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Ultrasound-guided techniques for managing length- unstable femoral shaft fractures in children

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Abstract

Objective The management of length-unstable femoral shaft fractures(LUFSFs) in pediatric patients is still controversial. This study aims to explore the clinical efficacy of ultrasound-guided closed reduction combined with external fixation for treating LUFSFs in children.

Methods We conducted a retrospective analysis of clinical data from 19 pediatric patients with LUFSFs who underwent ultrasound-guided closed reduction and external fixation between January 2018 and January 2023. Ultrasound was employed not only to facilitate closed reduction of the fracture but also to guide real-time insertion of Schanz pins and monitor pin length as it traversed the opposite cortex. Surgical time, intraoperative fluoroscopy count, hospital stay length, fracture fixation duration, complication incidence, fracture reduction quality at the final follow-up were recorded.

Results The patients' average age was 7.5 years(range: 5 to 11 years). The mean surgical duration was 70.4 min (range: 48–105 min), and the average intraoperative fluoroscopy count was 6.5 (range: 2–16). Fracture fixation lasted an average of 10.9 weeks (range: 7–20 weeks). All patients were followed up for more than one year. 6 cases of superficial pin tract infection occurred, which resolved with oral antibiotics and enhanced needle tract care. No deep infections were observed. Temporary stiffness of the knee joint was observed in 2 patients. According to Flynn's efficacy evaluation system, fracture reduction quality at the final follow-up was rated as excellent in 11 cases and satisfactory in 8 cases, yielding a combined success rate of 100% (19/19).

Conclusions The technique of ultrasound-guided closed reduction combined with external fixation offers favorable outcomes for children aged 5 to 11 years with LUFSFs, reducing reliance on fluoroscopic guidance.

Keywords Femoral shaft fracture, Length-unstable, Ultrasonography, Closed reduction, External fixation, Children

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Introduction

Femoral shaft fractures account for approximately 2% of all pediatric fractures, with an annual incidence of 16 to 19 per 100,000, a major trauma in children [1, 2]. The management of pediatric diaphyseal femur fractures remains variable and somewhat controversial [3]. Their treatment can be challenging, especially in cases of length- unstable femoral shaft fractures (LUFSFs). LUFSFs have been defined as spiral, long oblique, or comminuted fractures, with the length of the fracture line being at least twice the diameter of the femoral shaft at the level of the fracture [3–5]. While spica casting and traction can be effective, they have drawbacks such as excessive shortening, angular deformity, pain, and prolonged hospital stays. Heffernan et al. [6]. conducted a multicenter comparative study and observed that in comparison to spica casting, the use of titanium elastic nails is a viable treatment option for femur fractures in children. In children younger than 8 years old, both elastic stable intramedullary nail and external fixation can be considered as safe and effective choices for pediatric femoral shaft fracture [7]. However, prior studies have reported that LUFSFs treated with Titanium elastic nailing have worse outcomes and a higher risk of reoperations than length stable femur fractures [4, 5, 8, 9]. More complications were observed in unstable femoral shaft fractures treated with elastic stable intramedullary nail [4, 5]. External fixation devices are a viable option for stable fixation without anatomical reduction. There has been an increasing interest in external fixation as a standard treatment for femoral fractures in children [10, 11] .

The reduction of radiation dose in X-ray imaging has been recognized as a high priority in the medical community, especially for children who are the most vulnerable patient population [12].In recent years, ultrasound has emerged as a promising technology in the field of pediatric fractures, providing a non-invasive, radiation-free, and effective method for the diagnosis and treatment of fractures. Ultrasound has been increasingly utilized for the evaluation of musculoskeletal pathology in pediatrics. Our team has been dedicated to the minimally invasive treatment of pediatric fractures under ultrasound guidance for more than 10 years, and have achieved promising initial success, demonstrating the potential of this approach in improving clinical outcomes for young patients [13]. It has excellent testing characteristics to diagnose long bone fractures in children compared to the gold standard of plain radiographs [14, 15]. Yet, to our best knowledge, there is no research about the intraoperative ultrasound-guided closed reduction and external fixation of femoral shaft fracture.

