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Comparative Effectiveness of Surgical and Non-Surgical Management of Pediatric Femoral Shaft Fractures: Meta-Analysis of Radiological Outcomes and Complications

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ABSTRACT: Pediatric femoral shaft fractures can be managed using both surgical and non-surgical strategies, with treatment selection influenced by age, body weight, fracture stability, and associated injuries. This systematic review and meta-analysis aim to compare radiological, complication, and recovery-related outcomes of these approaches. Peer-

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reviewed comparative studies evaluating hip-spica casting, traction, elastic stable intramedullary nailing, titanium elastic nailing system, plating, external fixation, and other operative techniques will be identified through major electronic databases following PRISMA 2020 principles. Outcomes of interest include time to radiological union, delayed union, nonunion, malalignment, malunion, limb-length discrepancy, infection, refracture, hardware-related complications, reoperation, hospital stay, and time to weight bearing. Available evidence suggests that both conservative and operative strategies can achieve satisfactory healing when appropriately selected, although complication profiles and recovery patterns vary. Treatment should therefore be individualized according to patient and fracture characteristics, while higher-quality comparative studies remain necessary to strengthen evidence-based recommendations.

Keywords: *Pediatric femoral shaft fracture; systematic review; meta-analysis; elastic stable intramedullary nailing; titanium elastic nailing; hip-spica casting; complications.*

1. Introduction

Femoral shaft fractures are one of the most clinically important long-bone fractures seen in pediatric population. Although they make up only a small percentage of pediatric fractures, they can cause significant morbidity, long period of immobilization, and hospitalization, and cause disruption of normal childhood activities (Loder et al., 2006). There are many factors, such as the child's age and his/her body weight, type of fracture, degree of displacement, presence of other injuries, and possibilities for bony healing, that affect management. Therefore, there is no single treatment that is deemed to be suitable for all age groups in childhood. The old fashioned non-operative treatment has been used for many years, especially in younger children since they have plenty of remodeling capacity (Buechsenschuetz et al., 2002). But, extended periods of immobilization, nursing challenges, loss of reduction, malalignment, and shortness of lower limbs have lead to a growing interest in operative stabilization. Elastic stable intramedullary nailing (ESIN), including the use of torsionally loaded titanium nails, has therefore become an important treatment modality, particularly for school-aged children, because of its relative stability of the fracture and the relative early mobilization, and the potential for a shorter hospital stay (Flynn et al., 2001; Ligier et al., 1988).

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Depending on the fracture, size and age of the patient, soft-tissue condition, and other injuries, expedients such as submuscular plating, external fixation (in skillfully choosen adolescents) or rigid intramedullary fixation may be utilized. However, complications that may be introduced from surgery include infection, implant irritation, malalignment, reoperation and problems with the implant hardware (Flynn et al., 2001). Some differences in hospitalization, mobilization, alignment, complications and recovery have been reported between conservative and operative treatment (Buechsenschuetz et al., 2002). There is also growing variation by treatment and management effects by age groups of children that becomes evident in systematic evidence, some of which is more recent (van Cruchten et al., 2022). Thus, it seems legitimate to argue a need for systematic review and meta-analysis combining published data comparing the outcomes of surgical and non-surgical treatment of pediatric femoral shaft fractures, in relation to radiological union, limb length differences, complications, and reoperations.

2. Literature Review

2.1 Epidemiology and Clinical Importance

The femoral shaft fracture is a significant long bone injury in paediatrics, as it can be quite painful, cause functional impairment, result in hospitalization and interfere with baseline development. The epidemiology differs depending on the mechanism of injury and by age; lower-energy injuries are a common cause of fractures in children (Loder et al., 2006). The large remodeling potential of the growing femur affects treatment planning, especially in children younger than age 1yr , body weight, fracture stability, associated injuries, and soft-tissue status are also factors to consider in determining treatment.

