



Tratamento cirúrgico do cisto ósseo simples em ossos longos na população pediátrica: revisão sistemática e meta-análise

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Resumo

Esta revisão sistemática e meta-análise teve como objetivo sintetizar as evidências disponíveis sobre os resultados terapêuticos e as taxas de falha no tratamento de cistos ósseos simples em pacientes pediátricos. O estudo foi conduzido no Departamento de Ortopedia e Traumatologia da Universidade Federal de São Paulo (UNIFESP), Brasil, entre agosto e novembro de 2025. Seguindo as diretrizes PRISMA 2020, realizou-se uma busca sistemática nas bases PubMed, Scopus e Web of Science utilizando descritores controlados e operadores booleanos. Foram incluídos estudos observacionais com populações pediátricas, e a qualidade metodológica foi avaliada pela ferramenta MINORS. Uma meta-análise de efeitos aleatórios foi realizada para estimar as proporções de falha agrupadas. Sete estudos, totalizando 287 pacientes, foram incluídos, sendo 168 pacientes elegíveis para síntese quantitativa em oito braços de tratamento. A taxa de falha agrupada foi de 13% (IC 95%: 3–28), com heterogeneidade substancial ($I^2 = 75,1\%$). Técnicas que combinavam estabilização intramedular com curetagem e preenchimento da cavidade demonstraram as menores taxas de falha, enquanto procedimentos percutâneos isolados foram associados a piores desfechos. Conclui-se que o tratamento cirúrgico do cisto ósseo simples em pacientes pediátricos está associado a uma taxa de falha agrupada relativamente baixa, especialmente quando a estabilização intramedular é combinada com o tratamento local da lesão. No entanto, a heterogeneidade substancial entre os estudos ressalta a necessidade de definições padronizadas de desfecho e de estudos prospectivos bem delineados.

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Surgical techniques for the treatment of simple bone cysts in long bones of pediatric patients: a systematic review and meta-analysis

Abstract

This systematic review and meta-analysis aimed to synthesize the available evidence on treatment outcomes and failure rates for simple bone cysts in pediatric patients. The study was conducted at the Department of Orthopedics and Traumatology, Federal University of São Paulo (UNIFESP), Brazil, from August to November 2025. Following the PRISMA 2020 guidelines, a systematic search was performed across PubMed, Scopus, and Web of Science using controlled descriptors and Boolean operators. Observational studies involving pediatric populations were included, and methodological quality was assessed using the MINORS tool. A random-effects meta-analysis was conducted to estimate pooled failure proportions. Seven studies comprising 287 patients were included, with 168 patients eligible for quantitative synthesis across eight treatment arms. The pooled failure rate was 13% (95% CI: 3–28), with substantial heterogeneity ($I^2 = 75.1\%$). Techniques combining intramedullary stabilization with curettage and defect filling demonstrated the lowest failure rates, whereas isolated percutaneous procedures were associated with poorer outcomes. In conclusion, surgical treatment of simple bone cysts in pediatric patients is associated with a relatively low pooled failure rate, particularly when intramedullary stabilization is combined with local lesion management. However, the substantial heterogeneity among studies highlights the need for standardized outcome definitions and well-designed prospective studies.

Keywords: Unicameral bone cyst; Pediatric orthopedics; Surgical treatment; Meta-analysis; Intramedullary nailing.



1. **Introduction**

Simple bone cysts (SBCs), also known as unicameral bone cysts, are benign, fluid-filled pseudotumoral lesions lined by a thin fibrous membrane [1,2]. Predominantly affecting children and adolescents-with peak incidence in the first two decades of life-SBCs show a marked predilection for the metaphyseal regions of long bones, particularly the proximal humerus and proximal femur [3,4]. Diagnosis is often incidental or follows a pathological fracture, which represents one of the most common and clinically significant complications of this condition [5].

Despite their benign nature, SBCs may lead to pain, progressive deformity, functional impairment, and a considerable risk of recurrent fractures, especially in weight-bearing bones [6]. Therefore, appropriate therapeutic management is crucial to mitigate complications, promote bone healing, and restore structural stability and limb function. However, the optimal treatment strategy for simple bone cysts remains a subject of ongoing debate in the orthopedic literature [3,7].

