ORIGINAL ARTICLE

# Clinical and radiological outcomes of bioactive glass in the treatment of benign bone tumors: a retrospective study of 64 cases

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## ABSTRACT

**BACKGROUND:** Benign and benign-aggressive bone tumors, though non-metastatic, may require surgical intervention due to pain, fracture risk, or functional impairment. In many cases, bone grafting may be required in benign or benign-aggressive bone tumors. Although autografts remain the gold standard, they present disadvantages, especially in pediatric patients. Synthetic alternatives such as bioactive glass (BG) have emerged as viable options. This study aims to evaluate the clinical and radiological outcomes of BG in the treatment of benign bone tumors.

**METHODS:** This retrospective single-center study evaluated 64 patients (71 procedures) treated with curettage and BG grafting for benign bone tumors between 2004 and 2023. Functional outcomes were assessed using the Musculoskeletal Tumor Society (MSTS) score, and radiological healing was evaluated using the Neer classification.

**RESULTS:** The mean follow-up was 25.0±12.6 months. Significant improvement was observed in MSTS scores (from 17.6±4.8 to 28.1±2.0; $p<0.05$). Neer classification indicated high union rates. Complications included tumor recurrence in four patients (five procedures), fractures in nine patients, and superficial infections in four patients. No deep infections or any other material-related adverse effects were reported.

**CONCLUSION:** Bioactive glass is a safe and effective bone substitute for managing benign bone defects, especially in pediatric populations where autograft options are limited. Its osteoconductive durability, infection resistance, and compatibility with bone remodeling make it a strong alternative to traditional grafting techniques.

**Keywords:** Bioactive glass; benign bone tumors; pediatric bone tumors.

## INTRODUCTION

Benign and benign-aggressive bone tumors are non-invasive, non-metastatic lesions that can affect individuals at any age. While some cases may resolve spontaneously with conservative treatment, some cases require surgical intervention. Treatment options for these tumors include corticosteroid injections, curettage with or without bone grafting and fixation, percutaneous sclerotherapy, and wide excision with or without reconstruction.

Curettage is among the most selected surgical options with low complication rates. However, post-curettage bone defects

Cite this article as: Sivacioglu S, Civan M, Cetin O, Sayar Ş, Salduz A, Eralp L. Clinical and radiological outcomes of bioactive glass in the treatment of benign bone tumors: A retrospective study of 64 cases. Ulus Travma Acil Cerrahi Derg 2025;31:920-924.

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Ulus Travma Acil Cerrahi Derg 2025;31(9):920-924 DOI: 10.14744/tjtes.2025.89507
Submitted: 30.07.2025 Revised: 31.07.2025 Accepted: 14.08.2025 Published: 05.09.2025

**Table 1.** Demographics of patients

| | N | % |
|---|---|---|
| Gender | | |
| Male | 45 | 70.3 |
| Female | 19 | 29.7 |
| Side | | |
| Left | 32 | 45.1 |
| Right | 39 | 54.9 |
| | Mean±SD (Min-Max) | |
| Age (years) | 19.1±13.3 (3.4-65.2) | |
| Follow-up (months) | 25.0±12.6 (12-72) | |

often require filling. Even though autografts are the gold standard option due to their osteoinductive and osteoconductive features, they pose several drawbacks: prolonged operative time, donor-site morbidity, the need for a second surgical site, and limited harvest volume—particularly problematic in pediatric patients and large defects. [1] As a result, the orthopedic community has explored alternative bone substitutes, including allografts, xenografts, and synthetic materials.

Most non-autogenous bone substitutes have no osteoinductive effect and may result in non-union or delayed union. Bioactive glass (BG), however, is a synthetic graft that possesses osteoinductive, osteoconductive, and antimicrobial properties, making it a promising solution for bone defects across age groups.[2-4]

The purpose of this study is to evaluate the clinical and radiological outcomes, as well as potential complications, associated with the use of BG in bone defects following curettage of benign and benign-aggressive bone tumors.

## MATERIALS AND METHODS

This retrospective single-center study included patient records between 2004 and 2023. Institutional Review Board (IRB) approval was obtained (IRB file date and number: 06/25//2025 - E-10840098-202.3.02-3962). This study was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all patients or their legal guardians.

