Article

Comparative Assessment of Elastic Intramedullary Nailing Versus Conventional Plate Fixation for Pediatric Femoral Shaft Fractures in the Emergency Setting

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AIM: This study aims to compare the clinical outcomes between elastic intramedullary nailing and traditional open reduction and plate fixation for pediatric femoral shaft fractures in the emergency setting.
METHODS: This retrospective study enrolled 313 pediatric patients with femoral shaft fractures who underwent emergency surgical treatment at Qinghai Provincial Women and Children's Hospital between January 2023 and February 2024. After propensity score matching (PSM), patients who received elastic stable intramedullary nailing were assigned to the observation group (n = 120), whereas those who were treated with traditional open reduction and plate fixation were included in the control group (n = 120). Perioperative data, postoperative knee function, range of motion, and incidence of complications were compared between the two groups.
RESULTS: Patients in the observation group demonstrated shorter operative times and smaller incision lengths than those in the control group. They also experienced reduced intraoperative blood loss and minimal fluoroscopic exposures, and achieved full weight-bearing earlier than those in the control group ($p < 0.001$). At both 3 and 6 months after surgery, knee function scores, knee range-of-motion scores, and total Hospital for Special Surgery (HSS) scores were higher in the observation group, along with improved knee stability score ($p < 0.05$). At 3 months postoperatively, the hip function score, hip range-of-motion score, and total Harris Hip score were also higher in the observation group ($p < 0.01$). Successful fracture union was achieved in all children, with no serious postoperative complications observed in either group. In the control group, two cases developed incision-site infections, which were cured after debridement and anti-infective treatment.
CONCLUSIONS: In the emergency setting, both elastic intramedullary nailing and conventional open reduction with plate fixation can achieve favorable clinical outcomes in children with femoral shaft fractures. Elastic intramedullary nailing offers distinct advantages, such as minimal surgical trauma, earlier postoperative weight-bearing, and better early recovery, rendering it a suitable option in this clinical setting.

Keywords: emergency; femoral shaft fracture; elastic intramedullary nail; open reduction; plate fixation

Introduction

Pediatric femoral shaft fractures represent a clinically significant concern in orthopedics and are typically associated with high-energy trauma, such as traffic accidents or falls from height [1]. As the femur serves as the principal weight-bearing bone of the lower limb, its fracture often presents with severe pain, obvious deformity, and loss of mobility, frequently necessitating emergency management [2,3]. Treatment in emergency settings must balance multiple priorities, including achieving stable fracture fixation, minimizing surgical trauma, and promoting early functional recovery [4]. Currently, the traditional open reduction and internal fixation with plate is widely used in clinical practice and enables accurate anatomical alignment; however, it is associated with significant limitations, such as extensive surgical trauma or soft tissue disruption and extensive periosteal stripping [5].

Conversely, elastic intramedullary nailing follows the principles of biological osteosynthesis, providing better preservation of the blood supply at the fracture site. This technique is particularly useful for pediatric patients due to their high bone remodeling potential, and it has demonstrated favorable clinical outcomes in routine practice [6]. Despite its widespread applications in patient management, several existing studies have assessed these approaches in elective surgery or mixed clinical settings. Evidence specifically evaluating their efficacy in an emergency remains limited. In particular, there is a scarcity of systematic comparisons of perioperative efficiency, such as operative time and blood loss, along with early joint functional recovery and overall safety. Whether elastic intramedullary nail-

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ing can consistently enable earlier weight-bearing and enhanced early functional outcomes in emergency contexts remains to be properly established [7].

Therefore, to comprehensively assess this gap, the present retrospective cohort study compared clinical outcomes between elastic intramedullary nail fixation and open reduction with plate fixation for pediatric femoral shaft fractures, aiming to provide more precise, evidence-based guidance for surgical decision-making in emergency management.

Methods

Enrolled of the Study Participants

This study was designed as a retrospective analysis with propensity score matching (PSM). Initially, the study included 313 pediatric patients with femoral shaft fractures who underwent emergency surgical management at Qinghai Provincial Women and Children's Hospital between January 2023 and February 2024. To minimize baseline differences, a 1:1 nearest-neighbor matching method was applied using age, sex, and other baseline variables, with a caliper width of 0.2.

After PSM, patients treated with elastic stable intramedullary nailing were assigned to the observation group (n = 120), whereas those who received traditional open reduction with plate fixation were assigned to the control group (n = 120).

The study protocol was approved by the Medical Ethics Committee of Qinghai Provincial Women and Children's Hospital for clinical research (Approval No.: 2025QHFNETLL W (Article) 10).

Diagnostic, Inclusion and Exclusion Criteria

Diagnostic Criteria

Femoral shaft fracture was diagnosed based on established relevant clinical criteria [8] and confirmed using X-ray and computed tomography (CT) examinations.

Inclusion and Exclusion Criteria

Patients were found eligible if they were aged between 5 and 13 years, presented with a unilateral closed femoral shaft fracture, had a definite history of trauma, and received surgical intervention within 2 weeks of injury. Exclusion criteria were: ① incomplete baseline data; ② the fracture was pathological in origin, such as those secondary to bone tumors or osteoarticular tuberculosis; ③ neuromuscular disorders influencing lower-limb function; ④ pre-existing hip dislocation or valgus deformity before fracture; and ⑤ a history of femoral head necrosis. A flowchart of study design and patient selection is presented in Fig. 1.

Indications for Elastic Intramedullary Nailing

① Typically, aged 5–13 years with open growth plates and good remodeling potential; ② unilateral closed femoral shaft fracture classified as Arbeitsgemeinschaft für Osteosynthesefragen (AO)/Orthopaedic Trauma Association (OTA) type A (simple fracture) or type B (wedge or partially comminuted fracture); ③ moderate displacement of fracture fragments, where closed reduction was anticipated to achieve acceptable functional alignment; ④ absence of extreme medullary canal stenosis (diameter <6 mm) or significant proximal femoral anatomical anomalies, such as marked abnormal femoral anteversion.

