

## Reconstructing Humerus Defects after Tumor Resection Using an Intramedullary Cortical Allograft Strut

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**Background:** The humerus is a frequent involvement site of benign bone lesions. Various reconstruction methods have been adopted to restore the defect after excavating the lesion and/or to treat associated pathological fractures. In this study, we reviewed the clinical outcomes of using allogenous cortical struts to the treatment of patients with large humeral defects resulting from benign bone lesions, and investigated the mid-term fate of implanted allografts.

**Methods:** From 1988 through 1997, 29 patients with space-occupying humeral lesions were treated by eradication of the tumor and reconstruction with an intramedullary allogenous cortical strut. No additional internal fixation was needed for support. Clinical data were recorded, and functional and radiographic results were evaluated.

**Results:** The sizes of defects after eradication of the lesions ranged from 61 to 122 ml (mean, 92 ml). The patients were followed for a mean of 8.8 years. One local recurrence was noted and was successfully treated by repeating the procedure. All patients achieved good to excellent functional results. Follow-up radiographs showed complete healing of the defects, with partial to complete incorporation of the allografts into the host bones. Children had a better chance of complete allograft incorporation than adults.

**Conclusion:** Intramedullary allogenous cortical struts act as internal splint mechanically and bone graft material biologically. The combined use of intramedullary allogenous cortical struts and chipped cancellous bone grafts provided good stability and healing probability for large osseous defects in the humerus without the need for implant fixation. Allograft incorporation occurred slowly in adults and might not achieve complete incorporation in adults.

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**Key words:** allogenous cortical strut, bone tumor, union, allograft incorporation.

The humerus is the third most common site for benign space-occupying lesions after the distal area of the femur and the proximal area of the tibia.<sup>(1)</sup> Some benign lesions can grow, cause marked bony

destruction, and lead to pathologic fracture of the shaft or metaphyseal area. Consequently, adequate eradication of the lesion is necessary, except in the case of simple bone cysts.<sup>(2,3)</sup> However, tumor eradi-

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cation usually creates a defective and weakened limb. Small defects can be simply managed with an autograft or may even be left untreated, but extensive defects carry a high risk of postoperative fracture and can be slow to heal. Therefore, the treatment of large tumors or space-occupying tumor-like lesions generally focuses on restoring structural integrity after eradication of the bone lesions.

Large osseous defects remain orthopedic challenges. Various reconstruction options can be considered after eradicating the lesions, including autografts, allografts, and various biocompatible bone substitute materials. Autografts, either vascularized or non-vascularized, are considered the ideal graft materials.<sup>(4-6)</sup> However, autografts are not always available in sufficient quantity, especially in children. Donor site morbidity is another drawback prohibiting their wide application. Biocompatible bone substitute materials can only be used in areas with intrinsic skeletal stability and do not provide significant structural support.<sup>(7-9)</sup> Additional supports using various internal fixation devices or cast protection are often needed when autogenous cancellous bone grafts or bone substitute materials are adopted. Torsional and shear forces at the lesion site make good cast immobilization difficult to achieve, and the geometry of the humerus, particularly at its proximal and distal ends, limits implant choice. The site and size of the bony lesions can make stable intramedullary fixation difficult even when transfixation screws are used. A plate and screw fixation relies on the purchase of screws that vary with the quantity and quality of the remaining bone.

Given the above problems, allogenous cortical struts are attractive alternatives for treating large bony defects of the humerus. Allogenous cortical struts have been widely used to treat spinal conditions for interbody fusions, various nonunions of long bones, and in revision surgery for total joint arthroplasty.<sup>(10-15)</sup> In addition to acting as a bone graft, allogenous cortical struts provide immediate mechanical strength that can eliminate the need for any additional intramedullary nails or plates and screws.<sup>(15,16)</sup>

Though allografts have been widely used in various reconstructive fields of orthopedic practice, only a few researchers have examined the clinical results of using intramedullary allogenous cortical struts to treat benign humerus lesions. Furthermore, mid-

term results of allogenous cortical struts have also rarely been discussed. The purpose of this study was to review the clinical, functional and radiographic results of using intramedullary allogenous cortical struts to reconstruct large humerus defects after eradicating the lesions. Mid-term remodeling of the allogenous cortical struts and incorporation of the allografts to the host bones were also addressed.

