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Revolutionizing Pediatric Fracture Care: The Impact of Titanium Elastic Nails on Upper Limb Injuries in Children

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Abstract

Background: Pediatric fractures of the upper limb, particularly in the humerus and forearm, are common. They typically result from falls and road traffic accidents (RTAs) and require effective management to ensure proper healing and functional recovery. Recently, titanium elastic nails (TENS) have emerged as a viable treatment option for upper limb fractures in children, providing potential benefits compared to traditional casting and rigid plate fixation. The objective of this study was to assess the functional, clinical, and radiological outcomes of titanium elastic nails (TENS) in the treatment of humerus and forearm fractures in pediatric patients. Materials and Methods: This was a descriptive cross-sectional hospital-based study conducted at Atbara Police Hospital between April 2019 and November 2023, involving a total of three hundred and twenty-three pediatric patients with upper limb fractures of the humerus and/or the radius and ulna. The data were analyzed using the Statistical Package for the Social Sciences (SPSS) data analysis software, version 27. Results: This study involved a cohort of 323 pediatric patients who presented with upper limb fractures at Atbara Police Hospital. There were 272 male patients (84.2%) and 51 female patients (15.8%), resulting in a male-to-female ratio of 5.3:1. The majority of the patients were aged 6 to 10 years. All the

patients included in this study (323 patients) experienced excellent to good outcomes, with no poor outcomes recorded. There was a strong association between early presentation and higher rates of excellent outcomes. Additionally, forearm fractures are slightly more likely to achieve excellent outcomes than humeral fractures. Conclusion: This study revealed that the use of the titanium elastic nail (TENS) is the standard treatment modality for upper limb fractures in pediatric patients. The TENS has good functional, clinical, and radiological outcomes and is minimally invasive, with little scarring, a short operation time, and a low risk of complications. TENS also supports early mobilization, which is critical for preventing joint stiffness and muscle atrophy, leading to a faster return to normal activities.

Keywords

Titanium Elastic Nails (TENS), Pediatric Upper Limb Fractures, Humerus Fractures, Forearm Fractures, Functional Outcomes, Radiological Outcomes, Minimally Invasive Surgery, Early Mobilization

1. Introduction

Pediatric forearm fractures, also known as radius and ulna diaphyseal fractures, rank as the third most common fracture in the pediatric population, accounting for 13% - 40% of all pediatric fractures [1] [2]. The severity of these fractures ranges from minor deformities to noticeable displacement. Traditionally, these fractures are treated through nonoperative methods such as closed reduction and casting. However, there has recently been a shift toward more surgical interventions to enhance clinical results [3].

Treatment for these fractures is determined by factors such as the child's age, fracture type, and displacement. Considering the child's potential for growth, certain degrees of angulation may be acceptable based on age and remodeling ability. Long arm casts are still a suitable treatment for fractures within acceptable alignment parameters, with low risks of significant elbow stiffness. Surgical management is advised for fractures that cannot be adequately reduced through closed methods. Surgical options include rigid plate fixation and elastic intramedullary nails, which were first developed in the early 1980s by French surgeons in Nancy [4] [5]. The debate continues regarding which method yields better outcomes [6].

Humerus fractures are rare in children, constituting only 2% to 5.4% of all fractures. A small percentage of cases involve the humeral shaft, and surgical intervention may be necessary in certain cases, such as open fractures, bilateral fractures, or those associated with multiple injuries [7]. Flexible intramedullary nailing has gained popularity for managing unstable or open forearm fractures, despite recent reports of delayed healing in older children [8].

Elastic intramedullary nails are often used for treating adolescent long bone fractures. Compared to locking plates, elastic nails offer advantages such as mini-

mally invasive procedures, periosteum preservation, shorter hospital stays, and early mobility. However, their drawback lies in their stability immediately post-surgery, requiring a cast for approximately two weeks to ensure stability during the initial healing period. Numerous studies have demonstrated favorable outcomes and high union rates with the use of elastic nails [9].

