

## ≥5 cm Tumor with Cortical Breach Predicts Recurrence and Distinguishes ACT from Enchondroma in Long Bones

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### ABSTRACT

**Purpose:** This study aimed to validate potential clinical and radiological features for distinguishing enchondromas from atypical cartilaginous tumours (ACT) and to analyse the association between maximum tumour diameter and local recurrence of enchondromas. It is important to note that this research serves as a validation cohort rather than proposing a new diagnostic framework.

**Materials and Methods:** This retrospective study reviewed the clinical data of 50 patients pathologically diagnosed with enchondroma or ACT and treated in our center between 1 January 2015 and 1 June 2024. Imaging characteristics, recurrence outcomes and other variables were compared among patients, and chi-square tests were used to assess the influence of maximum tumour diameter and other relevant factors on the recurrence rate. This study has been approved by the ethics committee of our institution.

**Results:** Patients with a maximum tumor diameter  $\geq 5$  cm exhibited a higher recurrence risk (recurrence 8 % vs. non-recurrence 0 %,  $P = 0.01$ ,  $P < 0.05$ ). This difference is statistically significant and may aid in distinguishing enchondroma from ACT. Moreover, all recurrent cases exhibited cortical bone destruction, which further validates the importance of this imaging feature as a key differentiating point. The primary treatment consisted of curettage combined with bone grafting, yielding an overall favorable prognosis.

**Discussion:** A maximum tumor diameter of  $\geq 5$  cm and cortical bone destruction can be considered important predictive factors for local recurrence, and they may also assist in differentiating between atypical cartilaginous tumors (ACTs) and enchondromas. Based on our findings, we are more inclined to consider lesions  $\geq 5$  cm as ACTs, particularly when accompanied by cortical destruction, as these features suggest a more aggressive biological behavior. Therefore, we recommend performing extended curettage combined with intraoperative electrocautery or other effective local adjuvant techniques in such cases to achieve adequate tumor control and reduce the risk of recurrence.

**Keywords:** Enchondroma, atypical cartilaginous tumor, maximum tumor diameter, cortical destruction, extended curettage, long bones.

### INTRODUCTION

Cartilaginous tumors of long bones encompass a spectrum of entities ranging from benign enchondromas to low-grade malignant atypical cartilaginous tumors (ACTs). Despite their histopathological similarities, enchondromas and ACTs differ significantly in biological behavior and clinical management<sup>1,2</sup>. Enchondromas are typically indolent and often managed conservatively, whereas ACTs—considered grade 1 chondrosarcomas under the current WHO classification—exhibit locally aggressive behavior and require surgical intervention<sup>3</sup>. Consequently,

accurate discrimination between the two is essential<sup>4</sup>.

Accurate differentiation between these two entities is essential to avoid both undertreatment and overtreatment. However, this remains a diagnostic challenge due to overlapping histological features, such as mild nuclear atypia, occasional binucleation, and low mitotic activity<sup>5-7</sup>. Consequently, integration of clinical, radiological, and pathological data is necessary to establish a definitive diagnosis<sup>1,8</sup>.

Previous studies have identified several imaging parameters that may aid in distinguishing ACTs from enchondromas, including tumor size, endosteal scalloping, cortical destruction, and the presence

of soft tissue edema or extracompartmental extension<sup>9-11</sup>. Among these, tumor diameter has emerged as a potentially reliable predictor of biological aggressiveness. Gassert et al. proposed a threshold of 5 cm as a discriminatory cutoff between benign and malignant cartilaginous lesions in long bones<sup>12</sup>. However, the prognostic significance of this parameter, particularly in predicting local recurrence, remains underexplored.

In this retrospective study, we aimed to validate the role of maximum tumor diameter and cortical bone destruction in predicting local recurrence and facilitating the differential diagnosis between enchondromas and ACTs in long bones.

## METHODS

Approval for this retrospective study was granted by the local Ethics Committee. We consecutively enrolled 50 patients with postoperatively pathologically confirmed long-bone enchondroma or ACT who underwent surgery between January 2015 and June 2024. Individuals with concurrent malignant neoplasms or incomplete clinical/imaging data were excluded.