This retrospective study aims to figure out the surgical outcomes of LUFSFs in children aged 5 to 11 years managed by ultrasound-guided closed reduction and external fixation.

Materials and methods

Patient selection

The retrospective study was approved by our Institution's Ethics Committee. The clinical data of children with length-unstable femoral shaft fractures, who were treated at our hospital between January 2018 and January 2023, were included after obtaining written consent from their guardians. The study enrolled 19 pediatric patients, among whom 11 presented with long oblique fractures, 4 with spiral fractures, and 4 with comminuted fractures. Children aged 5 to 11 years old were eligible for inclusion. The inclusion criteria were as follows: (1) length-unstable femoral shaft fracture confirmed on AP and lateral radiographic images; (2) treatment with ultrasound-guided closed reduction and external fixation; and (3) a follow-up period of more than one year post-surgery. Length-unstable fractures were defined as comminuted, spiral, or long oblique. According to the AO Pediatric Comprehensive Classification of Long Bone Fractures [16], the fractures analyzed in this study should be classified as 32-D/5.1 and 32-D/5.2. Exclusion criteria included: (1) bilateral femur shaft fracture; (2) pathological fracture resulting from cerebral palsy, bone tumor, or osteogenesis imperfecta; and (3) follow-up periods of less than one year.

Ultrasonic apparatus

GE LOGIOe ultrasonic instrument(GE Healthcare, Milwaukee, WI, USA), 7.0 ~ 12.5 MHz variable frequency, shallow surface transducer(GE Healthcare, Tokyo).

Optimal instrument settings significantly enhance the sensitivity of the apparatus; consequently, the frequency and penetration depth were meticulously adjusted to acquire images of exceptional quality.

All surgeries were performed by the same experienced pediatric orthopedic surgeon (PZ).

Surgical techniques

Under general anesthesia, the patients were placed in a supine position with the surgical site being painted and draped. An adequate quantity of sterile ultrasonic coupling gel was applied to the sonographic transducer, which, along with the connecting cable, was subsequently enveloped in sterile plastic sleeves. Sterile bandages were used to wrap and fix the plastic sleeve on the transducer's surface to prevent sliding. Throughout the surgical procedure, sterile coupling gel, povidone-.

iodine, alcohol, or even normal saline could be employed between the sheathed ultrasonic transducer and the skin surface of the patient's thigh, enhancing the clarity and resolution of ultrasound images.

Closed reduction of a fracture was performed under ultrasonic guidance using manual manipulation. The leg was examined from four main directions: anterior, posterior, medial, and lateral.The nature of cortical bone causes reflection of ultrasound waves and produces a clear distinction from soft tissue, generating a hyperechoic reflection from the bony surface. The fracture is characterized by a discontinuity in the hyperechoic reflection. Initially, sagittal scanning was performed. The transducer was positioned anteriorly on the thigh, systematically scanning from the proximal to distal femur. The location of the discontinuous hyperechoic reflection indicated the fracture site. By evaluating the displacement of fractures displayed in different directions on ultrasound images, we can understand the extent of fracture displacement and perform manipulative reduction in real time. Ultrasonography enables surgeons to precisely understand the true angular position of femoral shaft fractures and to continuously monitor reduction across multiple planes. Similarly, coronal scanning and reduction was performed subsequently. Prior to the insertion of the initial Schanz pins, fractures were reduced under the guidance of ultrasonography. The displacement, which encompasses anterior or posterior, medial or lateral, and shortening or lengthening directions, could be identified approximately. With gentle traction applied to the thigh by an assistant, the surgeon skillfully realigned the fragment's tip using lateral digital pressure.