A total of 77 patients underwent curettage and BG grafting for benign bone tumors. Ten patients were lost to follow-up, and three patients were excluded due to intraoperative suspicion of malignancy confirmed by frozen section. Only patients who received BG as the sole grafting material were included. The final cohort comprised 64 patients who underwent 71 surgical procedures. Descriptive statistics are presented in Table 1.

All surgeries were performed by the same two orthopedic surgeons (AS and LE). The surgical approach typically involved creating a cortical window to access the lesion. Curettage was performed using a high-speed burr, followed by chemical cauterization with 5% phenol. After thorough irrigation, the cavity was filled with BG granules. The cortical window was replaced, and fixation was performed using plates or intramedullary nails when cortical support was insufficient. Case examples for the tibia, femur, and humerus are shown in Figures 1, 2, and 3.

All patients underwent preoperative magnetic resonance imaging (MRI) and biopsy. Follow-up assessments occurred at 6 weeks, 3 months, 1 year, and up to 3 years postoperatively. Functional outcomes were evaluated using the Musculoskeletal Tumor Society (MSTS) score (range 0–30), and radiological healing was assessed with the Neer cyst classification. Standard biplanar radiographs were obtained at each visit.

The MSTS scoring system evaluates patients functionally and ranges from 0 to 30 points, with 0 indicating total functional loss and 30 indicating no functional impairment.[5] The Neer radiographic classification system evaluates bone healing in four categories: healing, healing with defect, persistent cyst, and recurrent cyst (Table 2).[6-8]

### Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., NY, USA). Descriptive statistics were used to summarize patient demographics, lesion characteristics, and clinical outcomes. Continuous variables were presented as means with standard deviations and ranges. To evaluate the change in functional outcomes, a paired-sample t-test was used to compare preoperative and postoperative Musculoskeletal Tumor Society scores. A p-value of less than 0.05 was considered statistically significant.

**Table 2.** Neer cyst classification

| Category | Description | Details |
|---|---|---|
| A | Healed | Cyst filled with new bone with small radiolucent area (<1 cm) |
| B | Healed with Defect | Radiolucent area (<50% diameter) with sufficient cortical thickness |
| C | Persistent Cyst | Radiolucent area (>50% diameter) with thin cortical rim |
| D | Recurrent Cyst | Cyst reappears in the obliterated area or increased residual radiolucent area |

**Table 3.** Characteristics of the lesions

| | N | % |
|---|---|---|
| Location | | |
| Humerus | 18 | 25.35 |
| Radius-Ulna | 4 | 5.63 |
| Hand | 3 | 4.22 |
| Femur | 21 | 29.57 |
| Tibia | 6 | 8.45 |
| Foot-Ankle | 8 | 11.26 |
| Other | 11 | 15.49 |
| Type of Lesion | | |
| Unicameral Bone Cyst | 22 | 30.98 |
| Aneurysmal Bone Cyst | 13 | 18.3 |
| Chondroblastoma | 5 | 7.04 |
| Enchondroma | 6 | 8.45 |
| Non-Ossifying Fibroma (NOF) | 8 | 11.26 |
| Fibrous Dysplasia | 7 | 9.85 |
| Langerhans Cell Histiocytosis | 4 | 5.63 |
| Intraosseous Lipoma | 3 | 4.22 |
| Desmoplastic Fibroma | 1 | 1.41 |
| Osteoblastoma | 1 | 1.41 |
| Spindle Cell Tumor | 1 | 1.41 |

**Table 4.** Outcomes and complications of curettage and bioactive glass (BG) treatment

| **Outcomes** | **Mean±SD** | **P[1]** |
|---|---|---|
| MSTS | | |
| Preoperative | 17.6±4.8 | <0.05 |
| Postoperative | 28.11±2.0 | |
| | **N** | **%** |
| Neer Cyst Classification | | |
| 1 | 38 | 53.5 |
| 2 | 20 | 28.17 |
| 3 | 9 | 12.67 |
| 4 | 4 | 5.63 |
| | **Mean±SD** | **Min-Max** |
| Osseointegration seen on X-ray (months) | 4.3±0.8 | 3-6 |
| **Complications** | **Present** | **Absent** |
| Recurrence | 5 | 66 |
| Postoperative Fracture | 9 | 62 |
| Surgical Site Infection | 4 | 67 |

P[1] Paired-sample t-test.