Indications for Traditional Plate Fixation

① Comminuted femoral shaft fracture (AO/OTA type C) with severe instability requiring precise anatomical restoration; ② soft tissue interposition at the fracture site that cannot be resolved by closed reduction; ③ previous history of femoral surgery resulting in intramedullary canal narrowing or malunion, making intramedullary nailing technically challenging; ④ patients weighing >45 kg, where elastic intramedullary nailing was unlikely to provide adequate biomechanical stability.

Surgical Protocols

Elastic intramedullary nailing was performed in the observation group. Under general anesthesia, patients were placed in the supine position. Two small longitudinal incisions (approximately 2–3 cm) were made on the medial and lateral sides of the distal femur, about 2 cm proximal to the growth plate. After exposing the periosteum, cortical entry points were created bilaterally to access the medullary canal.

Based on preoperative imaging, two titanium elastic nails were selected, each with a diameter of approximately 40% of the narrowest part of the medullary canal. They were pre-shaped into a "C" curve, with the apex directed toward the fracture site. Under fluoroscopic guidance, the first nail was inserted retrogradely and advanced to the fracture level. Closed manual reduction was then performed, allowing the nail tip to cross the fracture line and extend into the proximal cancellous bone. The second nail was inserted in the same manner from the opposite side, creating balanced, symmetric intramedullary support. After confirming satisfactory reduction and alignment, the nail ends were trimmed to leave approximately 1.0–1.5 cm outside the cortex and were either capped or bent and buried beneath the soft tissue. The wounds were irrigated and closed in layers.

In the control group, conventional open reduction and plate fixation were performed. Under general anesthesia, patients were first placed in the supine position, and a lateral approach to the femur was used. A longitudinal incision measuring approximately 10–15 cm was made over the fracture site. Soft tissues were carefully dissected along the lateral intermuscular plane to expose the fracture. The periosteum was incised, and any hematoma or interposed soft tissue was removed under direct visualization.

Anatomical reduction was achieved and temporarily maintained using bone-holding forceps. Based on the fracture

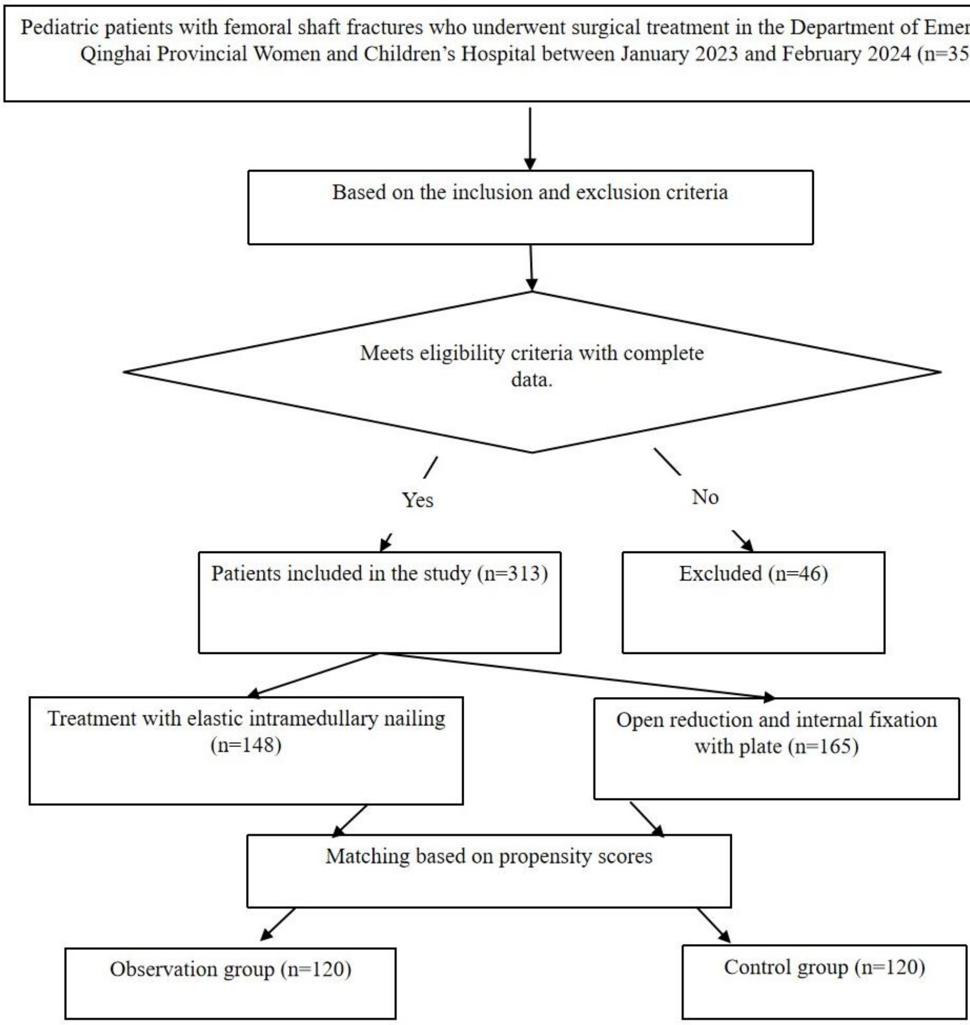

Fig. 1. Flow chart of patient selection and propensity score matching. Department of Emergency indicates the enrollment site where patients were enrolled.

characteristics and bone quality, a locking plate was uniformly selected as the internal fixation device and placed on the lateral side of the femoral shaft. After drilling, multiple cortical screws were inserted to obtain stable fixation. Throughout the procedure, fluoroscopy was used to verify reduction quality, plate positioning, and screw length. A surgical drain was routinely placed, and the incision was closed in layers.