In cases where fracture reduction could not be achieved by manipulation, a 2.5-mm to 3.0-mm K-wire was introduced percutaneously, depending on the patient's age and size, under ultrasonographic supervision. Analogous to the Kapandji [17] technique for treating distal radius fractures, the K-wire was percutaneously inserted from an anterolateral approach to the fracture site, functioning as a lever arm (K-wire leverage technique) to facilitate fracture reduction.If an adequate reduction still could not be achieved satisfactorily, we would insert Schanz pins on both sides of the fracture. The primary surgeon would grasp the Schanz pins on either side of the fracture with both hands, using them as leverage to further reduce the fracture in a precise manner. Typically, once the Schanz pins had been positioned, only slight adjustments were needed.

All children underwent ultrasound-guided closed reduction and external fixation using AO-type hybrid frame biplanar external fixators. The fractures were usually reduced before insertion of the Schanz pins under ultrasonography guidance.After achieving satisfactory realignment, four Schanz pins (Apex self-drilling) with diameters of either 3.5–5 mm were meticulously positioned via the anterolateral aspect of the femur along the designated safe zone, thereby circumventing potential injury to the neurovascular structures. The initial proximal-inferior pin was inserted through a lateral approach, utilizing minimal transverse skin incisions and a manual drill, at a distance of approximately 2–3 cm proximal to the fracture line. During this process, soft tissue preservation was ensured by employing a drill sleeve. Subsequently, the second proximal-superior pin was inserted into the femoral shaft along the same plane, maintaining a perpendicular orientation to the shaft and a parallel alignment to the first pin. The distal-proximal pin was carefully inserted close to the fracture fragment, while the distal-inferior pin was inserted approximately 3–4 cm to the epiphysis. During the drilling process, ultrasonography was utilized to dynamically check the direction of the needle in real time, to detect whether the pins has protruded, and to measure the length of the protrusion. It is essential to avoid placing the pins too posteriorly or too proximally. After the insertion of the pins, a rod was held with the clamp when the fracture was deemed satisfactorily reduced without affecting knee Range of Motion (ROM). Fluoroscopy is required for confirming the entire location of external fixation because US can identify only the near cortex of the bone.

Pin sites were enveloped by sterile gauze at surgery. After surgery, full weight bearing was allowed. Physiotherapy, including quadriceps strengthening exercise, was provided during the hospitalization period, primarily focusing on initiating mobilization utilizing crutches or a walking frame. Knee ROM exercises were started 3–5 days postoperatively.

Caregivers or the children themselves were instructed on the proper care of pin sites. Upon observation of radiographic confirmation of union and the patient's ability to ambulate independently without experiencing discomfort, external fixators would be removed in an outpatient setting without anesthesia. Following the external fixator's removal, no external protection was used, and the patients were permitted unrestrained weight bearing except for a temporary delay in sport activities for 3 to 4 weeks.

Evaluation tools

Information about age, gender, body mass index (BMI), laterality, fracture pattern, mechanism of injury, associated lesions, surgical time, intraoperative fluoroscopy count, hospital stay length, fracture fixation duration, complications, limb length discrepancy, and other additional pertinent findings was collected.[Tables 1 and 2].

After treatment, clinical and radiographic data were collected during the follow up period. The patients were followed up in the first month, second month, estimated healing, sixth month after the injury and annually thereafter. At the last follow-up, the quality of reduction of the femoral shaft fracture was assessed using Flynn's grading system [18]. This system encompasses limb length

Table 1 Characteristics of pediatric patients with LUFSF treated by US-guided closed reduction and external fixation