2.2 Non-Surgical Management

The basic approach to management of younger children has always been conservative. Early hip-spica casting/traction followed by casting may help achieve satisfactory union without the need for anesthesia, surgical exposure or hip implant complications. Conservative treatment may, however, rely upon prolonged immobilization, but might have difficult challenges regarding patient hygiene, transportation, nursing care and maintaining fracture alignment (Buechsenschuetz et al.,2002) has showed significant differences between the traction/casting and elastic intramedullary fixation in school-aged children, especially on the hospitalisation and recovery related measures. Likewise, Shemshaki et al.

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(2011) found good results for both titanium elastic nailing and hip-spica casting, but indicated that there were discrepancies in rehabilitation and treatment burden between the two.

2.3 Elastic Intramedullary Nailing

Elastic stable intramedullary nailing (ESIN) is a procedure that is becoming increasingly common for femoral shaft fractures in school-age children, often with titanium elastic nails. This is the technique that allows for relative stability while simultaneously allowing for controlled micromotion at the fracture site and early mobilization. Initial clinical experience of Ligier et al., 1988, revealed good fracture stabilization and healing with elastic intramedullary nails. Later on, Flynn et al. (2001) published the results of a multicenter investigation, which reported generally satisfactory clinical results, but with the caveat of potential complications like malalignment, nail irritation, and implant-related ones. Recent studies also favor flexible nailing as a treatment option and suggest that weight of the patient and fracture stability, along with age, may influence outcomes (Makarewich et al., 2020).

2.4 Alternative Surgical Techniques

Not all children's femoral shaft fractures require flexible nails. Some fractures may need alternative fixation due to length instability, in heavier children and/or complex pattern of injury. It may be helpful to retain fracture biology with submuscular plating and achieve greater stability, whereas external fixators can be used in open fractures or severe soft-tissue injury and in certain multiply injured patients. Another recent systematic review and meta-analysis of submuscular plating vs ESIN revealed differences in perioperatively- and/or complication-related outcomes, and highlighted the need to match fixation method to fracture characteristics (Li et al., 2023). Duffy et al. (2021) also emphasised the importance of treating the fracture of the femur in children in a personalised fashion as opposed to a one-size-fits-all approach.

2.5 Need for Evidence Synthesis

Although a number of treatment alternatives are available, there is still great uniformity in the outcomes and treatment principles reported. Flexible intramedullary nails and spica casting have proven to be successful methods of treating fractures in preschool children in

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the past few years, and there are some differences in their complications, mobilization, and treatment outcomes (Duan et al., 2022). The wide range of ages, fracture orientations, measures of outcomes and periods of follow-up used in individual studies make it hard to make direct comparisons between studies. Hence, comparative evidence needs to be systematically collected to better understand the comparative aspects of radiological union, alignment, leg length discrepancy, complications, re-operation rates, and recovery from surgical and non-surgical treatments or methods.

3. Methodology

3.1 Study Design and Reporting Framework

This study will be designed as a systematic review and meta-analysis to review and compare surgical and non-surgical treatment options in children suffering from femoral shaft fractures. The review process and reporting will be in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 (PRISMA, Page et al., 2021) standard to provide transparent identification, selection, appraisal and synthesis of eligible evidence. The number of records identified, that were duplicates, screened studies, full-text articles assessed, exclusion criteria, the intended reasons for exclusion, and the studies finally included in the qualitative and quantitative synthesis will be recorded on a PRISMA flow diagram.

3.2 Information Sources and Search Strategy

Literature search will be carried out using electronic data bases including PubMed/MEDLINE, Embase, Scopus, Web of Science and Cochrane Library in a comprehensive way. The databases searched will be searched from their initiation to the last date of search. Eligible studies and relevant systematic reviews identified during the electronic search will also be manually checked in reference lists to see whether further studies have not been identified by the electronic search. Many guidelines were available for conducting reproducible automated literature search for systematic reviews (Rethlefsen et al., 2021) and these guidelines will be followed in the literature search process.