Postoperative Management

All children received standardized postoperative rehabilitation management. Pain was controlled using a combination of nonsteroidal anti-inflammatory drugs and mild opioids during the first 48–72 h. A first-generation cephalosporin was administered intravenously 30 min before surgery and discontinued within 24 h postoperatively. Functional rehabilitation training was initiated on postoperative day 1 and included ankle pump exercises and isometric quadriceps contractions. From postoperative days 2–3, patients started gentle passive-to-active range-of-motion exercises for the knee and hip, within pain tolerance and under supervision.

Weight-bearing protocol differed based on the fixation methods. In the observation group, elastic intramedullary nailing provided elastic, three-point intramedullary support, allowing controlled micro-motion at the fracture site, which facilitates callus formation. Patients in this group were allowed to begin partial weight-bearing (approximately one-third of body weight) at 4–6 weeks postoperatively, progressing to full weight-bearing at 8–12 weeks once radiographic confirmation of continuous callus formation was observed.

In the control group, plate fixation aimed to achieve absolute stability and direct healing. Early weight-bearing could potentially compromise this process, so partial weight-bearing was delayed at 6–8 weeks postoperatively. Full weight-bearing was started at 12–16 weeks postoperatively, or after clear radiographic evidence of fracture union.

Table 1. Comparison of baseline characteristics before and after propensity score matching between the two groups.

General information	Before PSM matching				After PSM matching			
	Observation group (n = 148)	Control group (n = 165)	t/χ^2	p-value	Observation group (n = 120)	Control group (n = 120)	t/χ^2	p-value
Age (years)	9.18 ± 2.26	8.32 ± 2.29	2.718	0.007	9.02 ± 2.26	9.26 ± 1.78	–0.922	0.356
Height (cm)	133.87 ± 12.18	136.10 ± 9.04	–1.522	0.117	134.28 ± 12.03	136.33 ± 8.79	–1.505	0.134
Weight (kg)	29.42 ± 5.84	32.18 ± 5.81	–3.614	<0.001	29.78 ± 5.92	30.65 ± 5.24	–1.208	0.228
The time interval from fracture to surgery (d)	3.15 ± 1.08	3.68 ± 1.51	–2.615	0.011	3.27 ± 1.23	3.43 ± 1.43	–0.966	0.335
Gender (%)			6.897	0.009			2.069	0.150
Male	79 (53.38)	112 (67.88)			64 (53.33)	75 (62.50)		
Female	69 (46.62)	53 (32.12)			56 (46.67)	45 (37.50)		
Distribution on the affected side (%)			7.970	0.005			2.049	0.152
Left	58 (39.19)	91 (55.15)			47 (39.17)	58 (48.33)		
Right	90 (60.81)	74 (44.85)			73 (60.83)	62 (51.67)		
AO/OTA type (%)			2.155	0.341			1.540	0.463
A type	83 (56.08)	100 (60.61)			67 (55.83)	75 (62.50)		
B type	52 (35.14)	46 (27.88)			42 (35.00)	38 (31.67)		
C type	13 (8.78)	19 (11.51)			11 (9.17)	7 (5.83)		

PSM, propensity score matching; AO, Arbeitsgemeinschaft für Osteosynthesefragen; OTA, Orthopaedic Trauma Association.

Outcome Indicators

Data were collected retrospectively from the medical records of the hospital. To ensure data quality and accuracy, two trained investigators independently extracted information using a predefined standardized data collection form. Any inconsistencies were resolved through discussion, and when agreement could not be reached, a third senior investigator made the final decision. Baseline clinical data included age, sex, height, weight, side of fracture, time from injury to surgery, and preoperative AO/OTA fracture classification based on X-ray findings. Perioperative variables included operative time, incision length, intraoperative blood loss, and the number of C-arm fluoroscopic exposures. Follow-up data included time to full weight-bearing and the incidence of postoperative complications.

Knee function was assessed using the Hospital for Special Surgery (HSS) scoring system [9], which comprises pain (30 points), function (22 points, including activities of daily living), range of motion (18 points), muscle strength of the affected limb (10 points), flexion deformity (10 points), and joint stability (10 points), with a maximum score of 100. Higher HSS scores indicate better functional recovery. HSS score was used to assess knee function because it is widely applied in lower extremity trauma studies and has been used in pediatric populations with adequate cooperation.

Hip function was evaluated using the Harris Hip score [10], which includes pain (44 points), function (47 points), range of motion (5 points), and deformity (4 points), yielding a total score of 100 points. Higher scores indicate better recovery of hip function. Harris Hip score was used because it is widely applied in hip trauma studies and can be reliably completed in cooperative pediatric patients.

Radiographic healing was defined by progressive blurring or near-complete disappearance of the fracture line, along with the formation of continuous bridging callus traversing the fracture site, reflecting union of the bone fragments.

Statistical Analysis

Statistical analysis was conducted using SPSS (version 21.0, IBM-SPSS Statistics, Chicago, IL, USA) and R (version 4.0.0, R Core Team). Continuous variables were evaluated for normality using the Kolmogorov–Smirnov (K–S) test and were found to conform to a normal distribution. Accordingly, these variables were presented as mean ± standard deviation (SD), and between-group comparisons were performed using the independent-samples t-test. Categorical variables were expressed as numbers (percentages) and were analyzed using the chi-square (χ^2) test. A p-value of $<$0.05 was considered statistically significant.