Multiple surgical and minimally invasive approaches have been proposed over time. The most frequently reported techniques include intralesional corticosteroid injection, curettage with or without autologous, allogeneic, or synthetic bone grafting, the use of bone substitutes, decompression with cannulated screws, and stabilization using elastic intramedullary nails [8-11]. Each method presents distinct advantages and limitations, along with variable rates of radiographic healing, recurrence, and procedural complications, complicating the establishment of a universally accepted gold-standard treatment [9,12].

Therapeutic decision-making is influenced by several patient- and lesion-related factors, including age, cyst size and location, presence of pathological fractures, lesion activity, surgeon experience, and institutional resources [5,13]. Nevertheless, the current evidence base consists largely of observational studies, often limited by small sample



sizes, heterogeneous follow-up periods, and inconsistent criteria for defining radiographic healing and recurrence [7,12].

Given these limitations, a systematic review with meta-analysis represents a valuable approach to synthesizing available evidence in a comprehensive and critical manner [14]. By aggregating data across studies, meta-analysis enhances the precision of estimates regarding recurrence rates, radiographic healing, procedure-related complications, and the need for reintervention across different treatment modalities for simple bone cysts.

2. **Methodology**

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. A comprehensive literature search was performed in the PubMed/MEDLINE, Scopus, and Web of Science databases between August and November 2025, in Brazil. The search strategy combined Medical Subject Headings (MeSH) and free-text terms related to simple bone cysts, pediatric population, and treatment modalities, using Boolean operators (AND/OR). The complete electronic search strategies for each database are presented in 1.

Table 1: Electronic search strategy used in the systematic review conducted from August to November 2025, Brazil.

Database	Search terms
PubMed/ MEDLINE	("unicameral bone cyst" OR "simple bone cyst" OR "solitary bone cyst") AND ("surgery" OR "surgical treatment" OR "curettage" OR "bone grafting" OR "intra-medullary nailing" OR "elastic intramedullary nail" OR "percutaneous treatment" OR "steroid injection" OR "calcium sulfate" OR "decompression screw") AND ("child" OR "adolescent" OR "pediatric")
Scopus	TITLE-ABS-KEY ("unicameral bone cyst" OR "simple bone cyst" OR "solitary bone cyst") AND TITLE-ABS-KEY ("surgery" OR "curettage" OR "bone grafting" OR "intramedullary nailing" OR "percutaneous treatment" OR "steroid injection") AND TITLE-ABS-KEY ("child*" OR "adolescent*" OR "pediatric*")



Database	Search terms
Web of Science	TS=("unicameral bone cyst" OR "simple bone cyst" OR "solitary bone cyst") AND TS=("surgery" OR "curettage" OR "bone grafting" OR "intramedullary nailing" OR "percutaneous treatment" OR "steroid injection") AND TS=("child*" OR "adolescent*" OR "pediatric*")

Source: Authors (2025).

Eligible studies included observational designs (retrospective or prospective cohort studies and case series) involving children and adolescents diagnosed with simple bone cysts and reporting treatment outcomes. Studies including adult populations, aneurysmal bone cysts, experimental or animal models, review articles, or case reports were excluded. Two independent reviewers screened titles and abstracts, followed by full-text assessment of potentially eligible studies. Disagreements were resolved through consensus. Reference lists of all included studies were manually screened to identify additional relevant publications.

Data extraction was performed independently by two reviewers using a standardized form and included study characteristics, patient demographics, anatomical location of the cyst, treatment modality, follow-up duration, and reported outcomes. The primary outcome of interest was treatment failure or recurrence, as defined by each study.

Methodological quality was assessed using the Methodological Index for Non-Randomized Studies (MINORS), with total scores ranging from 10 to 13 points, indicating moderate to good methodological quality.

For statistical analysis, a quantitative meta-analysis of proportions was conducted, focusing primarily on failure and recurrence rates across different treatment techniques for simple bone cysts. Pooled proportions were calculated with corresponding 95% confidence intervals. Given the expected clinical and methodological heterogeneity among studies, a random-effects model was applied. Statistical heterogeneity was assessed using the Cochran Q test and quantified by the I^2 statistic, with I^2 values greater



than 50% considered indicative of substantial heterogeneity. Statistical analyses were conducted using Jamovi software (version 2.6.44), utilizing its meta-analysis module for the analysis of proportions.

