Introduction

Chondrosarcoma is a malignant bone tumor that is particularly likely to develop in the pelvis, yet it rarely occurs around the shoulder joint. The most common treatment for chondrosarcoma is surgical resection, and the procedure is extensive resection which may involve resection of the shoulder joint, with significant loss of function. When the shoulder joint is resected, joint reconstruction surgery is often required to preserve its function, but the most common method is replacement of the joint with a prosthesis. However, the postoperative outcomes of shoulder joint prostheses are not very good. There are many reports of the use of allogeneic bone grafting, autologous bone grafting, and recycled bone as reconstruction methods other than artificial joints. In addition, some recent reports have combined vascularized bone grafting with treated or autologous bone grafting. Most of these, however, have been used to treat malignant bone tumors of the femur or humerus. To our knowledge, there are no reports of reconstruction of the scapular glenoid.

Here, we report a case of extensive resection of a chondrosarcoma in the coracoid process, followed by reconstructive surgery using tumor-bearing bone treated with liquid nitrogen and a vascularized iliac bone graft. The purpose of this report is to describe the usefulness of recycled bone treated with liquid nitrogen combined with vascularized bone

for the reconstruction of the shoulder joint in a case of malignant tumor of the glenoid.

The patient and their family were informed that data from the case would be submitted for publication, and gave their consent.

Report of the case

A 63-year-old woman was referred to our institution following concern about right shoulder pain. She mentioned that the pain first appeared around 5 months previously. The range of motion of the right shoulder was restricted due to pain; abduction: 45 degrees, flexion: 60 degrees. We performed radiography, CT, and MRI scans. A bone tumor was found to be present, extending from the coracoid to the glenoid of the right shoulder. On X-ray and CT images, we recognized ballooning and osteolysis of the coracoid cortical bone (Fig. 1). On MR images, the tumor was marked by low intensity on T1-weighted images and high intensity on T2-weighted images. The tumor was located from the base of the coracoid to the proximal half of the glenoid (Fig. 2). No lesion outside of the bone was recognized. Uptake was observed on the early and delayed phase of ^{99m}Tc bone scintigraphy. Chondrosarcoma of the coracoid was suspected based on these imaging examinations. We performed a CT-guided biopsy, and histopathological examination revealed that the tumor of the coracoid was chondrosarcoma grade 1 (Fig. 3).

We performed wide resection of the tumor. The surgical margin was planned to create a wide margin on the basis of the MRI T1 sequence and gadolinium enhancement analysis. During the operation, the scapular bone was resected from the medial side of the scapular

notch to the upper half of the glenoid including the coracoid process. The anterior part of the deltoid muscle, the supraspinatus muscle, the proximal half of the subscapularis muscle, the conjoint tendon, and the distal half of the pectoralis minor were resected with the tumor (Fig. 4). The suprascapular nerve was also resected with the tumor.

After wide resection of the tumor, the glenohumeral joint was reconstructed using tumor-bearing bone treated with liquid nitrogen combined with an iliac vascularized bone graft (VBG). The soft tissue was removed from the bone, and the tumor was curetted before freezing. Liquid nitrogen was transferred to a sterilized flask immediately before use and the excised portion was dropped in and frozen for 20 minutes, then the bone was thawed in a dish at room temperature for 15 minutes, then in distilled water at room temperature for a further 15 minutes (1). The inside of the treated bone was empty and the cortical bone was so very thin that it was like eggshell (Fig. 5). The treated bone used alone would have easily fractured, so it was augmented with a bone graft. A portion of bone 2 cm thick, 3 cm wide, and 3 cm long was harvested from the anterior right iliac crest together with the deep circumflex iliac artery and vein, and grafted into the treated bone (Fig. 6), then the liquid nitrogen tumor-bearing bone combined with the vascularized iliac bone was replaced and fixed in position using two cortical screws. The artery of the donor bone was anastomosed to the thoracoacromial artery, and the veins were

anastomosed to the thoracoacromial vein and the cephalic vein (Fig. 7, 8). The anterior joint capsule attached to the humeral head was fixed to the edge of the glenoid distal half using two metal anchors (GII® Titanium Anchor, Depuy Synthes, Warsaw, IN, USA). The operating time was 7 hours and 54 minutes. The blood loss was 460ml. The result of the final histopathological examination after the operation was Grade 1, which is the same as the results of the biopsy.

After surgery, the right shoulder was immobilized using an abduction brace for 4 weeks. After removing the brace, passive and active motion training of the shoulder joint was started by physical therapists. Bone fusion took quite some time. Artifacts appeared as the anchor was inserted into the glenoid, making it difficult to determine bone fusion just on CT images. The x-ray images and CT images were used to evaluate the bone fusion. Finally, about one year after surgery, bone fusion was obtained. Initially, the osteotomy line was seen on the x-ray images, so it was about a year later when it could no longer be seen. Approximately four years later after surgery, there was no absorption and fracture of the treated bone, so we concluded that it had been fused (Fig.9).

