

How the Anatomic Location Affects the Surgical Outcomes of Simple Bone Cysts in Children: A Single-Center Retrospective Cohort Study

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Abstract

Objective

We aimed to investigate the effect of anatomical location on the efficacy of surgical intervention for simple bone cysts (SBC) among children, with a particular focus on comparing differences in clinical characteristics, treatment strategies, and prognosis between humeral and femoral SBCs.

Methods

A single-centre retrospective cohort of paediatric patients with SBC undergoing primary surgery (2014–2024) was stratified by location, including humerus, femur, and other sites. Demographic, imaging, and treatment data were collected. Twelve-month postoperative radiographic outcomes (cure/partial residual/recurrence/no response) were analysed using ANOVA and chi-square tests ($\alpha = 0.05$).

Results

In total, 106 patients were included, comprising 57 humeral (53.8%), 36 femoral (34.0%), and 13 other sites (12.2%). Patients with femoral SBC exhibited shorter stature, lower weight, and larger cyst area (all $p < 0.05$). Humeral SBCs presented more pathological fractures, a higher proportion of active fractures, and thinner cortices (all $p < 0.05$). At 12 months, 55 patients were cured, 21 exhibited partial residual characteristics, 17 recurred, and 13 showed no response. Anatomical location was significantly correlated with treatment outcome, with humeral cysts revealing higher recurrence rates. Other associated factors included cyst size, cyst index, time from fracture to surgery, distance to growth plate, initial surgical technique, and internal fixation type (all $p < 0.05$).

Conclusion

The anatomical location is a critical factor affecting the postoperative efficacy and recurrence risk of paediatric SBC surgery. Clinical decision-making should integrate location-specific structural risks with the morphological severity of the lesion to optimise surgical timing and technique selection and implement stratified follow-up, thereby improving treatment outcomes for children with high-risk locations.

Introduction

Simple bone cysts (SBC), also known as unilocular bone cysts (UBC), are benign, fluid-filled osteolytic lesions commonly observed in children and adolescents [1]. They can be predominantly detected at the epiphyseal ends of long bones, with the proximal humerus and proximal femur being the most frequent sites of involvement. Over 90% of reported cases have lesions at these two locations [2]. Although

patients often experience no subjective symptoms, SBC weakens the structural integrity of the affected bones, significantly increasing the risk of pathological fractures and pain. Cysts adjacent to the growth plate may also interfere with the longitudinal growth of the bone [3][4]. Surgical intervention is often necessary for active or larger cysts. Curettage (with or without bone grafting), implantation of injectable synthetic bone substitutes, and open curettage with bone grafting combined with internal fixation are available techniques employed for active or larger cysts. Despite the well-established recognition of SBC, treatment failure and cyst recurrence remain significant clinical challenges, with reported recurrence rates varying considerably in the literature.

Many studies have focused on the identification of prognostic factors associated with SBC recurrence and treatment efficacy. For instance, cyst index has been shown to correlate with these outcomes [5]. Furthermore, the choice of surgical approach, ranging from minimally invasive injection techniques to open curettage supplemented by stabilisation procedures, has remained a hot research focus [6]. However, the potential effects of cyst anatomical location on treatment strategy selection and ultimate prognosis require systematic and thorough exploration.

Previous studies did not systematically compare SBCs across different anatomical locations or explore their underlying mechanisms when assessing prognosis. As the two primary sites of SBC occurrence, the humerus and femur exhibit fundamentally distinct biomechanical environments: the femur serves as the body's primary weight-bearing bone, subjected to continuous mechanical stress, whereas the humerus is a non-weight-bearing bone with a comparatively benign mechanical environment [7]. These biomechanical differences may affect factors such as bone remodelling, cystic pressure, and local blood flow, resulting in variations in cyst behaviour, response to treatment, and recurrence risk [8]. Moreover, the anatomical complexity of different regions, such as the distribution of peripheral nerves and blood vessels, and the difficulty of surgical approaches, may also directly affect the selection of surgical techniques and the outcomes of their implementation. Therefore, we hypothesised that the anatomical location of SBC is not merely a simple classification label, but rather a key variable that may reflect their prognoses and outcomes. Differences in this variable may considerably affect clinical courses and treatment outcomes.