Results

Comparison of Baseline Characteristics Between the Observation and Control Groups Before and After Propensity Score Matching

Before PSM, both groups differed significantly in several baseline characteristics, such as age, body weight, time from fracture to surgery, gender distribution, and distribution on the affected side ($p < 0.05$). After PSM, no significant differences were observed across these variables. The two groups were comparable regarding age, height, weight, time from fracture to surgery, gender distribution, affected side distribution, and AO/OTA classification ($p >$ 0.05) (Table 1).

Table 2. Comparison of perioperative and postoperative recovery outcomes between the observation and control groups.

Group	n	Operation time (min)	Total length of the incision (cm)	Intraoperative blood loss (mL)	Intraoperative fluoroscopy (times)	Full weight–bearing time (weeks)
Observation group	120	52.24 ± 5.17	3.27 ± 0.94	55.02 ± 8.99	6.90 ± 1.52	9.85 ± 1.29
Control group	120	71.99 ± 6.86	9.91 ± 1.87	110.08 ± 16.79	11.79 ± 2.62	12.93 ± 1.54
t		–25.189	–34.690	–31.659	–17.717	–16.804
p		<0.001	<0.001	<0.001	<0.001	<0.001

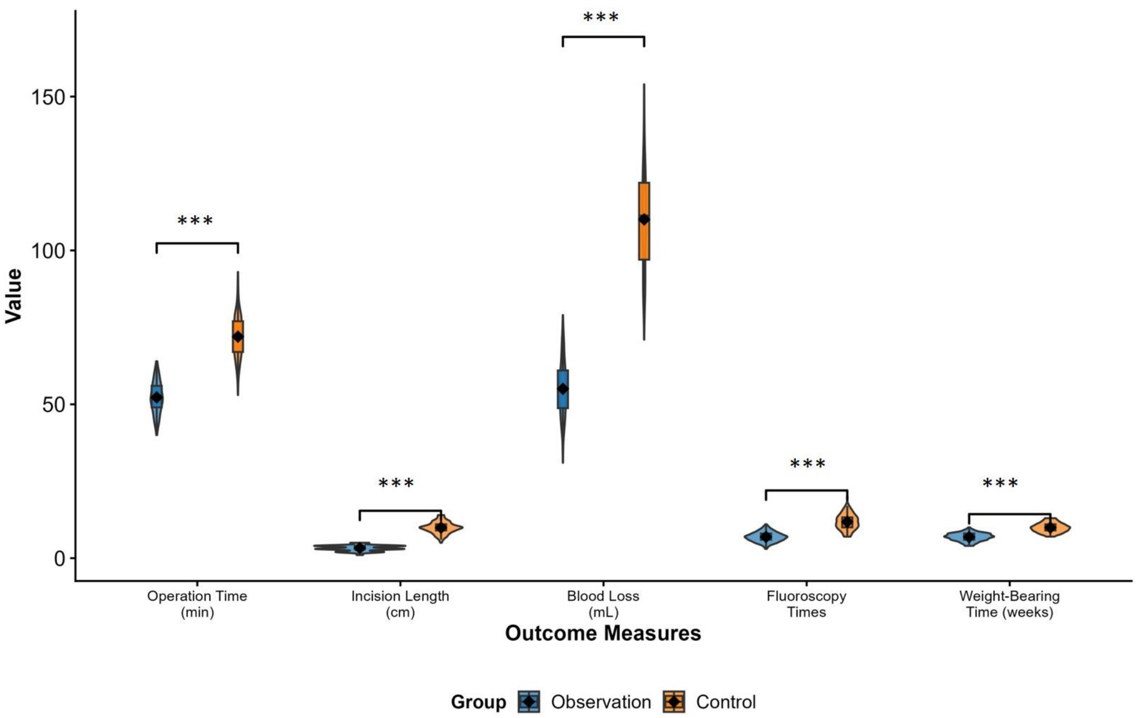

Fig. 2. A comparison of perioperative and postoperative recovery outcomes between groups. Note: Compared with the control group, ***$p < 0.001$.

Comparison of Perioperative and Postoperative Recovery Outcomes Between Groups

Compared with the control groups, patients in the observation group showed a shorter operative time, smaller incision length, reduced intraoperative blood loss, and required fewer fluoroscopic exposures. Furthermore, patients in the observation group also achieved full weight-bearing earlier. All these differences were statistically significant between the two groups ($p < 0.001$, Table 2, Fig. 2).

Comparison of Postoperative HSS Scores Between the Observation and Control Groups

At both 3 and 6 months postoperatively, patients in the observation group showed improvements in most knee function components compared with the control group. This was reflected by improved knee range-of-motion scores and higher overall HSS scores. Moreover, knee stability at 3 months was significantly better in the observation group. These differences between the two groups were statistically significant for most parameters, except for pain scores, muscle strength, and flexion deformity ($p < 0.05$, Table 3, Fig. 3).

Comparison of Postoperative Harris Hip Scores Between the Observation and Control Groups

At 3 months postoperatively, patients in the observation group demonstrated better hip function than those in the control group. This was evidenced by higher hip function scores, improved hip range-of-motion scores, and higher overall Harris Hip scores. These differences were statistically significant between the two groups ($p < 0.01$, Table 4, Fig. 4).

Incidence of Postoperative Complications Across Both Groups

Patients in both study groups achieved fracture healing, and no severe postoperative complications were observed. In the control group, two patients developed incision-site infections; both responded well to debridement and anti-infective treatment.

Table 3. Comparison of postoperative HSS scores between the observation and control groups.