3. **Development and Discussion**

The systematic search identified 186,353 records from databases. Following the application of filters for clinical trials, comparative studies, and observational studies, and after duplicate removal, 30 studies remained for title and abstract screening. Of these, 23 studies were excluded because they did not satisfy the eligibility criteria, mainly due to the inclusion of adult populations, aneurysmal bone cysts, experimental study designs, review articles, or case reports. After full-text screening, seven studies were included in the systematic review, comprising a total of 287 patients. Of these, 168 patients were eligible for quantitative synthesis and were included in the meta-analysis, based on treatment-specific data availability (1).

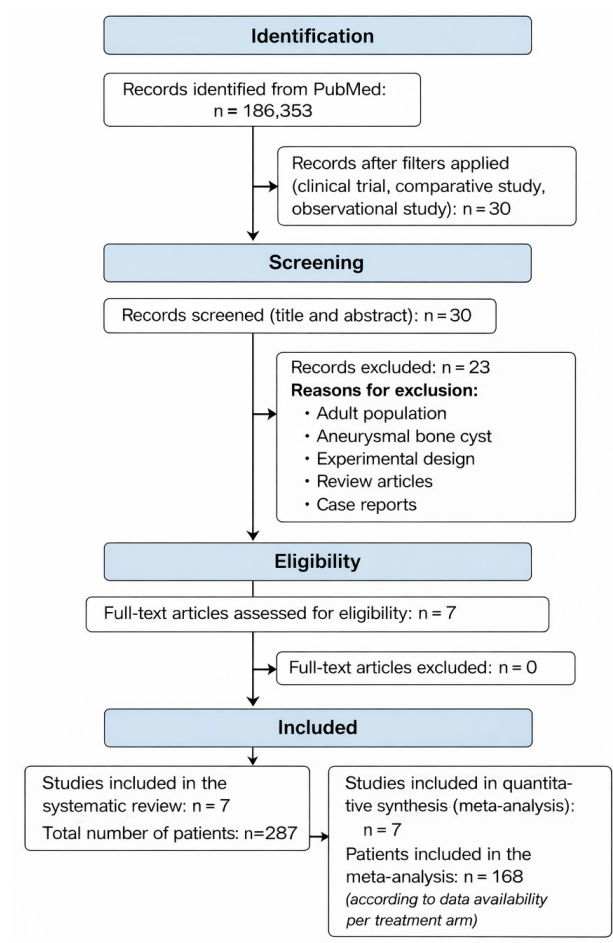


Figure 1: PRISMA 2020 flow diagram illustrating the study selection process for the systematic review and meta-analysis conducted from August to November 2025, Brazil.
Source: Authors (2025).

Publication dates of the included studies ranged from 2010 to 2024, and all adopted a retrospective observational design, with one study conducted in a multicenter setting. The methodological quality of these studies was evaluated using the Methodological Index for Non-Randomized Studies (MINORS), with scores ranging from scores 10 to 13 points (2).



Table 2: Methodological quality of the included observational studies assessed using the Methodological Index for Non-Randomized Studies (MINORS).

Study	MINORS
Erol 2017 [15]	10/14
Wang 2021 [16]	10/14
Schneider 2024 [17]	10/14
Xie 2024 [18]	11/14
Chen 2020 [19]	10/14
Zhang 2020 [20]	10/14
van Geloven 2024 [21]	13/16

Source: Authors (2025).

The study population across the included studies was predominantly male, with a higher prevalence among children aged 7–12 years. The proximal humerus was the most frequently involved anatomical site, consistently reported by Erol, Wang, Schneider, Xie and Zhang [15-18,20]. In contrast, proximal femoral involvement was more prominently described in the multicenter EPOS study conducted by van Geloven *et al.* [21].