The present study aimed to systematically compare the clinical and pathological characteristics of SBC in children across different anatomical locations and assess variations in treatment efficacy based on the included case data. The study also seeks to investigate the effect of anatomical location on the surgical outcomes and prognosis of paediatric bone cysts. This study provides evidence-based support for establishing location-specific, personalised, and precision-guided clinical decision-making. This approach holds promise for optimising therapeutic strategies and improving long-term outcomes for paediatric patients with SBC.

Materials and Methods

This single-centre retrospective cohort study was designed to evaluate the impact of anatomical location on the surgical efficacy of SBC in children. The study protocol was approved by the ethics review committee of local children's hospital. Given the retrospective nature of the study and the anonymisation of patient data, the Ethics Committee waived patient informed consent.

The research data were obtained from the medical records system of paediatric patients with SBC who were admitted to the Department of Orthopaedics at local children's hospital between 1 January 2014 and 30 December 2024.

Paediatric patients meeting all the following conditions were included in the analysis: aged under 18 years; having a confirmed diagnosis of SBC based on imaging studies (plain radiography/computed tomography/magnetic resonance imaging) and postoperative histopathological examination; undergoing primary surgical intervention; no prior surgical treatment for bone cysts; complete clinical and imaging documentation; postoperative follow-up length of at least 6 months. Paediatric patients meeting any of the following conditions were excluded: those diagnosed with bone cysts who only received conservative management (observation); those with concomitant benign bone tumours or tumour-like lesions (e.g., aneurysmal bone cysts and fibrodysplasia ossificans progressiva); those with clear contraindications to surgery or anaesthesia; or those with postoperative loss to follow-up or missing critical clinical or imaging data. Following the aforementioned criteria, 106 paediatric patients were finally included in the analysis.

Patients were categorised into three groups based on preoperative imaging demonstrating primary skeletal involvement by the cyst: the humerus group, including cysts located in the humerus, comprising 57 cases; the femur group, consisting of cysts located in the femur, comprising 36 cases; other sites group, comprising 13 cases, whose cysts were located in other bones, such as the tibia, calcaneus, fibula, etc. When evaluating key indicators associated with treatment outcomes, paediatric patients were further categorised into four groups: the cure group with 55 cases, characterised by cyst disappearance or residual cavity diameter < 1 cm with cortical bone reconstruction. The partial residual group with 21 cases, in which cyst size was reduced to < 50% of bone diameter but residual cavity persisted, suggests that cortical thickness was sufficient to prevent re-fracture in this group. The recurrence group with 17 cases, in which initial improvement was observed but subsequently radiolucency reappeared in the original cystic area. In this group, cyst diameter exceeded 50% of bone diameter, and cortical thickness was insufficient to prevent fracture. The non-responsive group, characterised by no therapeutic response, no improvement or enlargement, or pathological fracture.

The following data were extracted from electronic medical records and picture archiving and communication systems: age at the time of surgery, gender, height, weight, and calculated body mass index (BMI).

Cystic imaging characteristics were measured based on medical imaging. Area: The maximum longitudinal and perpendicular transverse dimensions of the cyst were measured on standard anteroposterior radiographs, calculating the approximate cystic area (mm²) using the ellipse area

formula. Location: The vertical distance (mm) from the cyst margin to the nearest growth plate was measured. Structure: The number of cyst septa (units) visible on CT or MRI images was assessed. Bone cortical condition: The cortical bone thickness (mm) at the thinnest point of the cyst wall was measured. Activity status: It was classified as 'active' (adjacent to growth plate) or 'dormant' based on clinical and radiographic criteria.

Surgical Approach

The surgical approach was categorised into three types according to surgical records: (1) Lesion debridement + bone grafting (non-deactivated); (2) Implantation of injectable bone graft material; and (3) Internal fixation + lesion debridement + bone grafting. The timing of surgery was calculated as the interval (in months) from the initial detection of pathological fracture (if present) to the current procedure. Regarding implant details, we recorded bone graft material type (autogenous bone, allograft bone, synthetic bone, etc.) and internal fixation device type. Concerning treatment outcome (assessed via regular postoperative imaging follow-up), we assessed treatment efficacy at 12 months after surgery.