Case	Age	Gender	BMI (kg/m2)	Laterality	Fracture Pattern	AO/OTA	Injury Mechanism	Associated Lesions
1	6.9	Female	15.2	Left	long oblique	32-D/5.1	Fall	-
2	7.1	Female	17.1	Right	long oblique	32-D/5.1	Fall	-
3	9.2	Male	16	Right	spiral	32-D/5.1	vehicle accident	-
4	8.4	Male	17.7	Left	long oblique	32-D/5.1	Fall	-
5	7.6	Female	18	Right	spiral	32-D/5.1	Fall	-
6	6.8	Male	15.3	Left	long oblique	32-D/5.1	Fall	-
7	8.6	Male	18.2	Left	spiral	32-D/5.1	Fall	-
8	9.1	Male	17.2	Left	long oblique	32-D/5.1	Fall	-
9	6.9	Female	14	Right	comminuted	32-D/5.2	vehicle accident	-
10	7.0	Male	17.7	Right	long oblique	32-D/5.1	Fall	-
11	5.1	Female	12.5	Left	long oblique	32-D/5.1	Fall	-
12	8.3	Male	23.7	Left	comminuted	32-D/5.2	Fall	-
13	6.3	Male	14.3	Left	long oblique	32-D/5.1	Fall	-
14	5.8	Female	17.1	Left	long oblique	32-D/5.1	vehicle accident	scalp hematoma
15	11	Male	17.3	Right	spiral	32-D/5.1	Fall	-
16	6.2	Male	16.6	Right	long oblique	32-D/5.1	vehicle accident	-
17	6.8	Male	15.2	Right	long oblique	32-D/5.1	Fall	-
18	5.5	Male	15.8	Left	comminuted	32-D/5.2	vehicle accident	-
19	10.2	Male	18.7	Left	comminuted	32-D/5.2	Fall	-

Table 2 Surgery related information and postoperative information

Case	Surgical time (min)	Intraoperativ-e fluoroscopy count	Hospital stay (days)	Fixation duration (weeks)	Complications	LLD (mm)	Flynn's scale
1	56	7	6	8	-	6	Excellent
2	63	6	8	10	pin-site infection	5	Satisfactory
3	54	7	5	8	-	4	Excellent
4	48	5	9	9	-	8	Excellent
5	79	16	6	16	pin-site infection	5	Satisfactory
6	66	6	8	20	pin-site infection	11	Satisfactory
7	69	5	7	8	-	7	Excellent
8	72	4	8	8	-	3	Excellent
9	65	5	5	19	Knee joint stiffness	13	Satisfactory
10	58	4	6	8	pin-site infection	3	Satisfactory
11	95	14	4	7	-	4	Excellent
12	90	7	7	15	-	4	Excellent
13	68	2	4	8	pin-site infection	7	Satisfactory
14	105	13	8	8	-	8	Excellent
15	70	4	6	7	-	5	Excellent
16	76	6	5	20	Knee joint stiffness	6	Satisfactory
17	61	2	5	10	-	9	Excellent
18	65	3	8	10	pin-site infection	6	Satisfactory
19	77	7	6	9	-	7	Excellent

LLD, limb length discrepancy

discrepancy, angular deformity, and complications, with the excellent category defined as having a limb length discrepancy of less than 1.0 cm, angular deformity less than 5°, and no complications. The satisfactory category is defined as having a limb length discrepancy of 1.0–2.0 cm, angular deformity less than 10°, and few or resolvable complications. The poor category is defined as having a limb length discrepancy of more than 2.0 cm, angular deformity greater than 10°, with severe or persistent complications.