A broad range of surgical and minimally invasive treatment strategies was evaluated. Curettage combined with bone grafting, with or without intramedullary fixation, was assessed in the studies by Erol, Wang, and Chen [15,16,19]. Intramedullary nailing associated with intralesional corticosteroid injection was reported by Zhang [20], whereas the combination of intramedullary fixation and calcium sulfate injection was evaluated by Xie [18]. Conventional open surgery for proximal femoral lesions, as well as comparisons between immediate and delayed surgical intervention following pathological fracture, were described in the multicenter EPOS study by van Geloven *et al.* [21]. Isolated osteosynthesis was assessed by Schneider [17], and isolated minimally invasive percutaneous procedures were also included in the EPOS cohort [21].

The mean follow-up duration varied from 16 months to 3.9 years across the included studies. Notably, van Geloven *et al.* [21] reported extended follow-up of up to 21 years, allowing for evaluation of long-term outcomes and late recurrence patterns.

Overall, high rates of radiographic and/or clinical healing were observed across most treatment modalities [15-21]. Curettage combined with bone grafting and intramedullary fixation demonstrated success rates ranging from 96% to 100% in the



studies by Erol, Wang and Chen [15,16,19]. Intramedullary nailing associated with corticosteroid injection achieved a 100% success rate without recurrence in the cohort reported by Zhang [20]. Similarly, intramedullary fixation combined with calcium sulfate injection resulted in complete consolidation in the study by Xie [18], although with a higher incidence of early reoperation.

In the multicenter EPOS study focusing on proximal femoral lesions, van Geloven *et al.* [21] reported failure-free survival rates of 77.8% at 1 year, 69.5% at 2 years, and 62.0% at 5 years, reflecting the greater biomechanical demands of weight-bearing bones. Treatment strategies incorporating curettage, defect filling, and intramedullary stabilization, especially evident when procedures were performed via open surgery, which were associated with the lowest failure rates [15,16,18-21]. However, isolated percutaneous procedures demonstrated the highest recurrence rates, especially in weight-bearing bones, underscoring their limited effectiveness when used as standalone interventions [21](3).

Table 3: Surgical Techniques and Failure/Recurrence Rates in the Treatment of Unicameral Bone Cysts in Children and Adolescents.

Surgical techniques	Studies (year)	Total (n)	Failure / Recurrence (approximate)
Curettage + bone grafting without intramedullary nail	Erol (2017); Wang (2021) [15,16]	44	Up to 23%
Curettage + bone grafting with intramedullary nail	Erol (2017); Wang (2021); Chen (2020) [15,16,19]	75+	4–12%
Intramedullary nail + corticosteroid injection	Zhang (2020) [20]	18	0%
Intramedullary nail + calcium sulfate	Xie (2024) [18]	11	0% recurrence; 18% early reoperation
Open surgery (proximal femur)	EPOS – van Geloven <i>et al.</i> (2024) [21]	50	28%
Isolated osteosynthesis	Schneider (2024); EPOS – van Geloven <i>et al.</i> (2024) [17,21]	9	0%
Isolated percutaneous procedures	EPOS – van Geloven <i>et al.</i> (2024) [21]	12	58%

Source: Authors (2025).



These findings were substantiated by the meta-analysis illustrated in 2, which incorporated eight treatment arms and included a total of 168 pediatric patients with simple bone cysts treated using different surgical techniques. Using a random-effects model, the pooled failure/recurrence proportion was estimated at 13% (95% CI, 3%–28%), indicating that most surgical strategies achieve satisfactory lesion control in this population. Substantial heterogeneity was observed among the included studies ($I^2 = 75.1\%$; $p < 0.01$), reflecting marked variability in failure rates across treatment modalities and clinical settings. This variability appears to be primarily attributable to differences in surgical technique (e.g., curettage with or without intramedullary stabilization, isolated percutaneous procedures, or isolated osteosynthesis), anatomical location of the cyst (proximal humerus versus proximal femur), presence of pathological fracture, and patient-related clinical characteristics.

The prediction interval ranged from 0.00 to 0.63, suggesting that failure rates may be negligible in certain clinical contexts, whereas in others they may approach 60%. This wide interval underscores the non-uniformity of outcomes and highlights the clinical relevance of treatment selection.