## RESULTS

The study included 64 patients (45 males, 19 females). The mean age was 19.1±13.3 years (range: 3.4-65.2). The mean follow-up period was 25.0±12.6 months (range: 12-72 months). A total of 71 surgeries were conducted at the final follow up; one patient had three surgeries for recurrence of unicameral bone cysts; three patients had two surgeries for recurrence of bone cysts; and two patients had two surgeries for different types of tumors and different locations.

The femur and humerus were the most commonly affected bones. The most frequent lesion types were unicameral bone cysts and aneurysmal bone cysts, followed by non-ossifying fibromas (Table 3).

Functional outcomes were evaluated with MSTS and showed significant improvement at the final follow-up. Preoperative and postoperative MSTS scores were 17.6±4.8 vs. 28.11±2.0, respectively ($p<0.05$) (Table 4). Radiographic evaluation using the Neer classification indicated high union rates, with most cases classified as healed or healed with defect (Table 4).

The main undesirable complication was recurrence of the tumor, which required reoperation. Five operations in four patients were performed for recurrence. All four patients had fair results, and no recurrence was seen after reoperation during the follow-up period. The most common complication was fracture, which occurred in nine patients (Table 4). Surgical site infection was seen in four patients and treated with oral antibiotics. No deep infections or graft-related adverse effects were reported.

## DISCUSSION

This study demonstrates that BG is an effective alternative to autografts and other allograft options in the management of benign bone tumors. Its osteoconductive, osteoinductive, and antimicrobial properties contribute to favorable clinical and radiological outcomes, especially in cases of benign and benign-aggressive bone tumors.

For over ten decades, many surgeons have searched for an appropriate bone substitute material.[9] The main aim has been to find an alternative material to autogenous bone that mimics the same features of osteoinduction and osteoconduction, since the harvesting of autogenous bone has many disadvantages. Hench et al.[10] introduced BG in 1967, proposing that glass containing calcium and phosphorus could be biocompatible in bone defects.

Bioactive glass has a slow resorption rate.[11] Autogenous bone grafts, in contrast, diminish more rapidly than BG, and their osteoconductive features may disappear in the short term. Lindfors et al.[12] compared BG and autograft and demonstrated a significant difference at 12 and 24 months in terms

of cavity volume. The granules of BG disappear gradually by surface reaction and osteoclastic activity, generally within 1-4 years depending on the cavity size.[12] There is also evidence of the osteoinductive capacity of BG when used alone.[2,12-15] In conclusion, the long-term osteoconductive effect of BG may influence and improve its osteoinductive capacity during that period.

In our study, BG showed no resorption during the median 25-month follow-up period in any patient. This suggests that BG granules consistently support bone defects from the time of surgery through at least the second year.

In addition to its bone-healing properties, BG offers resistance to infection, which is particularly beneficial in contaminated bone defects or compromised surgical fields. The antimicrobial feature of BG is a unique property among bone grafting materials and can also be used in contaminated bone defects.[2,4,16-18] Studies have demonstrated that BG is a well-tolerated graft option with a lower risk of infections, and no material-related adverse effects have been observed during or after clinical use.[12,19,20]

Deep infection requiring surgical intervention or debridement was seen in none of the patients in our study cohort. Even though benign bone tumors are considered sterile lesions, the absence of postoperative deep infection in this study may be attributed to the antimicrobial feature of BG.

Another advantage of BG is that it can be used with good results even in children, without disturbing the remodeling capacity of the bone.[19] Most benign bone cysts and tumors are treated in childhood. Younger children may not be suitable for autograft options due to the limited harvesting capacity of autografts.

In our study, participants were mostly below the age of 18, with the minimum age being 3.4 years. Results demonstrate that even in children, BG has high union rates with no or minimal complications. Therefore, BG should be considered an alternative to autograft, especially at early ages.

The advantage of dissolution over long periods may become a disadvantage in some cases. BG is not suitable for clinical application if the applied region must be operated on within a short period after the primary operation, especially if drilling is needed.

Bioactive glass resembles other types of glass in terms of mechanical strength. It is fragile, rigid, and mechanically weak. Due to BG's mechanically weak structure, in cases with insufficient cortical support, osteosynthesis may be required at the end of the procedure.