## METHODS

From 1988 through 1997, 189 patients were admitted to the orthopedic department of the Chang Gang Memorial Hospital with benign lesions in the humerus. Most patients were admitted for corticosteroid injections and multiple drilling for simple bone cysts, osteochondroma excision, or curettage and autogenous or combined allogenous and autogenous cancellous bone grafting for small lesions. Large humerus lesions were defined as those larger than 6 cm, expansile, associated with cortical destruction, and having a cavity exceeding 60 ml in volume. Twenty-nine patients were diagnosed with large humeral bone lesions, and treated using curettage and reconstruction of the humerus with an allogenous cortical strut, with or without supplementary cancellous bone graft. Clinical data regarding gender, age at surgery, diagnosis, location, estimated volume of the lesions, the presence or a history of pathological fracture, previous treatment, operation time, length of hospital stay, and complications were collected.

### Allograft preparation

The allografts were harvested and stored according to the guidelines set by the American Association of Tissue Banks.<sup>(17-19)</sup> Potential donors with malignancy, hepatitis, septicemia, death from unknown causes and those known to be at high risk (human immunodeficiency virus (HIV)-positive patients, acquired immune deficiency syndrome (AIDS) patients, drug abusers, homosexuals, prostitutes, and hemophiliacs) were excluded. All donors were screened for hepatitis, HIV, and venereal diseases. Blood cultures for aerobic and anaerobic organisms were undertaken and multiple bacteriological cultures of soft tissues and bone marrow were obtained during the recovery phase of bone banking. The bones were harvested within 24 hours of death and

stored at -70 °C. Small bones, such as the radius, ulna, or fibula, were used as cortical struts.

### Operative technique

The lesion was approached directly through a window in the cortex. Tissues were taken for the frozen section first. Definite surgery was performed after the diagnosis of the frozen section. Curettage was first performed and a dental burr was used to extend the margin to beyond the reactive zone of the tumor to ensure adequate eradication of the lesions. Local adjuvant chemocauterization with phenol and alcohol was performed in cases of fibrous dysplasia, aneurysmal bone cysts, and giant cell tumors.<sup>(20)</sup> The defect was then reconstructed with one or two appropriately contoured fresh-frozen allogenous cortical struts depending on the size of the defect. Most of the cortical allografts could be inserted and firmly anchored due to the geographic irregularities of the remaining cortex of the humerus. In some cases, when the allogenous cortical strut was not securely fixed, two additional screws were passed through the cortical allograft and the humeral cortices to achieve a so-called quadricortical fixation. Supplementary autogenous or allogenous cancellous bone grafts were used to completely fill the bony defect in 22 patients. No internal fixation implants such as intramedullary nails or plates and screws were used as the cylinder cortical graft acted as an internal splint and provided sufficient mechanical strength. Antibiotics were given once before operation and continued for 1 day postoperatively.

### Postoperative management

The humerus was initially immobilized in a sling and swathe. The patients were encouraged to perform gentle, protective, passive range of motion exercises from the third day after surgery, then gradually shifted to active motion exercise at 6 weeks after surgery. Patients were followed every 2 months for the 6 months, every 3 months for the next 6 months, and every 6 months thereafter.

### Functional evaluation

Functional results were evaluated at the last follow up, and were classified using the Musculo-Skeletal Tumor Society rating score of Limb Salvage for the shoulder and elbow.<sup>(21)</sup>

### Radiographic evaluation

Plain radiographs, including antero-posterior and lateral views, were taken preoperatively, immediately after surgery, and at every follow-up examination. All radiographs were independently reviewed by the authors and radiologists. The radiographic analysis was comprised of two aspects: the first aspect involved estimating the volume of the lesion in cubic centimeters using the method described by Glancy et al.,<sup>(4)</sup> while the second aspect involved determining the healing of the lesion and the extent of incorporation of the allogenous cortical struts into the host bones. Each radiograph was examined for trabeculation, internal callus formation, bone density, and borders between the cortical struts and the cavity. A lesion was considered healed if the preoperative cavity was completely obliterated. The lesion was considered partially or incompletely healed when residual lytic areas remained. The union was considered a failure if the cavity was not obliterated, no evidence of trabecular formation existed, or the graft was resorbed. Allograft incorporation into the host bone was considered complete if the graft was completely obliterated. Incorporation was considered partial if the graft was still visible but its border was blunted, and no incorporation if the contour of the allograft was unchanged from that of the initial postoperative radiograph. Factors that may have influenced the incorporation of the allogenous cortical struts were evaluated, such as patient age, defect size, allograft length, and supplementary autogenous or allogenous cancellous bone graft. Contingency tables were created for each factor as related to incorporation, and subjected to Fisher's exact test for nonparametric data and t test for continuous values. A statistical significance was defined as  $p < 0.05$  for each test.