Demographics (age, sex) were collected. Preoperative radiographs, CT and MRI were used to measure maximum tumor diameter and to evaluate margin definition, cortical breach, periosteal reaction, etc. Patients were stratified into <5 cm and  $\geq$ 5 cm groups using the 5 cm cutoff proposed by Gassert et al.<sup>12</sup>. Histopathologic specimens were re-reviewed by a musculoskeletal pathologist for cellularity, nuclear atypia and invasion.

All lesions were treated with extended curettage: the cavity was enlarged 2–3 mm beyond the radiologic margin with a high-speed burr, the wall was cauterized with a high-frequency electro-surgical electrode and rinsed with saline, and the defect was reconstructed with autologous cancellous bone or PMMA cement. Prophylactic plate or intramedullary fixation was added when >50 % of the cortex was absent or in high-load regions.

Patients were followed radiographically at 3, 6 and 12 months post-operatively and every 6–12 months thereafter. Local recurrence was defined as reappearance of tumor on imaging confirmed by biopsy or secondary surgery. Statistical analysis was performed with SPSS 26.0; categorical variables were compared using Fisher's exact test and continuous variables with the Mann–Whitney U test, with  $P < 0.05$  considered significant.

## RESULTS

Among the 50 long-bone cartilaginous lesions, 16 (32%) had a maximum diameter  $\geq$ 5 cm and 34 (68%) <5 cm; eight patients (16%) presented with multifocal disease, while 42 (84%) had a solitary lesion. Solitary tumors were distributed as follows: femur 21 cases (50%), humerus 19 cases (45%), and tibia 2 cases (5%). Age ranged from 1 to 66 years (mean 32.4 years). During postoperative follow-up, four patients (8%) developed local recurrence, all in the  $\geq$ 5 cm group, and preoperative imaging in each showed cortical bone destruction. On MRI, recurrent lesions exhibited predominantly T2-hyperintense signal with sparse, punctate or patchy calcification (Table I, Figure 1). Preoperative imaging revealed intramedullary, expansile cyst-like bone destruction located in the metaphysis or diaphysis of all lesions; 11 patients (22%) underwent prophylactic plate or intramedullary nailing because of cortical loss >50% or involvement of weight-bearing regions (Figure 2). Among the eight multifocal cases, one had synchronous lesions in the inferior right iliac wing, ischium, proximal and distal femur, and proximal tibia, and developed leg-length discrepancy after multiple surgeries. Postoperative pathological review showed slightly increased cell proliferation in five cases, of which three were ultimately diagnosed as ACT.

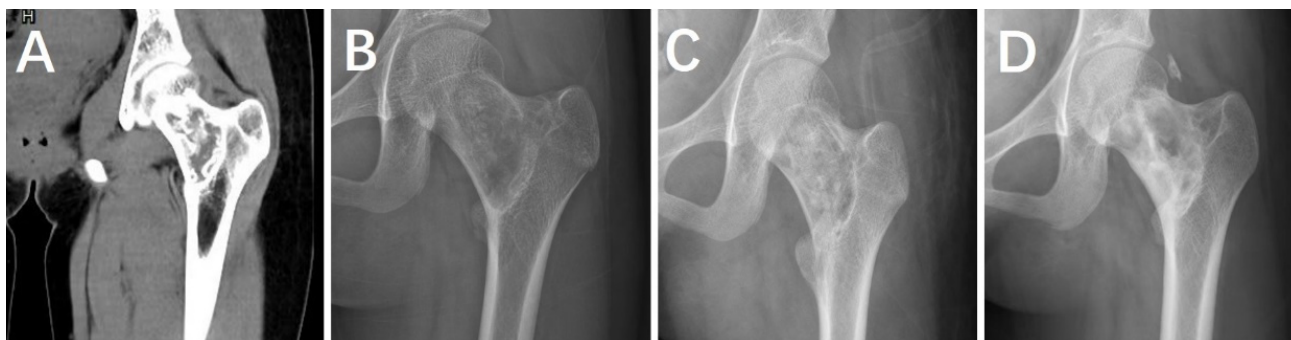
## DISCUSSION

Cartilaginous tumors of long bones form a continuous spectrum from benign enchondroma to low-grade atypical cartilaginous tumor (ACT). Histologically, the two entities overlap considerably in cellularity, nuclear atypia and binucleation, so small biopsy samples often lead to underestimation or misdiagnosis<sup>8,13,14</sup>. The WHO 2020 classification defines ACT as a “locally aggressive, grade 1 chondrosarcoma without metastatic potential,” yet its diagnosis still requires integration of imaging, pathology and clinical findings, and no single gold standard exists<sup>3,15</sup>.