Four years after the operation, there has been no recurrence or metastasis of the chondrosarcoma. The range of motion of the right shoulder is excellent; flexion: 170 degrees, abduction: 170 degrees, external rotation: 20 degrees, internal rotation: 60

77 degrees (MOV). The patient has no complaints of pain in the shoulder joint at all, either
78 at rest or in motion. At final follow-up the International Society of Limb Salvage score
79 was 27/30 (90%) and the score of Disability of Arm, Shoulder and Hand questionnaire
80 score was 11.25.
81

Discussion

It is controversial with respect to the planning of the resection margin in surgery for low-grade chondrosarcomas. Mohler et al. reported the good clinical course of curettage and cryosurgery for low-grade chondrosarcomas(2). They reported that the local recurrence rate was 4.3% and the mean MSTS score was 27.2 of 30 points. However, this report covers chondrosarcomas of long bone in the extremities, but not chondrosarcomas of the scapular. When curettage is performed on bones of the axial skeleton such as the pelvis or scapula, as reported by Normand et al., recurrence rates also can be substantially greater(3). Moreover, Schneiderbauer et al. reported that scapular chondrosarcomas had high rates of local recurrence and metastasis(4). They emphasize the importance of wide margins which must be achieved to provide local disease control.

In our case, CT imaging showed ballooning and very thinning of the cortical bone. There was no obvious tumor outside of the coracoid process, however the shoulder pain was more severe. These findings suggested a pathological fracture of the coracoid process. Imaging studies have determined that it may be Grade 2. Discrepancy between grade at biopsy and postoperative grade is frequently observed. Yoshimura et al. reported that fifty percent of chondrosarcomas diagnosed as grade 1 preoperatively were diagnosed as grade

2 postoperatively(5). In case of local recurrence, the additional wide resection is needed. However, the complex anatomical relationship around the shoulder joint makes it difficult. Adjuvant therapies including radiotherapy and chemotherapy are reported to be ineffective in the treatment of chondrosarcomas. For these reasons, we performed wide resection combined with the resection of muscles and suprascapular nerve.

Limb-salvaging surgery has recently become the standard therapy for malignant bone tumors. Furthermore, joint-sparing surgery is possible, allowing preservation of the joint structure in an effort to maintain normal limb function. Prostheses are the most popular joint reconstruction methods for joint sparing. However, this procedure has many complications and may require several revision surgeries. Teunis et al. reviewed the outcomes of upper extremity prostheses after tumor resection of the proximal humerus. The implant survival rate at the 5-year end point ranged from 38% to 100% (6). Asavamongkolkul et al. reported the outcomes of endoprosthetic reconstruction for malignant upper extremity tumors (7). The probability of endoprosthesis failure during the patient's lifetime was 7% at 5 years and 10% at 8 years after endoprosthesis reconstruction.

. Prosthetic arthroplasty for malignant bone tumors occurring in young people, such as osteosarcoma or Ewing's sarcoma, may not result in good outcomes in the future.

Other surgical procedures are the arthrodesis and the resection arthroplasty. There are numerous reports on the functional outcomes after shoulder arthrodesis. Of the 17 patients in the Hawkins and Neer study, 5 functioned reasonably well at head level (eg, hair combing, face washing), while 4 others had great difficulty (8). Fourteen patients could use their hands satisfactorily at waist level, but only 3 could reach the hand behind the back for hygiene. No patient was able to work overhead or with the arms abducted (eg, hammering, painting, climbing a ladder). Four of 17 patients could not return to jobs requiring manual labor. Five of the 17 patients returned to manual labor, but not at their preinjury level. Overall, 7 of the 17 patients were dissatisfied because of functional disability. Wick et al. found that patients were unable to reach behind the back, and most of them had difficulty with ADLs around the face (9) . In contrast, Cofield and Briggs reported that, of the 65 patients available for follow-up, 70% could lift moderate weights, dress themselves, tend to personal hygiene, and eat using the extremity with the fused shoulder (10). Although only 21% could use their arm for light work at shoulder level, 82% found their arthrodesis to be functionally beneficial. In summary, the patients' satisfaction with shoulder arthrodesis might be reasonably good, but it would be difficult to work above the head. On the other hand, there have been also numerous reports on resection arthroplasties. Stevens et al. reported the outcomes after 7 resection

arthroplasties (11). Most of the patients were satisfied with their resection arthroplasty, but patients had an average forward elevation of 63 degree and average external rotation of 27 degrees. Braman et al. reviewed outcomes at 20 months postoperatively for 7 patients with resection arthroplasty (12) . All of the patients could reach their opposite axilla, their back pocket, and their mouth, but no patient had satisfactory results. Debeer et al. also described outcomes after 7 resection arthroplasties (13). All patients had excellent pain relief, but functional outcomes were poor. Nevertheless, they also concluded that resection arthroplasty is a reasonable option for the shoulder surgery in elderly people. In summary, as with the shoulder arthrodesis, there are many reports of good patients' satisfaction, but many reports of poor functional outcome.