## RESULTS

A total of 29 patients were included in this study. There were 17 men and 12 women. The ages of the patients ranged from 11 to 52 years, with a mean of 21 years. Bone defects were located in the proximal end of the humerus in four patients, in the midshaft in 13 patients, and in the distal third of the humeral shaft in four patients. Four patients had bone involvement extending from the upper to the

middle third of the humerus, two had bone involvement extending from the middle to the lower third of the humerus, and two had lesions involving the whole humerus. Four (14%) patients had experienced one or more pathologic fractures, and three were treated with casting and local prednisolone injections, while one was treated with surgery. Twenty-five patients sought medical help because of pathological fracture after minor traumas. Four patients were referred for further treatment because of local recurrence following previous surgical intervention or failed repeated corticosteroid injection. The pathologic diagnoses were simple bone cyst in nine patients, fibrous dysplasia in 10 patients, aneurysmal bone cyst in five patients, and giant cell tumor in five patients. No immediate postoperative complications occurred. The mean hospital stay was 6 days.

### Oncological results

A minimum follow-up of 5 years was necessary to ensure no signs of local recurrence and to assess the long-term results of the allografts. After a mean follow-up period of 8.8 years (range, 5 to 14 years), one patient died of an unrelated cause and the remainders were alive at the last follow up. One patient suffered from local recurrence 1.5 years after surgery and was treated successfully with another curettage and allogenous cortical strut reconstruction. Another patient who had polyostotic fibrous dysplasia with whole humerus involvement also had residual tumor over the metaphyseal region, and was regularly followed without further surgical intervention. All pathologic fractures healed.

### Functional results

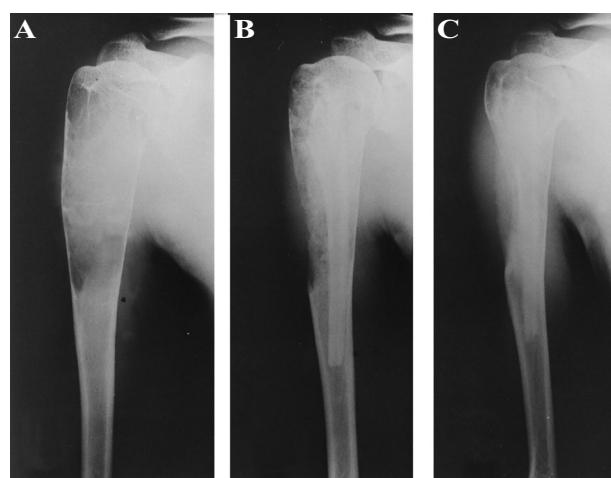
The functional evaluation revealed that 25 (86%) patients had no pain or discomfort, and enjoyed normal use of the affected limb, while four (14%) patients experienced occasional soreness of the affected limb after extended use. The second group of patients were still able to perform daily life activities without limitations and were satisfied with the results. At the last follow up, the average active shoulder elevation was 165 degrees, total shoulder abduction was 170 degrees, and arc of rotation exceeded 160 degrees. The average range of active elbow flexion was 145 degrees, pronation was 90 degrees, and supination was 100 degrees. The over-

all results were rated as good in four patients and excellent in 25 patients.

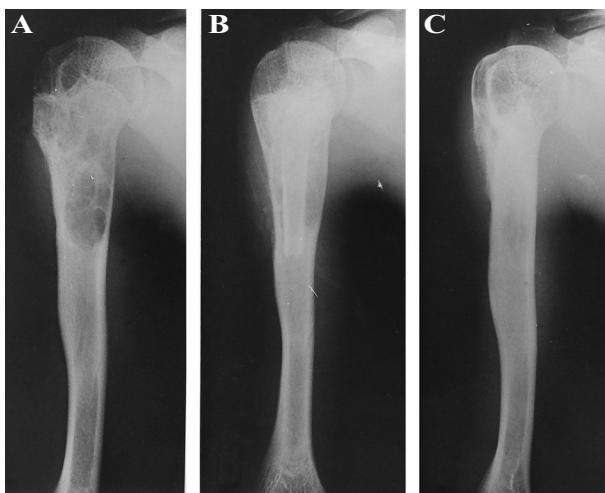
### Radiographic results

The sizes of the defects ranged from 61 to 122 ml with a mean of 92 ml after eradicating the lesions. Radiographs at 2 months postoperatively showed signs of new bone formation in the cavitary defect, which indicated healing. All radiographs except for the two above-mentioned cases showed complete union without any residual tumors 6 months after surgery.