Group	n	Pain		Function		Range of motion	
		3 months	6 months	3 months	6 months	3 months	6 months
Observation group	120	22.59 ± 2.97	25.22 ± 2.88	15.43 ± 2.00	18.81 ± 1.56	13.50 ± 2.24	15.13 ± 1.65
Control group	120	22.27 ± 2.85	25.30 ± 2.40	14.20 ± 1.74	18.00 ± 1.48	11.22 ± 1.86	14.68 ± 1.70
t		0.852	–0.234	5.083	4.126	8.578	2.081
p-value		0.395	0.815	<0.001	<0.001	<0.001	0.039

Group	n	Muscle strength		Flexion deformity		Stability	
		3 months	6 months	3 months	6 months	3 months	6 months
Observation group	120	8.28 ± 1.09	8.89 ± 0.86	8.06 ± 1.24	8.68 ± 0.77	6.80 ± 1.21	8.58 ± 0.85
Control group	120	8.18 ± 1.03	8.75 ± 0.93	7.80 ± 1.24	8.84 ± 0.92	6.09 ± 0.93	8.43 ± 0.90
t		0.730	1.211	1.624	–1.461	5.096	1.327
p-value		0.466	0.227	0.106	0.145	<0.001	0.186

Group	n	HSS total score	
		3 months	6 months
Observation group	120	74.51 ± 5.43	85.40 ± 3.99
Control group	120	69.04 ± 3.96	83.64 ± 3.62
t		8.916	3.579
p-value		<0.001	<0.001

HSS, Hospital for Special Surgery.

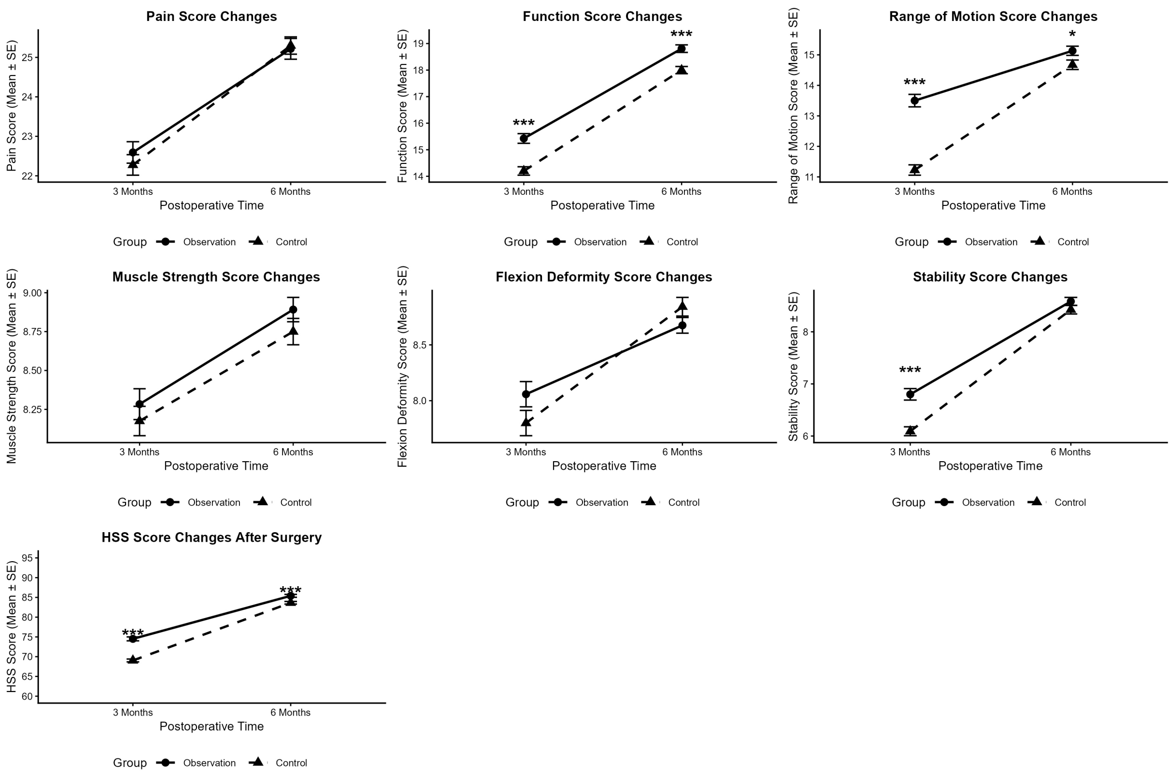

Fig. 3. Comparison of postoperative HSS scores between the two groups. Note: Compared with the control group, *$p < 0.05$, and ***$p < 0.001$. HSS, Hospital for Special Surgery.

Discussion

Pediatric femoral shaft fractures are a common emergency injury, and their treatment centers on achieving satisfactory reduction, stable fixation, and enabling early functional rehabilitation. In the emergency setting, surgical decision-making must consider operative efficiency, reduction of tissue injury, and the need for rapid rehabilitation. These practical limitations further emphasize the selection of the most appropriate fixation approach. While a previous comparative study largely focused on elective surgery

Table 4. Comparison of postoperative Harris Hip scores between the observation and control groups.

Group	n	Pain		Function	
		3 months	6 months	3 months	6 months
Observation group	120	35.40 ± 2.97	40.42 ± 1.81	38.24 ± 2.26	43.93 ± 1.03
Control group	120	35.23 ± 3.25	40.52 ± 1.47	36.83 ± 2.22	43.66 ± 1.16
t		0.415	–0.509	4.861	1.942
p-value		0.679	0.612	<0.001	0.053

Group	n	Range of motion		Joint deformity	
		3 months	6 months	3 months	6 months
Observation group	120	3.05 ± 0.59	4.05 ± 0.41	3.65 ± 0.59	4.10 ± 0.46
Control group	120	2.83 ± 0.65	3.98 ± 0.49	3.58 ± 0.69	4.08 ± 0.54
t		2.694	1.285	0.803	0.257
p-value		0.008	0.200	0.423	0.797

Group	n	Harris Hip score	
		3 months	6 months
Observation group	120	80.38 ± 3.45	92.50 ± 2.22
Control group	120	78.34 ± 3.87	92.16 ± 2.09
t		4.313	1.225
p-value		<0.001	0.222