Forearm fractures in children generally have a good prognosis due to the potential for bone remodeling; however, malunion remains a clinically important concern, particularly in diaphyseal fractures. Classic work by Christopher T. Price and colleagues demonstrated that residual angular deformities, even when considered acceptable, may lead to significant functional limitations, especially in forearm rotation. The degree of functional impairment depends on factors such as the child's age, fracture location, and the magnitude and direction of angulation. These findings highlight the importance of achieving optimal alignment during initial management to prevent long-term disability [10].

2. Materials and Methods

2.1. Study Design and Setting

This retrospective observational cohort study was conducted at Atbara Police Hospital, Sudan, between April 2019 and November 2023. The study evaluated pediatric patients presenting with upper limb fractures involving the humeral shaft or both bones of the forearm who were treated using titanium elastic nails (TENS).

2.2. Study Population

A total of 323 pediatric patients aged 15 years or younger who underwent TENS fixation for humeral or both-bone forearm fractures were included in the study.

2.2.1. Inclusion Criteria

- Children aged ≤ 15 years.
- Displaced or unstable diaphyseal fractures of the humerus, radius, and ulna.
- Fractures treated surgically using titanium elastic nails.
- Patients with a minimum follow-up period of six months.

2.2.2. Exclusion Criteria

- Undisplaced fractures managed conservatively.
- Metaphyseal or physeal fractures.
- Patients with incomplete medical records.
- Patients lost to follow-up before radiological union.

2.2.3. Indications for Surgical Fixation

Titanium elastic nailing was performed in cases of:

- Failure of closed reduction or inability to maintain reduction with casting.
- Significant displacement or angulation beyond acceptable pediatric limits.
- Unstable fracture patterns.

- Open fractures requiring surgical stabilization.
- Polytrauma cases requiring early mobilization.

Open fractures were classified according to the Gustilo-Anderson classification system.

2.3. Data Collection

Patient data were obtained from hospital medical records and operative registries. The following variables were recorded:

- Age and gender.
- Mechanism of injury.
- Time from injury to hospital presentation.
- Fracture type and location.
- Method of reduction (closed or open).
- Postoperative care.
- Complications.
- Functional outcomes.

2.4. Follow-Up Protocol

Patients were followed postoperatively at regular intervals, including:

- 2 weeks.
- 6 weeks.
- 6 months.

Additional visits were scheduled as necessary until clinical and radiological union was confirmed. Implant removal was performed once fracture healing had been achieved.

2.5. Outcome Assessment

Functional outcomes were evaluated using the Price *et al.* criteria, which classify results as excellent, good, fair, or poor based on forearm rotation and functional limitations.

Radiological union was defined as the presence of bridging callus across at least three cortices on orthogonal radiographs. Time to union was measured from the date of surgery to the first radiograph demonstrating union.

Malunion was defined as angulation greater than 10˚ or persistent rotational deformity affecting limb function.

2.6. Statistical Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 27. Categorical variables were summarized using frequencies and percentages. Associations between categorical variables were assessed using the Chi-square test or Fisher's exact test where appropriate. A P value < 0.05 was considered statistically significant.

Multivariable logistic regression analysis was performed to evaluate independ-

ent predictors of clinical outcome, including delayed presentation, open fractures, and prior consultation with bone setters.

2.7. Ethical Considerations

The study protocol was approved by the institutional ethics committee of Atbara Police Hospital. Written informed consent was obtained from the parents or legal guardians of all participating children, and assent was obtained from older children when appropriate.

3. Results

Three hundred twenty-three patients who had either humerus or both bone forearm fractures were treated using titanium elastic nails and were included in the study. Among them, 272 patients (84.2%) were male, and 51 patients (15.8%) were female. The largest group of patients fell within the 6 - 10 years age range, totaling 195 patients (60.4%). A total of 105 patients (32.5%) were under 5 years old, and 23 patients were between 11 and 15 years old (7.1%). A total of 167 patients (51.7%) arrived at the hospital immediately after the injury, 119 patients (36.8%) sought medical attention after a few weeks, and 37 patients (11.5%) delayed treatment for a month or more, as detailed in Table 1.

Table 1. Demographic characteristics of patients and time from injury to presentation.