In recent years, several retrospective studies have proposed that CT/MRI features such as diameter  $\geq$ 5 cm, cortical destruction or scalloping >2/3, soft-tissue edema, calcification occupying <1/3 of the matrix, and a continuous growth pattern can help distinguish ACT<sup>6,14,16</sup>. Gassert et al.<sup>14</sup> validated these criteria in 82 long-bone lesions and found significantly increased odds ratios when they were combined, but sensitivity and specificity remain insufficient for routine clinical decisions. In our consecutive cohort

**Table I.** — Clinical Characteristics of 50 Patients.

Characteristic	Study Patients (N=50)	Recurrence	No Recurrence	P-value
Gender				0.621
Male	22 (44%)	1 (2%)	21 (42%)	
Female	28 (48%)	3 (6%)	25 (50%)	
Tumor Diameter				0.010
Less than 50mm	34 (68%)	0 (0%)	34 (68%)	
Greater than or equal to 50mm	16 (32%)	4 (8%)	12 (24%)	
Tumor Location				0.761
Humerus	18 (36%)	2 (4%)	16 (32%)	
Femur	29 (58%)	2 (4%)	27 (54%)	
Tibia	3 (6%)	0 (0%)	3 (6%)	
Solitary/Multiple				0.514
Solitary	42 (84%)	3 (6%)	39 (78%)	
Multiple	8 (16%)	1 (2%)	7 (14%)	
Cortical Bone Destruction				0.078
Yes	26 (52%)	4 (8%)	22 (44%)	
No	24 (48%)	0 (0%)	24 (48%)	