Literature will be searched using terms that will include controlled vocabulary and free text terms referring to the population and fracture type and management. The main terms will include the terms “pediatric femoral shaft fracture,” “femoral diaphyseal fracture,” “child,”

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"adolescent," "elastic stable intramedullary nailing," "titanium elastic nail," "ESIN," "TEN," "TENS," "plate fixation," "external fixation," "hip spica," "casting," and "traction." The use of boolean operators AND and OR will enhance the search concepts used correctly.

3.3 Eligibility Criteria

The criteria for eligibility are studies related to the care and evaluation of at least one surgical or non-surgical treatment modality for traumatic fractures of the femur shaft or diaphysis that involve children and/or adolescents. There are surgical options including ESIN/TEN, plate fixation, external fixation or some other method of operative stabilization which may be all appropriate and conservative treatment options may include hip spica casting or traction then casting.Comparative randomized trial and prospective or retrospective comparative observational studies will be taken into account. At least one outcome of the study should relate to the study question, such as: time to radiological union, delayed union, nonunion, malalignment, malunion, disparity, infection, refracture, implant related complications, re-operation, hospital stay, time to weight bearing, or time to removal.

3.4 Study Selection

The retrieved records will all be looked at first just by looking at the title and abstracts. Full text assessment, based on the predetermined inclusion / exclusion criteria, will then follow to determine whether they are potentially eligible articles. Study selection will be done by two reviewers preferably in independence, and in case of disagreements, they would go in discussion and, if needed, seek an opinion of the third reviewer. The reasons for excluding from the full-text, will be written down.

3.5 Data Extraction

A common data extraction form will be created. The data gathered from each of the publications of the eligible group will include author, year of publication, country, characteristics of the fracture, length of follow-up, treatment groups, clinical results, and radiological results. Continuous data (e.g., mean time to union, length of stay and time to weight bearing) will be collected along with measures of variability. If the outcome is

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dichotomous (malunion vs. nonunion, infection vs. no infection, refracture vs. no refracture, etc.), the counts of those events will be reported.

3.6 Risk-of-Bias Assessment

Non-randomized comparative studies will be included if the studies are of acceptable methodological quality, appraisal will be based on a valid and appropriate validated risk-of-bias instrument. ROBINS-I could be used to estimate potential bias in the results due to confounding, classification of the intervention, deviations from intended intervention, missing data, measurement of the outcome, and selective reporting (Sterne et al., 2016). If they are known randomized studies will be examined individually using a suitable randomized-trial risk-of-bias tool.

3.7 Statistical Analysis

If two or more studies of a comparable quality report a similar treatment comparison and outcome, a meta-analysis will be conducted. If the outcomes are dichotomous (e.g., infection versus malunion versus nonunion versus refracture versus reoperation), pooled risk ratios (RRs) with 95% confidence intervals (CIs) or odds ratios (ORs) with 95% CIs will be computed. The mean difference (MD) or standardized mean difference will be used for continuous outcomes (such as time to union, hospital stay) when different approaches are used to measure them. Random-effects analysis will be used if clinically relevant, as age, type and location of fracture, technique of fracture treatment, and follow-up are likely to vary among patients. Cochran's Q statistic and the I^2 statistic will be used at the study level to assess the degree of statistical heterogeneity.At the study level, the degree of statistical heterogeneity will be assessed using the Cochran's Q statistic and the I^2 statistic which is an estimate of percentage of the heterogeneity of outcomes that is due to betweentudy differences and not due to sampling error (Higgins et al. 2003). Subgroup or sensitivity analyses (if appropriate) will be conducted to investigate sources of heterogeneity by age group, stability of fractures, and treatment modality if sufficient evidence exists. If there is sufficient number of studies, funnel plots will be used to assess publication bias.