	Frequency	Percent
Gender		
Male	272	84.2%
Female	51	15.8%
Age		
<5 years	105	32.5%
6 - 10 years	195	60.4%
11 - 15 years	23	7.1%
Time from injury to presentation		
At the time of injury	167	51.7%
2 weeks	119	36.8%
1 month	37	11.5%

Most of the fractures, specifically 230 cases (71.2%), were caused by falling, while 88 patients (27.2%) had fractures due to road traffic accidents. Additionally, 5 patients (1.5%) experienced fractures due to pathological reasons. Among the total patients, 275 patients (85.1%) had both bone forearm fractures, while 48 patients (14.9%) had humerus fractures. Left-sided fractures were found in 183 pa-

tients (56.7%), and right-sided fractures were found in 140 patients (43.3%). The most common fracture pattern was simple transverse fracture, which was observed in 200 patients (61.9%), followed by simple spiral fracture in 65 patients (20.1%), simple oblique fracture in 40 patients (12.4%), and comminuted fracture in 18 patients (5.6%). The hospital managed 302 closed fractures and 21 open fractures, as shown in Table 2.

Table 2. Mechanism of injury and fracture characteristics in the study population.

	Frequency	Percent
Mechanism of trauma		
Fall down	230	71.2%
RTA	88	27.2%
Pathological fracture	5	1.5%
Fracture location		
Humerus	48	14.9%
Both bones forearm	275	85.1%
Side of fracture		
Right	140	43.3%
Left	183	56.7%
Pattern of fracture		
Simple transvers	200	61.9%
Simple oblique	40	12.4%
Simple spiral	65	20.1%
Comminuted	18	5.6%
Type of fracture		
Closed	302	93.5%
Open	21	6.5%

The majority, comprising a total of 232 patients (71.8%), initially sought medical advice, while 91 patients (28.2%) consulted a bone setter first. A significant number of 268 patients (83%) underwent closed reduction, while 55 patients (17%) underwent open reduction. Among those who underwent open reduction, 48 patients (87.3%) were late presenters, and 7 patients (12.7%) faced challenges with reduction despite early presentation. A total of 28 patients (8.7%) needed a postoperative cast, while 295 patients (91.3%) did not require a postoperative cast. Regarding follow-up appointments, 266 patients (82.4%) attended, while 57 patients (17.6%) did not, as shown in Table 3.

Table 3. Initial management, reduction methods, and postoperative care.

	Frequency	Percent
Initial consultation		
Medical advice	232	71.8%
Bone setter	91	28.2%
Method of reduction		
Closed reduction	268	83.0%
Open reduction	55	17.0%
Causes of ORIF		
Delay presentation	48	87.3%
Fresh but difficult reduction	7	12.7%
Postoperative care		
Need supplementary cast	28	8.7%
without cast	295	91.3%
Removal of implant		
Come to removal	266	82.4%
Did not come	57	17.6%

The majority of patients, 70.27%, did not experience any complications. However, a smaller group of 96 patients experienced minor complications. Among them, 38 patients (11.7%) had prominent hardware issues only, 8 patients (2.4%) had pin tract infections alone, and 37 patients (11.4%) had both prominent hardware and pin tract infections. Additionally, 13 patients (4%) had both pin tract and frank infections, with no patients solely having frank infections. There were no reports of neurological injuries, nonunion, or malunion. Among all patients, 265 (82%) had excellent outcomes, while 58 patients (18%) had good outcomes, as displayed in Table 4.

Table 4. Postoperative complications and functional outcomes according to price criteria.

	Frequency	Percent
Complications		
No Complication	227	70.28%
Complications	96	29.72%
Site of prominent hardware		
Humerus	48	64.0%
Ulna	27	36.0%
Infection according to the type of fracture		
Open	13	56.52%
Closed	10	43.47%
Outcome		
Excellent	265	82.0%
Good	58	18.0%

Significant associations were found between the final outcome and age, time from injury to presentation, side of injury, pattern of injury, type of fracture, initial consultation, and postoperative care, with a P value of 0.000. Furthermore, the correlations between outcome and gender and mechanism of injury were statistically significant, with P values of 0.001 and 0.044, respectively. No significant difference was observed between the outcome and the location of the injury, with a P value of 0.350, as outlined in Table 5.