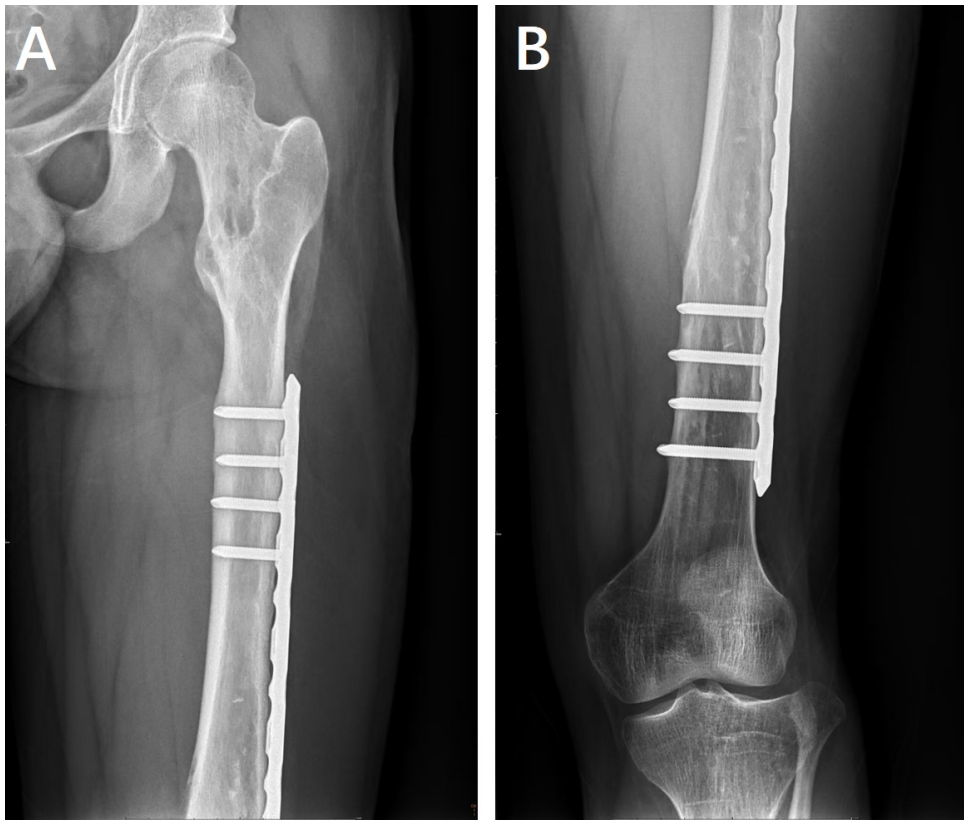


*Fig. 1 — A 12-year-old girl presented with left hip pain of one year’s duration. A. Pre-operative CT demonstrated a well-circumscribed, cystic, radiolucent, low-density lesion in the left femoral neck measuring ~60 × 35 mm, containing multiple lamellated and semicircular bony densities; no surrounding sclerosis, cortical breach, periosteal reaction, or soft-tissue mass was evident. B. Pre-operative radiograph showed a similar cystic, radiolucent lesion in the left femoral neck, ~69 × 35 mm, with scattered flocculent slightly hyperdense foci; the lesion exhibited mild expansion and a thin sclerotic rim. C. Post-operative radiograph revealed the cystic cavity to be adequately packed with high-density material, resulting in increased medullary density. D. Follow-up radiograph obtained more than two years later displayed heterogeneous bone density within the left femoral neck, with admixed areas of increased and decreased radiodensity.*

of 50 long-bone lesions, we reproduced the association between “≥5 cm plus cortical destruction” and local recurrence (8% vs 0%, p=0.01), providing independent validation of this threshold. Moreover, recurrent lesions showed heterogeneous T2 signal and sparse, punctate calcification, correlating with histological upgrade (three of five finally diagnosed as ACT), further supporting a hierarchical imaging-pathology correspondence.

This study, conducted in a single-center long-bone series, validated the predictive value of the 5 cm threshold and “cortical destruction” for recurrence risk; it also proposes a simple “large-diameter plus cortical breach” binary model that can be applied intra-operatively. Based on our findings, we advocate managing long-bone cartilaginous lesions ≥5 cm in

maximum diameter with cortical destruction as ACT: perform extended curettage with high-speed burr and high-frequency electrocautery cavity ablation, add prophylactic plate or intramedullary nailing when cortical loss exceeds 50% or in weight-bearing regions, and utilize the thermal effect of PMMA cement to further reduce residual tumor burden. Postoperative imaging surveillance every 3-6 months is recommended; Gabriel S. Makar et al. found in a retrospective study that for the vast majority of chondrosarcoma patients, not undergoing surgical treatment is associated with a significantly increased risk of death<sup>17</sup>. Therefore, any recurrence or histological upgrade should prompt conversion to wide resection<sup>18-20</sup>. Conversely, typical enchondromas <5 cm without cortical destruction can



*Fig. 2 — A 13-year-old boy presented on pre-operative radiographs with osseous destruction of the proximal and distal left femur and the proximal and distal left tibia. Owing to compromised skeletal stability after tumour removal, post-operative plate-and-screw fixation was performed to prevent fracture.(Figures A/B).*

be managed conservatively, with surgery reserved for lesions that become painful or enlarge >6 mm within 3 years<sup>21</sup>.

Our study has inherent limitations: its retrospective, single-center design, the small number of recurrence events, and heterogeneous follow-up intervals precluded multivariate survival analysis. Future multicenter prospective registries that incorporate texture analysis, radiomics, and molecular markers such as IDH1/2 mutations are needed to refine discrimination accuracy and define optimal intervention timing.

## CONCLUSION

In summary, we validated “≥5 cm plus cortical destruction” as a simple and effective combination for distinguishing ACT from enchondroma in long bones. Extended curettage with local adjuvant ablation achieved excellent local control while preserving function, providing new recommendations for individualized clinical decision-making.

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*Conflict of Interest:* The authors declare no conflicts of interest. The authors had no financial or personal relationships with any of the manufacturers of the products used in this study.

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