Technique-specific descriptive analyses demonstrated that approaches combining intramedullary stabilization with curettage and cavity filling were associated with the lowest failure rates, ranging approximately from 4% to 12% [15,16,18-21]. In contrast, techniques lacking mechanical stabilization, such as curettage with bone grafting alone, were associated with higher failure rates, reaching up to 23% [15,16]. Isolated percutaneous procedures, particularly when applied to proximal femoral lesions, showed markedly inferior outcomes, with recurrence rates of up to 58% [21], whereas isolated osteosynthesis achieved complete lesion control in the limited number of reported cases [17].



Collectively, these findings indicate a consistent trend favoring surgical strategies that integrate biomechanical stabilization with local cyst management, especially in weight-bearing bones [15,16,18-21].

Formal subgroup analyses were not feasible due to the limited number of studies and substantial between-study heterogeneity, precluding adequately powered comparisons by anatomical site or fracture status. Additionally, assessment of publication bias using funnel plots was not possible, representing a further limitation of the meta-analysis.

Reported complications were generally mild and infrequent, including irritation related to fixation hardware, valgus deformity of the humerus, transient local pain, and late fractures following treatment, the latter occurring in 6.8% of cases in the EPOS study [21]. Reoperations were predominantly observed in patients treated with calcium sulfate injection, most commonly due to early material leakage, particularly in cases of recurrence or failure and in open procedures without intramedullary stabilization [18].

In the study by Chen *et al.*, recurrence rates did not differ significantly between immediate and delayed surgical intervention following pathological fracture (8.8% vs 16.1%), although immediate surgery was associated with a significantly shorter duration of immobilization [19].

Overall, surgical techniques combining intramedullary stabilization with curettage and bone grafting demonstrated the highest success rates and lowest recurrence [15,16,18-21]. In contrast, isolated percutaneous procedures yielded inferior outcomes [21], while isolated osteosynthesis, despite limited case numbers, showed excellent disease control with minimal complications [17] (2).

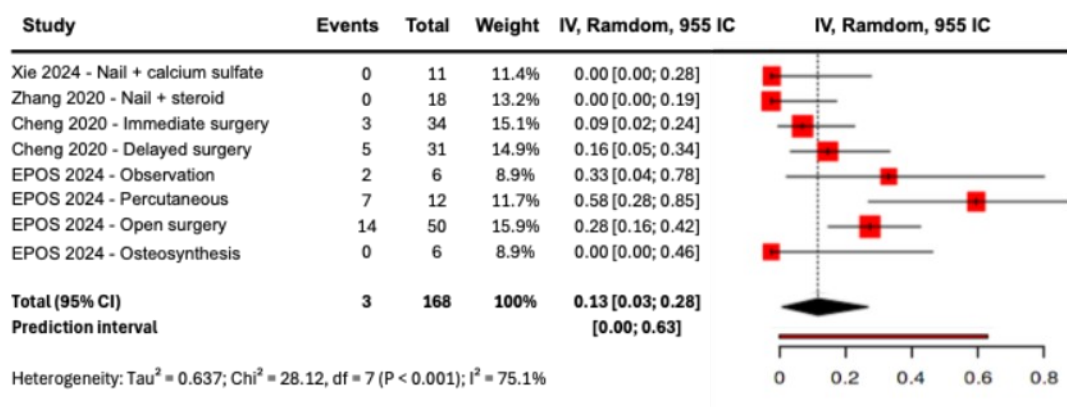


Figure 2: Forest plot of failure/recurrence rates for various surgical techniques in the treatment of unicameral bone cysts in pediatric patients. The diamond represents the pooled odds ratio with 95% confidence interval.

Horizontal lines indicate individual study confidence intervals. The prediction interval is shown below the diamond.

Source: Authors (2025).

The present meta-analysis evaluated the main surgical strategies used for the treatment of simple bone cysts (SBCs) in children and adolescents and demonstrated that techniques combining intramedullary stabilization with curettage and defect filling yield the most favorable outcomes in terms of healing and lower recurrence rates. By contrast, isolated percutaneous procedures were associated with inferior performance and higher failure rates.