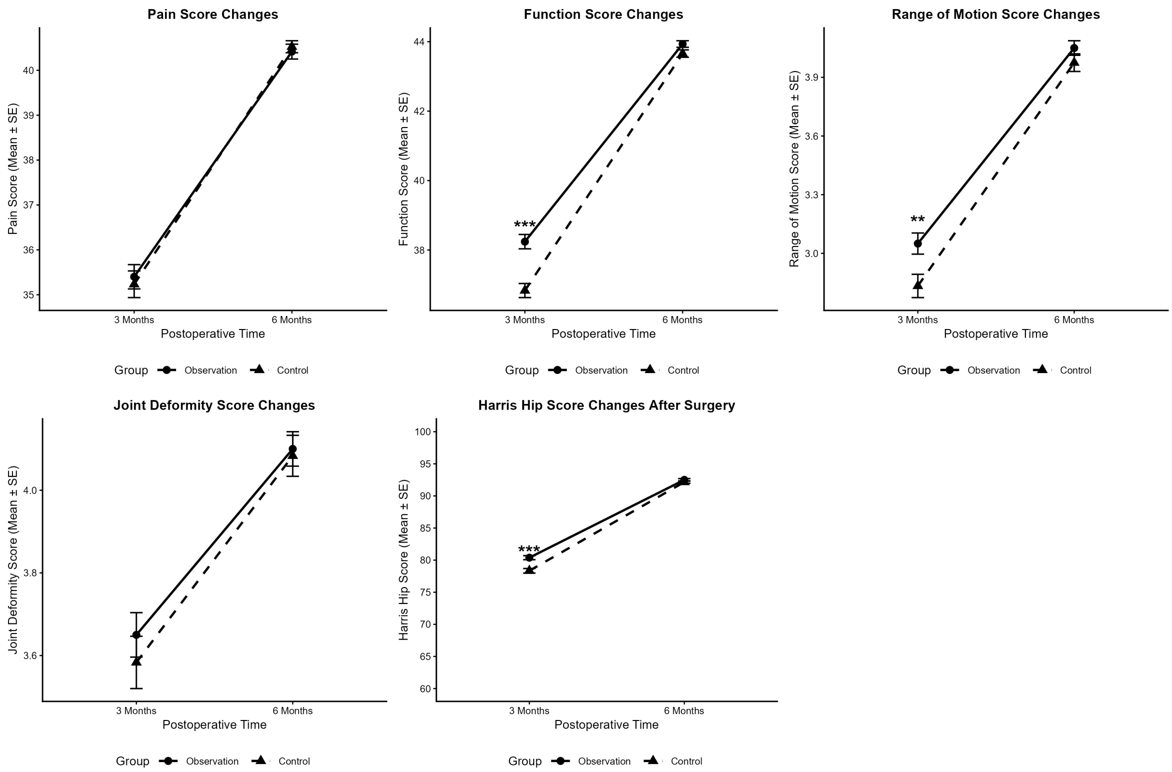

Fig. 4. Comparison of postoperative Harris Hip scores between groups. Note: Compared with the control group, **$p < 0.01$, and ***$p < 0.001$.

[11]. The present study specifically assessed outcomes in an emergency setting, comparing elastic intramedullary nailing with conventional plate fixation to provide clinically relevant guidance for preferential selection of a minimally invasive fixation strategy that better aligns with pediatric physiological characteristics in this specific patient cohort.

The present study indicates that elastic intramedullary nailing provides significant perioperative benefits. Compared with the control groups, the observation group demonstrated shorter operative time, lower intraoperative blood loss, fewer fluoroscopic exposures, and smaller incisions. Furthermore, patients in the observation group progressed to full weight-bearing earlier. These findings can be largely attributed to the fundamental differences in surgical technique between the two procedures, with elastic intramedullary nailing being minimally invasive and therefore associated with better outcomes. The use of two small incisions at the distal femur in elastic intramedullary nailing minimizes iatrogenic disruption of periosteal and soft-tissue perfusion around the fracture, thereby directly contributing to reduced operative time, less blood loss, and smaller incisions. Similar observations have been reported in a previous study, underscoring that minimally invasive approaches help reduce surgical trauma and facilitate early postoperative recovery [12]. During elastic intramedullary nailing, fluoroscopy is primarily required during fracture reduction and initial nail placement. Once a satisfactory alignment is achieved, subsequent nail advancement typically requires minimal fluoroscopic guidance. Hence, the observation group in this study required fewer fluoroscopic exposures. This finding is consistent with previous reports indicating that proficient closed reduction techniques can effectively limit fluoroscopy time during surgical management of pediatric long-bone fractures [13,14]. In contrast, although plate fixation allows reduction under direct visualization and may reduce fluoroscopic use, multiple lateral—and sometimes oblique—fluoroscopic checks are routinely necessary to confirm appropriate screw length and to avoid penetration of the contralateral cortex. This requirement, which is integral to standard operative practice, objectively increases the total number of fluoroscopic exposures and thus the cumulative radiation dose [15].

The difference in full postoperative weight-bearing between the two groups can be explained by distinct biomechanical principles underlying these two techniques. Elastic intramedullary nailing provides flexible internal support, enabling controlled micromotion at the fracture site, which promotes callus formation and enables earlier weight-bearing. In the present study, patients in this group started partial weight-bearing as early as 4 to 6 weeks postoperatively. In contrast, plate fixation achieves absolute stability of the fracture through a rigid construct, aiming for direct healing. The stresses introduced by early weight-bearing could potentially interfere with this delicate process. Consequently, the accompanying rehabilitation protocol is more conservative, stipulating that partial weight-bearing be delayed until 6 to 8 weeks postoperatively. Therefore, the earlier full weight-bearing in the observation group essentially represents the clinical translation of the unique biomechanical advantage inherent to the elastic intramedullary nailing technique [16,17].