Table 5. Association between patient and fracture variables and functional outcomes.

		Outcome		P value
		Excellent	Good	
Age	<5 years	105	0	0.000*
	6 - 10 years	155	40	
	11 - 15 years	5	18	
Time from injury to presentation	At the time of injury	167	0	0.000*
	2 weeks	98	21	
	1 month	0	37	
Side	Right	103	37	0.000*
	Left	162	21	
Pattern	Simple transvers	200	0	0.000*
	Simple oblique	0	40	
	Simple spiral	65	0	
	Comminuted	0	18	
Type of fracture	Closed	265	37	0.000*
	Open	0	21	
Consultation	Medical advice	232	0	0.000*
	Bone setter	33	58	
Postoperative care	Need supplementary cast	5	23	0.000*
	without cast	260	35	
Gender	Male	232	40	0.001*
	Female	33	18	
Mechanism	Fall down	195	35	0.044*
	RTA	65	23	
	Pathological fracture	5	0	
Location	Humerus	38	10	0.350*
	Both bones forearm	227	48	

The relationships between the time elapsed from injury to presentation, method of reduction, and complications were statistically significant, with a P value of 0.000, as shown in Table 6.

Table 6. Relationship between time to presentation, method of reduction, and complications.

		Time			P value
		At the time of injury	2 weeks	1 month	
Method of reduction	Closed reduction	160	98	10	0.000*
	Open reduction	7	21	27	
Complications	None	162	65	0	0.000*
	Pin track infection	0	31	37	
	Prominent harware	5	33	0	
	Frank infection	0	13	10	

Similarly, the association between the type of reduction and complications also exhibited statistical significance, with a P-value of 0.000, as shown in Table 7.

Table 7. Association between type of reduction and postoperative complications.

		Type		P value
		Closed	Open	
Complications	None	227	0	0.000
	Pin track infection	37	21	
	Prominent harware	76	0	
	Frank infection	10	13	

Furthermore, the correlation between the first consultation and complications was statistically significant, with a P-value of 0.000, as presented in Table 8.

Table 8. Association between initial consultation and postoperative complications.

		Consultation		P value
		Medical advice	Bone setter	
Complications	None	227	0	0.000
	Pin track infection	0	58	
	Prominent harware	5	70	
	Frank infection	0	23	

Finally, the relationship between the pattern of injury and postoperative care was statistically significant, with a P value of 0.000, as shown in Table 9.

Table 9. Relationship between fracture pattern and postoperative care.

		Pattern				P value
		Simple transvers	Simple oblique	Simple spiral	Comminuted	
Postoperative care	Need supplementary cast	5	13	0	10	0.000
	without cast	195	27	65	8	

4. Discussion

Pediatric fractures of the upper limbs involving the humerus and forearm are prevalent among children. Forearm fractures, in particular, account for 13% - 40% of all pediatric fractures [1] [2], while humerus fractures, though less common, represent up to 5.4% of all fractures [7].

This research focused on evaluating the effectiveness of titanium elastic nail (TENS) in treating upper limb fractures in pediatric patients, specifically those involving the humerus and forearm. Our findings underscore the positive clinical and radiological outcomes associated with TENS treatment, leading to successful bone healing with minimal complications. These results not only corroborate previous studies but also provide fresh insights into how age and the type of fracture impact healing outcomes.

A total of 323 pediatric patients with upper limb fractures were involved in this study at The Police Hospital in Atbara. The demographic analysis revealed that 84.2% of the population was male, with the remaining 15.8% being female. The male-to-female ratio was 5.3:1, with most patients falling in the 6 - 10 years age group. Although the total population differed from that in previous studies, the age distribution remained consistent [11] [12]. It is noteworthy that girls demonstrated a lower likelihood of sustaining such injuries [13] [14].

The correlation between the timing of medical presentation and treatment outcomes was explored, indicating that early intervention was linked to better results [15]. A critical observation from our study was that children who promptly sought medical assistance following their injury consistently experienced positive outcomes.