Throughout the included studies, approaches incorporating intramedullary fixation in conjunction with curettage and bone grafting achieved consistently high success rates, ranging from approximately 96% to 100%, with substantially lower recurrence when compared with techniques lacking mechanical stabilization [15-19]. These findings support the biomechanical rationale that stabilization of the affected bone reduces pathological fractures, micromotion, and cyst persistence, thereby facilitating bone consolidation. This concept aligns with classical pathophysiological models that identify mechanical instability as a key factor in SBC recurrence [1,6].



The combination of intramedullary nailing and intralesional corticosteroid injection demonstrated excellent results, with complete healing and no reported recurrence in the evaluated cohort [20]. The anti-inflammatory properties of corticosteroids, together with the mechanical stability provided by intramedullary fixation, may explain these favorable outcomes. However, the limited sample size restricts the external validity of these findings and underscores the need for further investigation.

Similarly, intramedullary fixation combined with calcium sulfate injection resulted in complete radiographic consolidation, although it was associated with a higher incidence of early reoperations, mainly due to material extravasation [18]. While effective in promoting ossification, calcium sulfate may be linked to increased early complications, suggesting that its use should be considered with caution, particularly in patients presenting with pathological fractures.

Isolated percutaneous procedures, especially for proximal femoral SBCs, yielded the poorest outcomes, with failure rates reaching up to 58% in multicenter data [21]. These results reinforce current evidence indicating that minimally invasive techniques, although attractive due to reduced surgical morbidity, may be insufficient for larger, unstable lesions or those located in weight-bearing bones such as the femur.

A noteworthy finding was the excellent performance of isolated osteosynthesis, which showed no failures in the limited number of reported cases [17,21]. This suggests that in selected scenarios, particularly when mechanical instability from a pathological fracture is the predominant issue, simple stabilization may be sufficient to allow spontaneous cyst resolution. Nevertheless, the small number of cases precludes definitive conclusions.

Regarding the timing of surgery following pathological fracture, recurrence rates were comparable between immediate and delayed surgical approaches, whereas immediate intervention was associated with a shorter immobilization period, potentially



favoring earlier functional recovery [19]. These findings suggest that early surgical management may offer functional advantages without increasing the risk of failure.

Overall, complications were infrequent and predominantly mild, including implant irritation, minor deformities, and transient local pain. Late fractures were uncommon and were primarily observed in studies involving proximal femoral lesions, highlighting the inherent complexity of managing SBCs at this anatomical site.

From a methodological perspective, all included studies were observational and predominantly retrospective, reflecting a moderate level of evidence. Nonetheless, methodological quality was generally acceptable, with MINORS scores ranging from moderate to good. The substantial heterogeneity observed across studies, related to differences in surgical techniques, anatomical locations, and outcome definitions, represents an important limitation and should be considered when interpreting the pooled results.

The absence of randomized controlled trials limits causal inference between treatment strategies, and small sample sizes further constrain statistical power. Despite these limitations, the pooled analysis demonstrated a combined failure proportion of 13%, even though with high heterogeneity, indicating marked variability across clinical scenarios.

Taken together, the findings consistently indicate superior outcomes for treatment strategies that integrate intramedullary stabilization with curettage and defect filling, compared with isolated percutaneous approaches, particularly in weight-bearing bones. These results support a treatment paradigm that prioritizes mechanical stability alongside local management of the cyst cavity in pediatric SBCs.



4. **Final Considerations**

This meta-analysis demonstrates that surgical techniques combining curettage, defect filling, and intramedullary stabilization yield the most favorable outcomes in the treatment of simple bone cysts in children and adolescents, with lower recurrence rates and improved mechanical stability, particularly in weight-bearing bones and in cases associated with pathological fractures. Minimally invasive approaches using intramedullary fixation combined with steroid or calcium sulfate injection proved effective; however, calcium sulfate was associated with a higher rate of early reoperations. In contrast, isolated percutaneous procedures showed inferior performance, especially in proximal femoral lesions. Despite limitations related to study heterogeneity and the lack of randomized controlled trials, the findings support intramedullary stabilization combined with local lesion treatment as the most reliable strategy currently available. Further prospective studies are warranted to optimize treatment selection across different clinical scenarios.

5. **Declaration of Rights**

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