Results

The study included 19 patients diagnosed with LUFSFs who underwent treatment with ultrasound-guided closed reduction and external fixation. Of the patients, 13 were male and 6 were female. Table 1 provides a summary of their general information. The patients' ages ranged from 5.1 to 11 years, with an average age of 7.5 years. Of the 19 fractures, 11 occurred in the left limb and 8 in the right, all of which were closed fractures. The causes of injury were vehicle accidents for 5 patients and falls from height for 14 patients. Based on the AO/OTA classification of fracture type [16], 4 patients had type 32-D/5.2 and 15 patients had type 32-D/5.1. The average surgical time for this group of patients was 70.3 min (ranging from 48 to 105 min), with an average number of 6.5 intraoperative fluoroscopy count (ranging from 2 to 16). The external fixation was removed at an average of 10.9 weeks (ranging from 7 to 20 weeks), and no re-fractures occurred. All patients were followed-up for more than 12 months after surgery. At the final follow-up, the affected limbs showed good function, with no restrictions in hip and knee joint mobility compared to the unaffected side. At the last follow-up, the reduction quality of femoral shaft fractures was assessed using the efficacy evaluation system proposed by Flynn et al. [18]. The results showed that the reduction quality was excellent in 11 cases and satisfactory in 8 cases, yielding a combined success rate of 100% (19/19).All patients had no obvious deformities such as angulation, shortening, overgrowth or rotational malalignment, and the lower limb axis was restored well. Although pin site infections were frequently observed (6 out of 19), they were superficial and were effectively managed with local pin care and a brief course of oral antibiotics. None of the patients experienced any deeper infections. None of the patients required intravenous antibiotics or early removal of the external fixator due to loosening. Temporary stiffness of the knee joint was observed in 2 patients. At the last follow-up visit, two patients exhibited a lower limb discrepancy greater than 10 mm. See Fig. 1 for typical case images.

Discussion

Children are not miniature adults, and they possess unique physiological characteristics. In cases of LUFSFs, anatomical reduction is often unnecessary due to their exceptional molding potential. Although both spica casting, or traction, followed by spica casting have the potential to achieve good healing effects, there are still many problems. For example, early spica casting can easily lead to excessive shortening and angular deformity, and there are also many disadvantages for traction methods, such as pain, skin complications, and prolonged hospital stay. Due to enhanced understanding of the biology underlying fracture healing alongside advancements in fixation methods and operative techniques, there has been a general trend towards operative intervention for stabilizing femoral shaft fractures in the pediatric population [19]. While plate fixation effectively stabilizes fractures, it involves longer surgical times and greater trauma compared to other methods, such as elastic intramedullary nailing, and is more likely to cause deformities like distal femoral valgus [20, 21]. Flexible intramedullary nailing can be challenging in LUFSFs due to potential risks of unacceptable shortening [22]. A strong note of ESIN caution was struck by the Denver Children's Hospital group [5].They presented a shocking 62% overall complication rate (major and minor) with the flexible nail technique and largely attributed the risk of such complications to LUFSFs. They concluded that in patients with LUFSFs, consideration should be given to methods of treatment other than titanium flexible intramedullary nails. While elastic intramedullary nails require higher precision in fracture reduction to be effectively inserted and fixed, external fixation devices are well-suited to the physiological characteristics of pediatric femurs, as they can achieve stable fixation without requiring anatomical reduction, thereby facilitating early rehabilitation for the young patients. Additionally, external fixators are associated with lower levels of trauma than intramedullary nails, and can be easily removed in an outpatient setting without requiring a second hospitalization or anesthesia. External fixation offers advantages in the stabilization of these fractures, such as technical ease of manipulation, minimal complication rates, and a low risk of physeal damage, which can make it a beneficial option compared to intramedullary nails or plating under specific circumstances [23].

Ultrasound-guided reduction and external fixation has distinct advantages in the treatment of LUFSFs. Firstly, without the use of radiation, real-time ultrasound can be used to observe the fracture end and determine the direction of displacement from the four longitudinal sections of the femur's anterior, posterior, medial, and lateral sides. During reduction, the first and second assistants maintain continuous traction, while the surgeon uses

