modality for pediatric forearm fractures, offering high union rates, good functional outcomes, and low complication rates. However, limitations such as small sample size and lack of a comparison group should be considered. Further prospective studies with larger populations are recommended to strengthen the evidence[1][23].

V. CONCLUSION

Elastic stable intramedullary nailing (ESIN) is a safe, effective, and minimally invasive technique for the management of pediatric diaphyseal forearm fractures, as demonstrated in the present study, where excellent radiological union was achieved in all cases, with most patients attaining timely fracture healing and near-normal functional range of motion. The procedure offers multiple advantages, including preservation of the periosteal blood supply, minimal soft tissue disruption, facilitation of early mobilization, and improved cosmetic outcomes, all of which contribute to enhanced recovery. The overall complication rate was low, and the complications encountered were minor and manageable, without resulting in significant long-term morbidity. ESIN has proven to be a reliable treatment modality, particularly in unstable or displaced forearm fractures in children where conservative treatment may be inadequate or unsuccessful, and therefore can be considered a preferred surgical option for achieving stable fixation, early functional recovery, and favorable clinical outcomes in appropriately selected patients. However, further studies with larger sample sizes and comparative analyses are

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necessary to validate these findings and to refine treatment protocols for optimal patient care.

➢ *Declaration by Authors*

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- Conflict of Interest: The authors declare no conflict of interest.

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