Among the fractures studied, the majority (71.2%) were attributed to falls, with road traffic accidents accounting for 27.2% and only 1.5% resulting from pathological causes. These findings align with existing research that underscores falls as a primary cause of upper limb fractures in children, especially those affecting the forearm [16] [17].

In a prior investigation, it was discovered that fractures in the distal forearm were the most common [18], and the results of the present study were similar to those in 85.1% (275 patients) of all fractures. The study also revealed that fractures involving both bones in the forearm were linked to higher rates of favorable outcomes.

Our current research indicated that transverse fractures were the most frequent type, occurring in 61.9% (200 patients), followed by oblique fractures in 12.4% (40 patients), spiral fractures in 20.1% (65 patients), and comminuted fractures in the remaining 5.6% (18 patients). Among these, transverse fractures had the highest percentage of excellent outcomes, at 61.91%. Similar findings regarding transverse and comminuted fractures were observed in another study, although they reported a higher incidence of oblique fractures [19].

A previous study demonstrated that open fractures comprised 8.5% of the total population in their investigation [20]. However, in our study, the incidence of open fractures was notably lower (6.5%) than that of closed fractures. Patients with closed fractures consistently achieved excellent to good outcomes, while those with open fractures tended to have good outcomes due to complications such as infection, which affected 13 patients with open fractures.

Among all patients, closed reduction was carried out in 83% (268 patients), and open reduction was carried out in 17% (55 patients), showing a substantial correlation between open reduction and delayed presentation. Our study's rate of open reduction was lower than that reported in another study, where open reduction was necessary in 38.5% of cases [21].

The titanium elastic nails system is often favored for treating pediatric fractures due to its minimally invasive nature and quick mobilization. In our study group, only 8.7% of patients required an additional cast, aligning with previous research that emphasized the reduced need for immobilization with TENS [9]. This aspect is particularly crucial in pediatric patients to prevent stiffness and loss of joint function due to prolonged immobilization.

Another study reported that two-thirds of their population had nails removed, whereas our study showed a higher rate of nail removal, with 82.4% (266 patients) undergoing this procedure [22].

The current investigation revealed a minimal incidence of complications, with a majority of patients (70.28%) reporting no complications. The remaining individuals experienced minor complications, with 38 patients (11.7%) demonstrating notable hardware. This percentage closely aligns with the findings of a related study [23]. Noteworthy hardware occurrences were predominantly associated with fractures in the proximal ulna and distal humerus, as the nails were placed in the posterior part of the elbow, where muscle coverage was insufficient to hide them. Additionally, 8 patients (2.4%) developed pin tract infections, while 37 patients (11.4%) experienced both notable hardware and pin tract infections.

Severe infections were observed in 13 patients (4%), mirroring the results of another investigation [24]. Frank infections were observed only in conjunction with pin tract infections, and all patients initially sought assistance from bone setters before turning to medical professionals. The treatment of frank infections typically involves debridement, implant removal, and antibiotic therapy.

Our research also highlights the impact of age on the outcomes of TENS procedures. Compared with adolescents aged 11 to 15 years, children aged between 6

and 10 years exhibited a greater frequency of favorable outcomes. This difference is likely due to the advanced regenerative capabilities of younger children. This observation is consistent with previous research indicating that age influences the rate of fracture healing [25].

5. Limitations

This study has several limitations. First, it was conducted at a single center, which may limit the generalizability of the findings. Second, approximately 17.6% of patients did not return for implant removal, which may affect the completeness of long-term follow-up data. Third, the study lacked a comparison group treated with alternative methods such as casting or plate fixation, limiting the ability to directly compare outcomes between treatment modalities. Finally, the retrospective design introduces potential selection and reporting biases.

6. Conclusion

In conclusion, titanium elastic nailing is a reliable and minimally invasive surgical option for the treatment of selected pediatric humeral and forearm fractures. The technique demonstrated favorable functional and radiological outcomes with a relatively low rate of complications in this cohort. However, further prospective multicenter studies and comparative trials are required to confirm these findings and to determine the optimal indications for this technique.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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