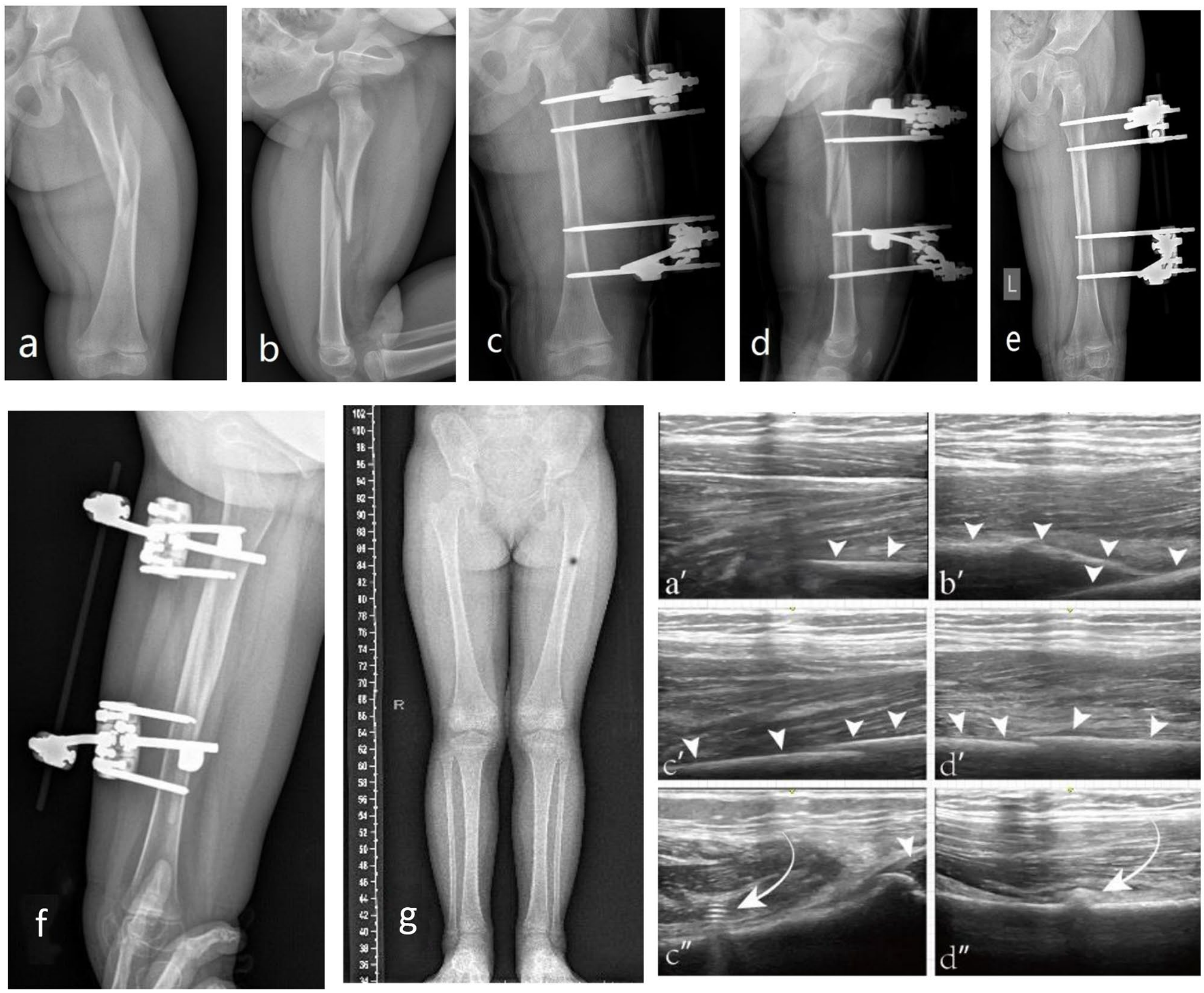

Fig. 1 (**a**, **b**) :a long oblique femur shaft fracture in an 5.8-year-old girl; (**c**, **d**): postoperative radiographs; (**e**, **f**):removal of EF; (**g**): X-ray AP and lateral view of the same patient 18 months postoperative.(**a**′,**b**′):The ultrasound image before the reduction of the fracture; hyperechoic lines representing the cortical bone at both sides of the fracture indicated by the arrowhead. The high density of the cortical bone induces the reflection of a substantial proportion of ultrasonic waves, consequently constraining ultrasonography to the examination of just one side of the cortical bone. However, this limitation does not hinder our intraoperative observations and assessments of fractures from various directions.(**c**′,**d**′):Real-time ultrasound-guided reduction and fixation had been performed at the fracture site and the alignment of the fracture improved markedly. (**c**″,**d**″):the curved arrow in **c**″ indicated the entry point of the Schanz pin, while the arrowhead indicated the distal femoral epiphysis. The curved arrow in **d**″ indicated the exit point of the Schanz pin.The ultrasound imaging features facilitated the selection of appropriate needle insertion points, avoiding the growth plate and fracture site, and providing real-time information on the length of Schanz needle penetration, obviating the need for repetitive fluoroscopic guidance