A previous study has emphasized that preserving soft-tissue attachment sites during surgery contributes to improved postoperative joint function [18]. Functional outcomes further supported the application of minimally invasive elastic intramedullary nailing. In the present study, children in the observation group demonstrated better knee and hip functions during follow-up. At both 3 and 6 months postoperatively, patients in the observation group achieved higher knee scores, better range of motion, and higher overall HSS scores, with improved early knee stability. During the same follow-up period, hip function and range-of-motion scores and the total Harris Hip score were likewise superior in the observation group. These observations indicate that elastic intramedullary nailing is favorable for postoperative rehabilitation of hip function. From a technical perspective, the minimally invasive distal femoral incisions used in the observation group avoided direct exposure of the fracture region and reduced disruption to key structures such as the quadriceps muscle, thereby maximizing preservation of periarticular soft-tissue integrity and directly contributing to higher postoperative knee function scores. Moreover, because the incisions were remote from the proximal femur, the attachments of the hip abductor musculature (e.g., the gluteus medius) at the greater trochanter were preserved, supporting coordinated active hip motion and a greater range of motion; this likely explains the better hip range-of-motion scores observed in the observation group [19].

From a biomechanical perspective, elastic intramedullary nailing restores the physiological axis of the femur and supports balanced load distribution during early hip weight-bearing and mobilization, which may further contribute to improved functional recovery. Unlike many previous studies that focus predominantly on mechanical stability, the present study assesses both structural and functional outcomes in an emergency setting, further demonstrating that combining minimally invasive techniques with physiologically aligned fixation has a significant synergistic effect on rapid and comprehensive recovery of hip function in children with femoral shaft fractures [20,21].

No serious complications, such as nonunion or malunion, occurred in either group, indicating that both elastic intramedullary nailing and conventional plate fixation constitute safe treatment options for pediatric femoral shaft fractures in the emergency setting. It is widely accepted that the risk of surgical-site infection is positively associated with the extent of surgical trauma and the degree of soft-tissue dissection [22,23]. Two cases in the control group developed incision-site infections, which were likely attributable to the long incision and extensive soft-tissue stripping required for open reduction and plate fixation. Nevertheless, both infections were managed with debridement and anti-infective therapy, did not compromise ultimate fracture union, and further underscore the strong healing potential of pediatric bone. In emergency care, the minimally invasive elastic intramedullary nailing technique may theoretically reduce the overall risk of surgery-related complications, including infection, by minimizing initial soft-tissue injury.

This study has several limitations that should be considered before interpreting these findings for clinical application. This retrospective design can introduce the possibility of residual confounding, despite the PSM. Additionally, the functional scoring systems used in this analysis, such as the HSS and Harris Hip scores, were originally developed for adult patients. Although these scoring systems are widely used in clinical practice, their application in children may introduce some degree of measurement bias. Future multicenter, prospective studies are warranted to further validate these findings and to develop age-specific assessment tools.

Conclusions

In the emergency setting, both elastic intramedullary nailing and conventional open reduction with plate fixation achieve favorable clinical outcomes in children with femoral shaft fractures. However, elastic intramedullary nailing offers distinct advantages, such as less surgical trauma, earlier postoperative weight-bearing, early mobilization, and improved functional recovery, making it an appropriate option in this clinical setting.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

LZ and GM conceived and designed the research and performed the experiments. YG and CB collected and analyzed the data. LZ and CS equally contributed to the study design, data analysis, and drafted the manuscript. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

The study adhered to the principles outlined in the Declaration of Helsinki and the study protocol was reviewed and approved by the Medical Ethics Committee of Qinghai Provincial Women and Children's Hospital (Approval No.: 2025QHFNETLL W (Article) 10). The guardians of all patients signed informed consent forms after being informed of the study objectives.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Laitakari E, Koukkula T, Huttunen TT, Mattila VM, Salonen A. The incidence, trends, and costs of treatment of femoral shaft fractures among Finnish children aged 2–12 years between 1998 and 2016. Journal of Children's Orthopaedics. 2024; 18: 49–53. https://doi.org/10.1177/18632521231217267.

[2] Hu D, Xu Z, Shi T, Zhong H, Xie Y, Chen J. Elastic stable intramedullary nail fixation versus submuscular plate fixation of pediatric femur shaft fractures in school age patients: A PRISMA-compliant systematic review and meta-analysis. Medicine. 2023; 102: e35287. https://doi.org/10.1097/MD.0000000000035287.

[3] Li J, Rai S, Ze R, Tang X, Liu R, Hong P. The optimal choice for length unstable femoral shaft fracture in school-aged children: A comparative study of elastic stable intramedullary nail and submuscular plate. Medicine. 2020; 99: e20796. https://doi.org/10.1097/MD.0000000000020796.

[4] Strait RT, Pankey C. Submuscular Plating Versus Elastic Intramedullary Nailing in Children with Femoral Shaft Fracture; a systematic review and meta-analysis. Journal of Clinical Orthopaedics and Trauma. 2023; 42: 102203. https://doi.org/10.1016/j.jcot.2023.102203.

[5] Maciejewski M, Klincewicz J, Janusz P. Treatment of Unstable Tibia Shaft Fractures in Children With Elastic Stable Intramedullary Nails or Minimally Invasive Plate Osteosynthesis: Comparative Study on 2 Treatment Options. Journal of Pediatric Orthopedics. 2026; 46: 1–5. https://doi.org/10.1097/BPO.0000000000003077.

[6] Soni A, Singh B. Design and Analysis of Customized Fixation Plate for Femoral Shaft. Indian Journal of Orthopaedics. 2020; 54: 148–155. https://doi.org/10.1007/s43465-019-00025-1.