Consolidation and remodeling of the implanted allograft struts were observed in radiographs taken between 9 months and 1 year after operation. Incorporation of the allograft struts increased with time and reached a plateau at 2 to 3 years after surgery except in some children. Bone remodeling continued after 2 to 3 years and complete obliteration of allograft strut border was noted in six children. At the last follow up, the radiographic evaluation revealed blunting of the border between the allograft struts and the host bone bed in most patients (23/29, 79%) (Fig. 1). The allogenous cortical struts remained visible in the intramedullary canal but were incorporated into the endosteal surfaces of the humerus. Six patients displayed complete oblitera-



**Fig. 1** A 28-year-old man with a bone cyst of the humerus. (A) Preoperative radiograph shows thinning of the cortex, and an expansile proximal humerus. (B) Immediate postoperative radiograph reveals allogenous cortical strut in situ. (C) The lesion healed well, but the allogenous cortical strut is still visible 5 years postoperatively.



**Fig. 2** A 15-year-old boy with a simple bone cyst refractory to repeated steroid injection. (A) Radiograph shows a cystic lesion involving proximal third of the humerus. (B) Immediate postoperative radiograph reveals allogenous cortical strut reconstruction. (C) Five years postoperative radiograph displayed healing of the cystic lesion with complete obliteration of the allograft border indicating good incorporation of the allograft struts to the host bone.

tion of the allogenous cortical struts, indicating complete incorporation of the allograft to the host bone (Fig. 2). Younger patients (under 16 years old) had better chances for complete allograft incorporation than the adults (6/18 versus 0/11,  $p=0.039$ ). However, incorporation of the allograft to the host bone was not influenced by lesion size or location. There were also no differences in the incorporation time of patients with or without supplementary cancellous bone grafts.

## DISCUSSION

Benign space-occupying lesions in the humerus are often small and silent. Only less than 10% of lesions are large enough to mandate surgery. Simple bone cysts, though large in size, can usually be treated by drilling and repeated steroid injections in most cases.<sup>(2,3)</sup> Small lesions that do not compromise the structural integrity of the bones can be treated with curettage and cancellous bone grafts only. The use of intramedullary allogenous cortical strut reconstruction techniques for benign space-occupying lesions in the humerus is thus limited to a few spe-

cially selected patients. This was reflected by the fact that only 29 of 189 patients admitted for treatment of benign lesions in the humerus received this procedure. Indications for this technique include lesions that are large, have thin cortex, display cortical destruction, fail to heal, or fail to respond to non-surgical treatment.

The goals of treatment for benign bone lesions are lesion eradication to prevent local recurrence, and restoration of functional integrity to avoid subsequent fracture or deformity. Bone grafts are often needed to fill bone defects resulting from tumor evacuation. Large bone defects also weaken the bony structure and metallic internal fixation devices are often needed. Conventional internal fixation devices such as intramedullary nails or plates and screws are associated with morbidity and are rarely performed in children. Consequently, a more sophisticated surgical procedure that simultaneously provides bone grafts and stability is desired.

Allogenous cortical struts have been used both to provide mechanical support and supplement bone healing in various areas.<sup>(10-15)</sup> The present series successfully extended this technique to treat large bone defects caused by the extraction of space-occupying lesions in the humerus. The mechanical loading of a cortical strut graft is primarily in compression. However, the loading of the strut grafts may also include some bending or torsion in some settings. Previous studies have shown that deep-freezing had only a minimal influence on the biomechanical properties of bone allografts.<sup>(4,16,22)</sup> The mechanical demands of the upper limbs are much less than those of the lower limbs. Healing of the allograft struts to the adjacent host bone further reduced the mechanical demands on the struts.<sup>(23,24)</sup> The intramedullary cortical struts may thus provide sufficient stability to the lesion site by acting as an internal splint, while simultaneously functioning as a bone graft material. This technique may not be as successful in treating long bone defects of the lower limbs, where the mechanical demands of the long bones are relatively high.

Conventional massive allograft reconstruction demonstrated union at the cortico-cortical junction of the allograft and the host bone. This union occurred very slowly (taking approximately 12 months) and was achieved by host derived external callus bridging the junction and filling the gap between abutting

cortices.<sup>(23-25)</sup> Placing the allogenous cortical struts intramedullaryly facilitated union because of the large contact area between the cortical strut and the endosteal surface of the humerus. The preservation of periosteal blood supply further enhanced the defect healing. In the present series, all bony defects showed good union at less than 6 months after surgery. This added an additional advantage of the novel technique in reconstructing large humeral bone defects.