ultrasound to examine the fracture's distal end from the four longitudinal sections to determine the direction of displacement and instruct the assistants to adjust the traction direction and force to reduce the fracture.

Secondly, the surgeon can adjust the fracture alignment under ultrasound guidance by holding the Schanz pins at both ends of the fracture. The Schanz pins appear as bright signals on the ultrasound image, allowing us to monitor whether the pin has penetrated the opposite cortical bone and measure its protruding length during the needle-penetration process without relying on fluoroscopy. Ultrasound-guided treatment of LUFSFs can effectively reduce surgical time, and when the ultrasound examination shows good alignment of the fracture end on the four longitudinal sections, indicating good reduction, the combination of external fixation can be performed under ultrasound guidance and monitoring. Ultrasonography was used in the diagnosis of children forearm fractures, with a sensitivity of 91.5% and a specificity of 87.6%, no better or worse than X-ray [24]. Thanks to the real-time ultrasound system, surgeons can continuously observe the translation and angulation while manipulating the distal segment to reduce the fracture without radiation exposure [25].

Thirdly, ultrasound examination can accurately identify the femoral distal epiphysis and facilitate needle insertion for the distal segment's fracture location, avoiding epiphyseal injury and repeated needle penetration, which cannot be shown by X-ray examination due to the cartilage covering the epiphysis. In addition, ultrasound can reduce radiation exposure to both doctors and patients during the operation. Intraoperative fluoroscopy produces ionizing radiation, and although the current clinical radiation dose is small, children's growing bone tissue is more sensitive to radiation and more susceptible to X-ray damage [26]. Zhang et al. conducted a comparative study between ultrasound-guided reduction and fixation of pediatric femoral shaft fractures and traditional radioscopy-guided reduction and fixation. The findings revealed that the average number of radioscopy instances in the radioscopic group was 51.6 times, while the intraoperative average number of radioscopy instances in the ultrasound group was only 13.8 times. Notably, the utilization of ultrasound guidance resulted in a significant reduction ($p<0.05$) in the average number of radioscopy instances during the procedure, as compared to the procedures that relied solely on radioscopy guidance [27]. In the group of our study, the average number of intraoperative fluoroscopy was only 6.5 times. This data not only highlights the reduced radiation exposure compared to traditional fluoroscopy-guided surgery and ultrasound-guided ESIN fixation, but also emphasizes ultrasound's efficacy in minimizing radiation exposure during complex or unstable fracture treatments.

Before implementing this technique, the operator must receive training in ultrasound imaging of the morphology of the distal femoral epiphysis and shaft in children. Comparing the ultrasound images of the affected and unaffected sides can facilitate the accurate diagnosis of fractures. According to Hedlin et al. [28], physicians without prior ultrasound experience can achieve the same level of diagnostic ability as experienced ultrasound imaging physicians after attending a 1.5-hour course on ultrasound diagnosis of pediatric distal radius fractures.A prospective observational study conducted by Thomas et al. [29] revealed that, after a standardized formal training session lasting 1 h, non-ultrasonographers were able to perform ultrasound-based detection of long-bone fractures with relative ease. Notably, none of the physicians possessed prior ultrasonography expertise. Following the training, the participating physicians commented on the apparent ease of identifying mid-shaft fractures of the femur or humerus.Ultrasound shows promise as an effective diagnostic imaging tool in fracture detection.