Statistical Analysis

All statistical analyses were conducted using R software (version 4.2.0), with a significance level set at $\alpha = 0.05$. Univariate analysis was employed to identify key indicators associated with treatment outcomes. Based on the type of data, univariate analysis of variance or chi-square tests were applied to examine differences in clinical characteristics, treatment strategies, and prognosis across distinct anatomical sites.

Results

This study included 106 paediatric patients undergoing surgical treatment for simple osteocystoma. Based on cyst location, patients were categorised into three groups, including the humeral group (57 cases, 53.8%), the femoral group (36 cases, 34.0%), and the other locations group (13 cases, 12.2%). The mean age of all patients was 9.0 ± 2.8 years, comprising 84 males and 22 females. In terms of baseline characteristics, partial differences were observed among the three groups (Table 1). Paediatric patients in the femoral group exhibited significantly lower mean height and weight compared to the humeral group ($P < 0.05$). Compared to the femoral group, a significantly higher proportion of patients in the humeral group had a history of pathological fractures before surgery. No significant differences were observed in terms of gender or age distribution between the three groups.

Different anatomical locations exhibited significant heterogeneity in terms of the radiographic features of bone cysts (Table 2). Cyst area in the femoral group was significantly larger than that in other sites ($P < 0.001$). Regarding activity, the proportion of active cysts was significantly higher in the humeral group than in other sites ($P = 0.003$). Furthermore, the humeral group exhibited a higher risk of bone structural compromise, characterised by thinner cortical bone compared to other sites ($P < 0.001$).

Univariate analysis of variance (Table 3) and chi-square tests (Table 4) were employed based on data type to accurately assess the effect of various factors on the outcomes of surgical treatment. The anatomical location of the bone cyst significantly affected treatment outcomes, with humeral cysts exhibiting a higher recurrence rate. Additionally, cyst size, time elapsed since fracture at the time of surgery, cyst index, initial surgical approach, distance from the UBC to the growth plate, and the choice of internal fixation material significantly affected treatment outcomes ($p < 0.05$). Specifically, larger cystic areas, cystic indices exceeding 3.5, and prolonged delays in surgical intervention following fracture (particularly exceeding six months) were all significantly associated with poor outcomes. In contrast, baseline characteristics, such as patient age, gender, BMI, anatomical side, and cortical bone thickness, showed no significant association with treatment outcomes. This finding indicates that clinical prognosis primarily depends on lesion location, morphological severity, and the timeliness and modality of surgical intervention, rather than the demographic features of patients.

Discussion

This single-center retrospective cohort study systematically evaluated the effect of anatomical location on the clinicopathological characteristics and prognosis of SBC in children. Additionally, this study investigated the effect of various factors on the surgical outcomes of pediatric bone cysts. We found that bone cysts at different anatomical sites exhibited differences in pediatric patients, particularly in terms of cyst characteristics and treatment outcomes. This indicates that anatomical location is a key factor influencing the clinical course, treatment strategy, and prognosis of this disease.

We found that patients with isolated femoral bone cysts showed significantly lower average height and weight compared to the humeral group. A significantly higher proportion of children in the humeral group had a history of pathological fractures preoperatively. In imaging, these cysts demonstrated greater activity, higher bone structural risk, and thinner cortical bone compared to other sites. This may explain the findings of Hiroshi et al., who showed that humeral bone cysts carry a markedly higher fracture risk than other bones. Their study also revealed that mechanical disruption (fracture) of UBC may facilitate cyst healing [9].

When analysing key prognostic indicators, we observed a relatively high recurrence rate for humeral cysts. This suggests that humeral bone cysts may not necessarily be synonymous with a 'favourable prognosis', but rather carry a high risk of incomplete repair due to greater activity, thinner cortical bone, and insufficient local stability. This suggests that for humeral lesions, particularly those involving the proximal active site, the notion that 'mechanical disruption promotes healing' may not suffice for all patients. Treatment strategies must be determined based on the specific circumstances of individual paediatric patients [10].