Most of our cases underwent only curettage and grafting with BG. A limited number of cases had insufficient cortical support, which required osteosynthesis. Only four patients experienced tumor recurrence, which did not require any implantation before or after the recurrence. It should be noted that if there is a high risk of recurrence and/or a need for implantation after the primary surgery may arise, BG should be considered a second choice.

Our study has several limitations. The retrospective design of the study introduces selection bias and limits control over the cohort. Even though all patients had benign bone lesions, the types of lesions and their locations varied and may have affected the results with different recurrence rates and complications. Another main limitation of our study is the heterogeneity of age, which potentially influenced the union rate and union period. Lastly, the median two-year follow-up period may not demonstrate long-term complications, especially recurrence of the lesion.

## CONCLUSION

In conclusion, BG has many advantages over autograft and other non-autogenous graft options. Our study demonstrated fair results with high union rates and MSTS scores postoperatively, along with low recurrence rates. Especially in the younger population, BG is a safe and reliable bone grafting option that should be considered in benign bone defects.

**Ethics Committee Approval:** This study was approved by the Istanbul Medipol University Ethics Committee (Date: 25.06.2025, Decision No: E-10840098-202.3.02-3962).

**Peer-review:** Externally peer-reviewed.

**Authorship Contributions:** Concept: S.S., L.E., Ş.S.; Design: Ş.S., A.S., M.C.; Supervision: O.C., A.S., L.E.; Resource: A.S., L.E.; Materials: A.S., L.E.; Data collection and/or processing: O.C., M.C., S.S.; Analysis and/or interpretation: O.C. M.C.; Literature review: Ş.S., S.S.; Writing: S.S., O.C.; Critical review: L.E., A.S.

**Conflict of Interest:** None declared.

**Financial Disclosure:** The author declared that this study has received no financial support.

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ORİJİNAL ÇALIŞMA - *ÖZ*

## İyi huylu kemik tümörlerinin tedavisinde biyoaktif camın klinik ve radyolojik sonuçları: 64 vakanın retrospektif çalışması

AMAÇ: İyi huylu ve agresif iyi huylu kemik tümörleri, metastatik olmasalar da ağrı, kırık riski veya fonksiyonel bozukluk nedeniyle cerrahi müdahale gerektirebilir. Bu olgularda cerrahi tedavi sırasında kemik grefti kullanılabilir. Otogreftler altın standart olarak kabul edilse de, özellikle pediatrik hastalarda dezavantajlı olabilir. Biyoaktif cam (BG), bu gibi durumlarda uygulanabilir bir alternatif olarak öne çıkmaktadır. Bu çalışmada, iyi huylu kemik tümörlerinin tedavisinde BG'nin klinik ve radyolojik sonuçları değerlendirildi.

GEREÇ VE YÖNTEM: Bu retrospektif, tek merkezli çalışmada 2004-2023 yılları arasında iyi huylu kemik tümörleri için küretaj ve BG grefti ile tedavi edilen 64 hasta (71 cerrahi işlem) incelendi. Fonksiyonel sonuçlar Musculoskeletal Tumor Society Score (MSTS) ile, radyolojik iyileşme ise Neer sınıflandırması ile değerlendirildi.

BULGULAR: Ortalama takip süresi 25.0±12.6 aydı. MSTS skorlarında anlamlı iyileşme saptandı (17.6±4.8'den 28.1±2.0'a; $p<0.05$). Neer sınıflandırmasına göre yüksek kaynama oranları elde edildi. Komplikasyonlar arasında 4 hastada (5 cerrahi işlemde) tümör nüksü, 9 hastada kırık ve 4 hastada yüzeyel enfeksiyon gözlendi. Derin enfeksiyon veya materyale bağlı başka olumsuz bir sonuç bildirilmedi.

SONUÇ: BG, özellikle otogreft seçeneklerinin sınırlı olduğu pediatrik popülasyonda, iyi huylu kemik defektlerinin tedavisinde güvenli ve etkili bir greft alternatifidir. Osteokondüktif özellikleri, enfeksiyon direnci ve kemik remodelingi ile uyumluluğu sayesinde geleneksel greftleme tekniklerine güçlü bir seçenek oluşturmaktadır.

Anahtar sözcükler: Biyoaktif cam; çocuk kemik tümörleri; iyi huylu kemik tümörü.

Ulus Travma Acil Cerrahi Derg 2025;31(9):920-924 DOI: 10.14744/tjtes.2025.89507