It must be noted that with extremity fractures, the risk of X-ray radiation exposure during surgery is much higher for surgeons, assistants, and anesthetists than for patients, due to the frequent nature of such procedures for them. Compared with other radiation-exposed workers, orthopedic surgeons are at significantly higher risk of developing malignant disease [30]. It is crucial to raise awareness of radiation exposure among orthopedic surgeons, and to make concerted efforts to minimize exposure during surgeries, not only for the health of surgeons themselves but also for the entire surgical team [31]. Ultrasound-guided surgery can reduce the need for fluoroscopy during procedures, thereby lessening radiation exposure to the surgical team. However, patients are not only exposed to radiation during surgery; follow-up visits often require multiple X-ray examinations, which also involve radiation. Although ultrasound is helpful for fracture reduction and fixation, it primarily reduces radiation exposure during surgery. The use of ultrasound to assess fracture healing post-surgery is still not a mature technology and requires further research.

Typical soft tissue complications after external fixation of femoral fractures encompass pin tract infections, pin site scarring, and a reduced range of motion in the knee joint. The most common complication is infection or inflammation at the site of the pin. Pin tract infection and drainage were quite common during the application of an external fixator[[32]. In our study, 6 cases of superficial pin tract infection occurred, which resolved with oral antibiotics and enhanced needle tract care. No deep infections were observed. In our cases, the visibility of resultant scars in our cases was dependent on whether an infection has occurred or not. If an infection occurred, the scarring at the pin site usually became more noticeable. Another significant consideration is the impediment to muscular motion, especially around the knee joint, due to the Schanz pins. This can lead to obstacles in knee joint mobility. To mitigate this issue, we've endeavored to insert the pins while the knee is in a flexed position to minimize post-operative limb mobility impact. Early post-operative weight-bearing coupled with active functional exercises has been our standard practice. However, temporary stiffness of the knee joint was still observed in 2 patients but it returned to normal after removal of the EF and subsequent rehabilitation.

There are still some limitations to this study. The study is hampered by a relatively small sample size. The absence of comparable groups that received alternative surgical techniques serves as an additional limitation. Although all the patients achieved clinical and radiographic union, further studies with more patients and long-term follow-up are necessary. When the operator uses the ultrasound probe to examine the fracture site, two assistants are needed to maintain continuous traction. In this group, intraoperative fluoroscopy remained indispensable to confirm the alignment and the entire location of external fixation. Despite the limitations, the findings of this study reveal that ultrasound-guided closed reduction and external fixation provides satisfactory outcomes, offering a viable alternative for the management of LUFSFs in children.

Conclusions

The technique of ultrasound-guided closed reduction combined with external fixation offers favorable outcomes for children aged 5 to 11 years with LUFSFs, reducing reliance on fluoroscopic guidance.

Abbreviations

LUFSFs	Length-unstable femoral shaft fractures
ROM	Range of motion
BMI	Body mass index
LLD	Limb length discrepancy

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Not applicable.

Author contributions

JW participated in the literature search, study design, and paper drafting and editing. XS, TW and JL were in charge of gathering data and doing follow-up evaluations. XC and YL were in charge of the language polishing and the grammar revision.BT and PZ designed the study, modified and approved the final version of the manuscript.All authors read and approved the final manuscript.

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Data availability

The datasets used and analyzed during the present study are not publicly available due to ethical considerations but are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study adheres to the principles of the Declaration of Helsinki and received approval from the Ethics Committee of Wuhan Children's Hospital (Wuhan Maternal and Child Healthcare Hospital), Tongji Medical College, Huazhong University of Science & Technology. Informed consent to participate in this study was obtained from the legal guardian or next of kin for all patients. All methods were carried out in accordance with the relevant guidelines and regulations.

Consent for publication

Informed consent for the publication of their clinical data and accompanying images was acquired from the legal guardian or next of kin of all patients.

Competing interests

The authors declare no competing interests.

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