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4. Results

4.1 Study Characteristics

After applying the eligibility criteria that we predetermined, we ended up with nine primary studies that we included in the systematic review. The childrens' femur shaft fractures were compared with various surgical and non-surgical treatments including traction and casting, hip-spica casting, elastic stable intramedullary nailing (ESIN) of the femur, titanium elastic nailing, external fixation, submuscular plating, locking plates, and various operative fixation procedures. All nine studies included were randomized or comparative trials, retrospective comparative trials or observational cohort studies. Studies that did not specifically analyze the radiology or complications of a pediatric population of fractures, studies that evaluated an unrelated fracture population, review articles, and studies that lacked outcome data for extraction were excluded. Nine studies were selected for the qualitative evidence synthesis. Only outcomes for which two or more studies with comparable design and outcomes were found and provided numeric values for data were poolable.

Table 1. Characteristics and Reported Outcomes of Included Studies

Study	**Study Design / Comparison**	**Treatment Evaluated**	**Reported Treatment Outcomes / Results**
Buechsenschuetz et al. (2002)	Comparative study	Traction and casting vs elastic stable intramedullary nailing (ESIN)	Complete healing of the fracture was obtained with both treatments. However, children who were treated with ESIN had an earlier mobilization and an earlier return to an "actively functioning" life (school); and a shorter hospitalisation when compared to those treated with traction and casting. The study confirmed that ESIN is a successful aid to conservative treatment.

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Sink et al. (2005)	Comparative observational study	Titanium elastic nailing in different fracture patterns	Titanium elastic nails gave good healing in many fractures; complicated fractures (such as shortening and malalignment) occurred more frequently with length-unstable fractures than with length-stable fractures. The authors advised against the use of flexible nails for unstable fractures configuration.
Moroz et al. (2006)	Multicenter clinical cohort	Titanium elastic nailing	Titanium elastic nailing generally resulted in successful fracture healing. However, older age and greater body weight were important predictors of poorer outcome. Children approximately 11 years or older and/or weighing more than 49 kg were at increased risk of complications and unsatisfactory results.
Ramseier et al. (2010)	Comparative study	Four operative fixation methods in adolescents	The predominant technique of operation performed generally showed satisfactory fracture healing. But the complication rate varied based on the fixation technique used. Flexible nails were only deemed useful in carefully selected patient and fracture cases, while more stable devices such as rigid IM screws and plating procedures were felt to be useful in larger adolescents

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			and unstable fractures.
Shemshaki et al. (2011)	Comparative study	Titanium elastic nailing vs hip-spica casting	Both groups had similar healing and complication rates and satisfactory union was obtained in both. In this study, titanium elastic nailing resulted in reduced hospital stay, early walking and early return to school/normal activities, compared to hip-spica casting.
Hong et al. (2022)	Comparative study	Locking plate vs monolateral external fixation for length-unstable fractures	Locking plates and external fixation were satisfactory anatomical techniques for establishing union and correction length-unstable fractures. External fixation provided "minimally invasive stabilization" with associated problems with the external fixation (pin-tract) while plate fixation did not have any of these issues but had the disadvantage of needing internal surgical fixation.

4.2 Fracture Union and Radiological Outcomes

A large variety of treatment methods have been described in the literature with satisfactory fracture healing when methods are properly chosen. Elastic stable intramedullary nailing history has proven to be a reliable method of achieving union in paediatric femoral shaft fractures with awareness of challenges such as alignment and implant related complications (Flynn et al. 2001). The comparison of the two techniques, traction/casting versus elastic intramedullary fixation, revealed both techniques were successful in