Another advantage of the novel technique is its relatively unlimited availability. Repeated grafting with another allograft strut remains possible in cases of incomplete healing or failure of union. In the present series, one patient was noted to have local recurrence and was successfully treated with repeated curettage and an additional intramedullary allogenous cortical strut. Disadvantages of using allogenous cortical struts include a small risk of transmission of infectious organisms, such as human immunodeficiency and hepatitis B and C viruses. However, these risks are significantly reduced by using modern screening, preservation, and sterilization techniques.

The fate of allogenous cortical struts has seldom been discussed. Allograft incorporation is a complex, multifaceted process, and multiple variables influence the rate, pattern, and completeness of healing. Although union with the host bone can be achieved with large allografts, incorporation occurs slowly if at all. A large series of clinicopathological studies of retrieved human allografts showed that the extent and distribution of cortical revascularization rarely exceeded 2 mm during the first year. Beyond two years, osteoclastic resorption was markedly decreased and rarely penetrated more than 10 mm into the cortex.<sup>(25)</sup>

Radiographical assessment of the remodeling or incorporation of allograft struts is very difficult. Since no retrieved specimens were available in the present series, we can simply use radiographic signs, such as blunting or complete obliteration of allograft borders, as signs of allograft remodeling. This method was quite subjective, but reasonably qualitative. Based on our observation, the children appeared to have a better chance of allograft strut incorporation than the adults. However, allograft strut incorporation was not influenced by diagnosis, lesion size or location. Incorporation time was not influenced by whether or not patients had supple-

mentary cancellous bone grafts. However, since the host bone takes over the mechanical load after bone defect unions, the degree of allograft incorporation did not appear to affect the final results of the patients.

In conclusion, an intramedullary allogenous cortical strut acts as an internal splint mechanically and as a bone graft material biologically. The combined use of intramedullary allogenous cortical struts and chipped cancellous bone grafts provided good stability and healing rate for large osseous defects of the humerus without the need for implant fixation. Remodeling of the allograft and incorporation to the host bone occurred slowly and might not be complete in adults.

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# 使用區段異體皮質骨重建大型肱骨良性骨腫瘤的臨床報告

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**背景：**體積大於60立方公分的肱骨病灶會造成骨頭強度降低，甚至引起病理性骨折。治療這種大型的肱骨骨腫瘤除了徹底刮除腫瘤外，留下的骨骼缺損常需要特別的重建手術。重建此種大型骨骼缺損的方法有許多，卻各有其利弊和使用的限制。

**方法：**從1988到1997年間，共有29位大型的肱骨骨腫瘤的病患在長庚醫院接受治療。手術的方法為徹底刮除腫瘤組織後，以一根或多根區段異體皮質骨來重建骨骼缺損。一方面利用此皮質骨當作內支撐物，所以不需要另外的鋼釘或髓內釘固定；另一方面，此皮質骨也可當作骨移植。在平均8.8年後進行功能評估及放射線追蹤檢查。並且就X光的變化分析影響異體皮質骨在體內結合的因素。

**結果：**腫瘤學的結果顯示，除了一例病人死於不相關的疾病外，所有的病人都存活。29位病人中，只有一例病人有局部腫瘤復發，後來再經一次同樣的手術治療後，結果很好。另一例病人有殘留的腫瘤組織，在繼續追蹤中。25位病人功能評估為極優，其他病人為佳。放射線檢查顯示刮除腫瘤後的空腔在術後二個月即可見明顯的癒合現象，在術後六個月可見幾乎完全的癒合。但異體皮質骨在體內與自體骨結合的速度很緩慢，甚至可能不會完全，追蹤至10年的病人，仍可見異體骨的外型。另外，小孩子異體皮質骨在體內與自體骨結合的速度快於大人，而骨缺損的大小、異體皮質骨的長度、及是否有補充切碎的海綿骨等並不影響異體皮質骨在體內與自體骨結合的速度。

**結論：**區段異體皮質骨不只是可以重建大型肱骨骨骼缺損，提供足夠的穩定力量使得肱骨不會骨折或變形，本身也是移植骨，可加速骨缺損的癒合速度，是個治療大型肱骨骨骼缺損的不錯選擇。尤其使用於小孩子，既不需取自體骨，又有較佳的與自體骨癒合的速度，遠較其他的重建方法好。

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**關鍵字：**異體皮質骨，骨腫瘤，骨癒合，自體骨結合。