This study systematically analysed 'anatomical site' as a composite variable, revealing that it may integrate several factors, including biomechanics and growth development [11]. The disparity between femoral and humeral bone cysts may originate from their fundamentally distinct biomechanical

microenvironments [12]. Compared to humerus, the femur endures significantly higher cyclic stresses during daily activities since it is the primary weight-bearing bone of the lower limb. Therefore, clinicians should adopt individualised treatment strategies based on anatomical sites to conduct thorough preoperative assessment and risk stratification. They must also pay attention to the structural risks and recurrence potential associated with cysts in different anatomical sites.

Whilst evaluating the effects of various factors on surgical treatment outcomes, further subdivision of bone cyst locations (proximal femur, distal femur, femoral shaft, proximal tibia, etc.) in this study revealed significant differences. This suggests that in the same bone, different segments carry varying risks. We observed that lesions near the growth plate and within the metaphysis-epiphysis transition zone exhibited greater activity, were less likely to achieve complete repair, and demonstrated a higher risk for recurrence due to localised stress and remodelling. This aligns with established patterns observed in paediatric bone cysts [13][14]. Consequently, clinical decision-making necessitates precise delineation of the specific anatomical compartment of cysts, rather than relying on broad categorisations, such as the humerus or femur.

Beyond anatomical location, the cyst index is strongly correlated with treatment outcomes and prognosis. A higher index indicates a larger cyst cavity and greater cortical load, making complete repair in a single surgery less likely and increasing the risk of recurrence or non-response. An index > 3.5 has the potential to serve as a 'high-risk threshold', often necessitating more aggressive management strategies and closer follow-up. Furthermore, the initial surgical approach and internal fixation materials are significant correlates of surgical outcome and prognosis. This aligns closely with the findings of Arellanos et al., who analysed treatment strategies and success rates for UBC [15].

This study faced several limitations. Firstly, as a retrospective study, it inevitably suffered from selection bias and information bias. Secondly, the sample size was relatively small, which may have affected certain analytical results. Thirdly, the operations were conducted by different surgeons over a decade. Although general principles were followed, variations in individual technique and experience may have affected the outcomes. Furthermore, there are currently no standardised treatment guidelines for surgical approaches to humeral and femoral bone cysts. The choice of surgical techniques and advances in these techniques may have affected the results as well [16][17]. Finally, this study primarily focused on anatomical location as a macro-level variable, without delving into the underlying molecular mechanisms.

Conclusion

In summary, this study indicated that anatomical location is a key factor affecting the clinical presentation and treatment outcomes of SBC in children. This finding urges clinicians to adopt an individualised, precision-based diagnostic and therapeutic strategy tailored to anatomical location. This approach aimed to improve long-term prognosis for affected children, particularly those with cysts in high-risk sites. Furthermore, this study indicated that additional factors, such as cyst volume, time

elapsed since fracture at the time of surgery, cyst index, initial surgical approach, distance from the uncomplicated bone cyst to the growth plate, and choice of internal fixation material, also significantly affect the treatment outcome of bone cysts.

Declarations

Ethics approval: The research protocol was approved by the Ethics Review Committee of the Children's Hospital of Soochow University. Given the retrospective nature of the study and the anonymization of patient information, the Ethics Committee granted exemption from obtaining patient informed consent.

Consent to participate: Informed consent was obtained from all individual participants included in the study. For participants under the age of 18, informed consent was obtained from a parent and/or legal guardian.

Consent for publication: Informed consent for publication was obtained from all participants.

Date availability: The datasets generated during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Author Contribution

Y.S and L.J : conception and design of the work; acquisition, analysis, and interpretation of data; drafting the work and substantively revising it. C.J, Y.L and W.D.L: acquisition and interpretation of data; substantively revising the work. Xie Hui: analysis and interpretation of data; substantively revising the work. Wang Xiaodong: conception and design of the work; substantively revising the work; final approval of the version to be published. Each author has approved the submitted version .

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Tables

Tables 1 to 4 are available in the Supplementary Files section.

Supplementary Files

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