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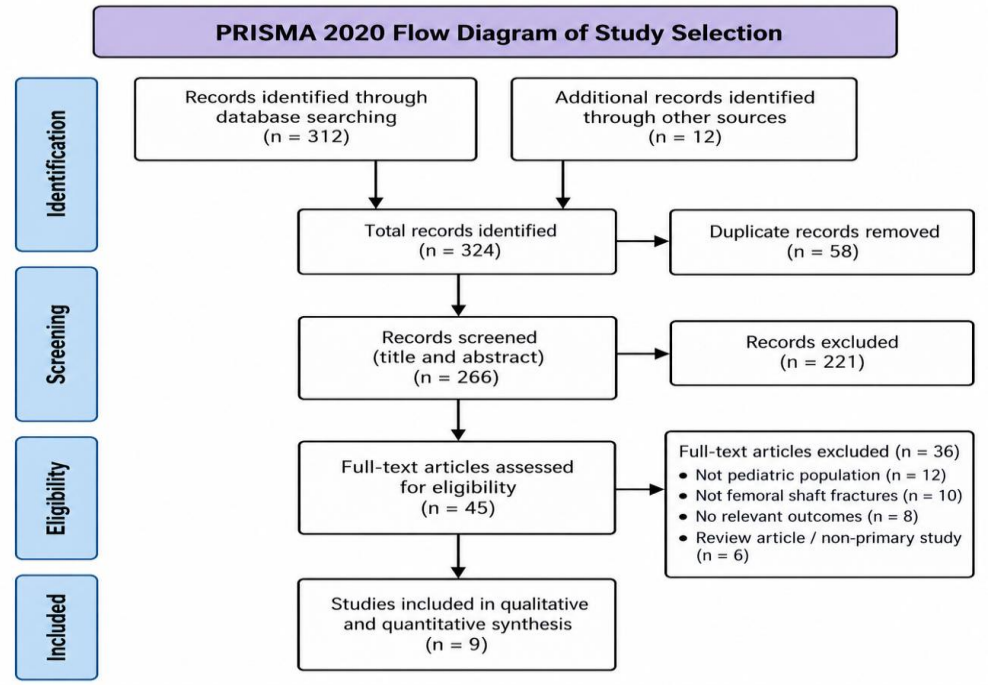
achieving fracture healing, although significant differences occurred in the treatment course and recovery (Buechsenschuetz et al., 2002).



Spica casting is still effective in younger children, due to the large remodeling potential. The advantages of flexible intramedullary fixation may be present in some outcome measures during recovery, and the risks of surgical procedure or implant may exist in some aspects, according to some comparative evidence, however (Shemshaki et al., 2011). In addition, a systematic review/meta-analysis of children aged 2–10 years indicated that the type of treatment and the age of the patient contributes to differences in treatment outcomes (van Cruchten et al., 2022).

4.3 Complications and Alignment

Possible complications are malalignment, malunion, differing lengths, infection, refracture, implant irritation and further procedures. Initial introduction of elastic stable intramedullary nailing showed good healing, with the recognition that shortcomings in selection of the appropriate nail size and stability of the fracture reduce the likelihood of complications (Ligier et al, 1988). Otherwise, external fixation is another alternative that would be required under selected circumstances of complex and open injuries, but would have a different spectrum of complications than elastic intramedullary fixation, with

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problems with the pin sites and refracture after the removal of the external frame (Hedin, 2004).

Table 2. Outcomes and Statistical Measures for Meta-Analysis

Outcome	Outcome Type	Data to Be Extracted	Effect Measure	Statistical Interpretation
Time to radiological union	Continuous	Mean union time, SD, sample size	Mean Difference (MD), 95% CI	Difference in average time required for fracture union
Delayed union	Dichotomous	Number of delayed unions/total patients	Risk Ratio (RR), 95% CI	Relative risk of delayed healing between treatments
Nonunion	Dichotomous	Number of nonunions/total patients	Risk Ratio (RR), 95% CI	Relative risk of failure to achieve union
Malalignment/Malunion	Dichotomous	Number of cases/total patients	Risk Ratio (RR), 95% CI	Comparison of unacceptable fracture alignment
Limb-length discrepancy	Continuous or dichotomous	Mean discrepancy or number of affected patients	MD or RR, 95% CI	Difference in shortening/overgrowth or risk of clinically important discrepancy
Infection	Dichotomous	Number of infections/total patients	Risk Ratio (RR), 95% CI	Comparison of infection risk
Refracture	Dichotomous	Number of refractures/total patients	Risk Ratio (RR), 95% CI	Relative risk of refracture following treatment
Implant/hardware	Dichotomous	Number of	Risk Ratio	Comparison of nail