[7] Ulici A, Odagiu E, Haram O, Ionescu A, Sterian GA, Carp M, *et al*. Poor prognostic factors of femoral shaft fractures in children treated by elastic intramedullary nailing. SICOT-J. 2020; 6: 34–38. https://doi.org/10.1051/sicotj/2020031.

[8] Park JW, Jo WL, Park BK, Go JJ, Han M, Chun S, *et al*. Reliability of the 2018 Revised Version of AO/OTA Classification for Femoral Shaft Fractures. Clinics in Orthopedic Surgery. 2024; 16: 688–693. https://doi.org/10.4055/cios23292.

[9] Mao Y, Wang L, Zhang A, Shen J, Tang K, Wang L. Elastic Stable Intramedullary Nailing Improves Fracture Healing and Mobility in Children with Femoral Fractures. Alternative Therapies in Health and Medicine. 2023; 29: 496–500.

[10] Qiao F, Shang X, Jiang F. Closed reduction and intramedullary nails for acute completely displaced femoral diaphysis fracture in children aged 2-6. Frontiers in Pediatrics. 2024; 12: 1346456. https://doi.org/10.3389/fped.2024.1346456.

[11] Li D, Wang X, Lu J, Xue M. Submuscular plating vs. elastic stable intramedullary nailing for diaphyseal femur fractures in children: a systematic review and meta-analysis. Frontiers in Pediatrics. 2023; 11: 1256630. https://doi.org/10.3389/fped.2023.1256630.

[12] Alkan H, Turhan Y, Veizi E, Naldoven ÖF, Aras B, Kanlikaya UG, *et al*. Elastic Stable Intramedullary Nailing in Length Stable Versus Unstable Pediatric Femoral Shaft Fractures: A Comparison of Clinical, Radiographic, and Pedobarographic Outcomes. Journal of Pediatric Orthopedics. 2024; 44: e711–e716. https://doi.org/10.1097/BPO.0000000000002737.

[13] Greenhill DA, Herman MJ. Treatment of Pediatric Femoral Shaft Fractures. The Journal of the American Academy of Orthopaedic Surgeons. 2022; 30: e1443–e1452. https://doi.org/10.5435/JAAOS-D-22-00415.

[14] Eken G, Ermutlu C, Sarisozen B, Atici T, Durak K, Cakar A. Less malunion and shorter bone union time with titanium elastic nail treatment for isolated femoral shaft fractures in three- to six-year-old children. European Journal of Orthopaedic Surgery & Traumatology. 2023; 33: 893–898. https://doi.org/10.1007/s00590-022-03223-0.

[15] Xing H, Wu Q, Lan S, Wang C, Ye J, Ye F, *et al*. Ipsilat-

eral femoral neck and shaft fracture in children: Two case reports. Medicine. 2021; 100: e23616. https://doi.org/10.1097/MD.0000000000023616.

[16] Guo J, Feng W, Song B, Zhu D, Wen Y, Wang Q. Femoral shaft fractures in preschool children: external fixation and elastic intramedullary nail treatments in clinical practice. Journal of Pediatric Orthopedics. Part B. 2025; 34: 209–217. https://doi.org/10.1097/BPB.0000000000001221.

[17] Al-Doori O, Abdalla M, Alkhaion SZ. Comparative Outcomes of Elastic Stable Intramedullary Nailing vs. Plate Fixation in Pediatric Femoral Shaft Fractures. A Prospective Study. Ortopedia, Traumatologia, Rehabilitacja. 2024; 26: 369–373. https://doi.org/10.5604/01.3001.0054.4650.

[18] Denis-Aubrée P, Dukan R, Karam K, Molina V, Court C, Bouthors C. Bilateral femoral shaft fracture in polytrauma patients: Can intramedullary nailing be done on an emergency basis? Orthopaedics & Traumatology, Surgery & Research. 2021; 107: 102864. https://doi.org/10.1016/j.otsr.2021.102864.

[19] Tang X, Liang J, Zhang B, Rai S, Hu Q, Zou Y, *et al*. An alternative choice for overweight pediatric patient with femoral shaft fracture when rigid nail is contraindicated due to narrow intramedullary canal: Elastic stable intramedullary nail plus temporary external fixator. Journal of Orthopaedic Science. 2025; 30: 941–945. https://doi.org/10.1016/j.jos.2025.01.002.

[20] Atassi O, Fontenot PB, Busel G, De La Fuente G, Donohue D, Maxson B, *et al*. "Unstable" Pediatric Femoral Shaft Fractures Treated With Flexible Elastic Nails Have Few Complications. Journal of Orthopaedic Trauma. 2021; 35: e56–e60. https://doi.org/10.1097/BOT.0000000000001886.

[21] Landau AJ, Oladeji AK, Cummings JL, Goldstein R, Lin A, Hosseinzadeh P. Outcomes of Elastic Stable Intramedullary Nailing for Surgical Treatment of Pediatric Tibial Shaft Fractures. Journal of the American Academy of Orthopaedic Surgeons. Global Research & Reviews. 2023; 7: e23.00031. https://doi.org/10.5435/JAAOSGlobal-D-23-00031.

[22] Oberthür S, Piatek S, Krause H, Rüther H, Roch PJ, Zoch A, *et al*. Complication rate after femoral shaft fractures in childhood and adolescence depending on patient factors and treatment measures. Der Chirurg. 2022; 93: 165–172. https://doi.org/10.1007/s00104-021-01437-2.

[23] Wekunga ES, Abzug J, Dunham AM, Stepanovich M, Ruzzi S, Herman MJ. Pediatric and Adolescent Tibial Shaft Fractures: Flexible Nail, Rigid Nail, Plate, or External Fixation. Instructional Course Lectures. 2026; 75: 661–668.