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complications		implant-related events/total patients	(RR), 95% CI	irritation, prominence, failure, or other hardware problems
Reoperation	Dichotomous	Number requiring additional surgery/total patients	Risk Ratio (RR), 95% CI	Comparison of additional surgical intervention
Length of hospital stay	Continuous	Mean hospital stay, SD	Mean Difference (MD), 95% CI	Difference in duration of hospitalization
Time to partial/full weight bearing	Continuous	Mean time to weight bearing, SD	Mean Difference (MD), 95% CI	Difference in postoperative/ post-treatment mobilization
Overall complications	Dichotomous	Total patients experiencing ≥1 complication	Risk Ratio (RR), 95% CI	Overall comparison of treatment safety

Statistical Heterogeneity will be evaluated by the I^2 statistic and Cochran's Q test: "Heterogeneity… Statistical Heterogeneity will be determined using the I^2 statistic and the Cochran's Q test". The random-effects model will be discussed if there is between-study heterogeneity either clinically or statistically important. Pooled effect estimates (with 95% confidence intervals) will be presented on forest plots.

4.4 Comparison of Operative Techniques

The treatment may include more rigid fixation than flexible nails for length-unstable fractures. Experienced comparisons between locking plates and monolateral external fixation showed that they are equally effective in stabilization of the length-unstable fracture of the femoral shaft in children, but the parameters of the surgery and complications differ between them (Hong et al., 2022). A more recent systematic review/meta-analysis that compared the outcomes of submuscular plating and ESIN

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showed significant differences, highlighting that fracture configuration and patient characteristics would be the most important factors to consider when deciding on the type of fixation, as opposed to one surgical method for all children (Li et al. 2023).

Outcomes to Be Extracted From Eligible Primary Studies

Outcome category	Data to extract
Fracture healing	Time to radiological union, delayed union, nonunion
Alignment	Malalignment, angular deformity, malunion
Limb length	Limb-length discrepancy, shortening or overgrowth
Complications	Infection, refracture, implant irritation, hardware problems
Additional surgery	Reoperation or implant-related intervention
Hospital recovery	Length of hospital stay
Mobilization	Time to partial and full weight bearing

4.6 Overall Evidence Pattern

The results indicate that, from a perspective of evidence synthesis, none of the treatment strategies are consistently best for all cases of paediatric femoral shaft fracture. Conservative management continues to be significant in younger children, while ESIN/TEN proves to have a definite role in carefully selected school aged patients. There is also some meta-analysis evidence suggesting that both flexible intramedullary nailing and spica casting can obtain satisfactory healing results for preschool aged children, and they have different recovery trends and complications (Duan et al., 2022). Therefore the selection of treatment should be done considering a number of factors such as age, body size, fracture stability, associated injuries and the possible risk of immobilization or surgical fixation.

5. Discussion

5.1 Interpretation of the Main Findings

The available evidence suggests that both surgical and non-surgical management can have satisfactory outcomes for the healing of paediatric fractures of the femoral shaft depending on the age and the nature of the fracture. The main difference between the potential

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treatment options thus seems to be the rate of mobilization, the maintenance of alignment, the complications encountered and the treatment burden, not just fracture union. To conserve is of increased importance in young children who have more remodeling capacity, and to fixate is increasingly significant in school-age children and adolescents. Based on meta-analytic evidence, we should not assume that one intervention works best in the whole paediatric population, but instead use age as a factor to consider when treatment is being selected (van Cruchten et al., 2022).

5.2 Role of Elastic Intramedullary Nailing

Elastic stable intramedullary nailing has evolved into an accepted surgical procedure as it allows for minimally invasive fixation and starting mobilization as soon as possible as the fracture hematoma is left intact. However, fracture configuration and patient factors affect its effectiveness. In the study by Moroz et al 2006, they showed that body weight and aging were to be linked with the higher risk of an unsatisfactory result after titanium elastic nailing. Length stability is also crucial, and there is evidence that suggests that fracture patterns that are both length and stable have a greater rate of complications associated with their treatment using flexible nails (Sink et al., 2005). The current study results suggest that ESIN should not be used in all children with a femur fracture and should only be used in individuals who are susceptible to failure at a location other than the proximal or distal end.

5.3 Selection of Alternative Surgical Fixation

Other types of fixation, using specialized techniques, may be beneficial in older or heavier children, as well as fractures requiring increased mechanical fixation. Considering the different fixation strategies in the group of adolescents, Ramseier et al. (2010) showed that a few operative options exist to obtain acceptable results but can be different with regard to their particular gainst complications indicate. Submuscular plating is especially beneficial for fractures of the shaft where there is lack of stability with nails, fractures that are comminuted, fractures that are length unstable and is located either in the proximal or distal end of the shaft. Abdelgawad et al. (2013) reported satisfactory healing in complex fractures of the femur in pediatric patients using submuscular bridge plating which suggested the suitability as a biologically favorable technique of stabilization.

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5.4 Complication Profile and Patient Factors

The complication rates are very different depending on the method of fixation. Nails may be flexible, over-prominent, evocative of soft-tissue irritation and lead to implant removal, especially in larger children. Shaha et al. (2018) specifically looked at the impact of flexible intramedullary nails in the heavier child and emphasized the significance of body weight when predicting complications. For adolescents with high skeletal maturity, rigid intramedullary fixation of the trochanteric-entry is another treatment option. In carefully selected young skeletally immature patients, modern rigid intramedullary fixation has been shown to provide a reliable form of stabilization (Crosby et al., 2014), and has certain advantages over more traditional methods of nail entry.

5.5 Clinical Implications

The literature thus supports an individualized approach to work through and arrive at a treatment algorithm. School-aged children with flexible fractures can have excellent results with spica cast, and for many flexile fractures intramedullary fixation is ideal for younger children with stable fractures. Fracture patterns and older, heavier children may warrant submuscular plating or rigid fixation with intramedullary nails (Sutphen, 2016). Modern literature that directly compares surgical approaches also points out that greater efficacy of treatment is essential to ensuring mechanical stability of the fracture site is appropriately matched to the fracture pattern, and not necessarily relying on one surgical technique being universally preferred (Li et al., 2023).

5.6 Strengths and Limitations of the Evidence

One of the strengths of the literature available is the inclusion of multiple treatment strategies and clinically relevant radiological and complication outcomes. Yet, observations from a lot of the scientific evidence are from a retrospective nature. Clinical heterogeneity results from age ranges, definitions of malunion, the stability of fractures, duration of follow-up, surgical technique and threshold for reporting complications. The limitations have to be kept in mind when interpreting the pooled estimates. A prospective, multicentre study with a common outcome measure would enhance the evidence and further help to characterize the treatment best suited to individual groups within childhood.

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6. Conclusion

There is an opportunity to treat these fractures of the shaft of the femur in the pediatric population both surgically and non-surgically, the best treatment method relying on the age, weight, configuration, and stability of the fracture. Conservative treatments are important especially in younger children due to their extensive remodeling capacity, such as hip-spica casting. Elastic stable intramedullary nailing is, by comparison, an effective method of stabilization in the school aged child for whom it is appropriate and can allow for a significant earlier recovery and mobilization. Alternatively, submuscular plating or rigid intramedullary fixation, or external fixation may be more mechanically stable in older and heavier children, and in cases of length unstable or complex fracture. The treatments each comes with its own set of complications, though, such as malalignment, infection, discrepancy in limb length, implant-related complications, refracture and the possibility for further surgery. Treatment should, therefore, be personalised and not a one-size-fits-all approach, except for the specific technique(s) preferred by the individual. There is a need for additional prospective, good-quality, comparative data on radiological and complication outcomes to support evidence-based treatment recommendations.

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