Recycled bone, which is treated by methods such as autoclaving (14), pasteurization (15), irradiation (16) or freezing (1), is useful for reconstruction because it is perfectly matched to the defect and easily fixed in position with plates and screws, as well as inducing no immune reaction.

However, there are some disadvantages, which include the risk of infection due to the lack of blood flow, pseudarthrosis due to slow regeneration or lack of bone regeneration ability, and the possibility of bone resorption. Kohler et al. investigated the strength of autoclaved bones in an experiment using rabbits. They confirmed that complications such

154 as mechanical failure, loosening, and failure of the union often occur when autoclaved
155 bone is used (17). Sakayama et al. reported the pathological findings of pasteurized bone
156 retrieved 5 months after implantation. In that study, the pasteurized bone was necrotic
157 and no new bone formation was seen (18). Araki et al. reported subchondral bone collapse
158 in 55% of irradiated bone grafts within 30–104 months (16). On the other hand, Marciani
159 et al. reported good remodeling quality of liquid nitrogen-treated bone (19), while
160 Higuchi et al. reported earlier osteogenesis and new bone formation in a frozen autograft
161 treated with liquid nitrogen (1). Tanzawa et al. reported the pathological findings of frozen
162 bone retrieved between 2 and 75 months after implantation. In their study, bone
163 regeneration in frozen autografts began less than 5 months after implantation (20). Frozen
164 autografts contain autogenous proteins, growth factors, and cytokines (21), and they do
165 not elicit an immune reaction. Consequently they have the advantages of early bone union,
166 a low risk of bone resorption, and rapid progression toward incorporation. In our case,
167 four years after the operation, the frozen autograft bone has not been resorbed.
168 Allogeneic bone grafting has previously been reported to be a useful method in
169 reconstructive surgery. Enneking et al. reported that the total extent of repair was
170 approximately 30% in allografts retrieved 2 years after implantation. They observed that
171 internal repair was confined to the terminal and peripheral parts of the cortex (22).

Allografts may be better than recycled bone for bone regeneration after implantation. However, allografts carry the risk of HIV infection (23) and antigenicity and grafting is difficult to perform in countries in which bone bank systems have not been well developed.

There are some reports of the use of osteoarticular grafts of recycled bone for joint reconstruction. Tanzawa et al. reported the histological examination of frozen osteoarticular grafts treated with liquid nitrogen. They examined four specimens of joint cartilage, and found that three of them showed fibrillation of the superficial surface and irregularities in the thickness of the frozen articular cartilage, while the persisting cartilage was totally devoid of chondrocytes in the lacunae (20). The loss of viable chondrocytes is the cause of osteoarthritis. Cartilage frozen in liquid nitrogen develops osteoarthritic changes over time, as is seen in osteochondral allografts (24). Additional surgeries, such as total knee arthroplasty, may be needed in the future for some patients. Koyanagi et al. reported that pasteurized bone used for osteoarticular grafts was absorbed and additional surgeries were required. They proposed that it is preferable to use pasteurized bone in combination with a VBG or autologous bone graft for osteoarticular grafting (25). To the best of our knowledge, there were no large-scale reports comparing vascularized bone graft and non-vascularized bone graft (autologous bone graft)

combinations in reconstruction with osteochondral bone treated with liquid nitrogen. Oike et al. reported the long-term outcomes of an extracorporeal irradiated autograft for limb salvage operation in musculoskeletal tumors (26). They reported that there was no difference in union rates between vascularized and non-vascularized bone graft. However, of the 27 patients in their study, the irradiated autografts were completely removed in three patients owing to complications, and these patients were reconstructed without vascularized bone grafts at primary operations. They concluded that the use of vascularized fibula grafts did not enhance union, but irradiated autografts combined with vascularized fibular grafts were well preserved. Errani et al. analyzed 81 patients with femoral or tibial sarcomas who underwent intercalary resection and microsurgical reconstruction with massive bone allograft and vascularized fibula (27). Nineteen of all patients had fractures of the bone allograft-vascularized fibula construct. However, after surgical or conservative treatment, all the fractures successfully healed. They concluded the biology of vascularized fibula was able to save the reconstruction in most of the cases. In addition to these reports, there are many other papers that demonstrate the effectiveness of vascularized bone graft (28) (29). Based on these reports, we believe that support for vascularized bone grafting is effective in joint reconstruction using osteochondral treated bone. In our case, no degenerative changes nor osteoarthritis of the shoulder joint were

evident four years after the operation. The shoulder is a non-weight bearing joint, so osteoarthritis might be less likely to occur. However, longer follow-up is considered necessary.

Many reports have confirmed that VBGs are useful for reconstruction in bone and joint surgery. In particular, VBGs are frequently used after wide resection of malignant bone tumors. Because vascularized bone has blood flow, complications such as pseudarthrosis and infection could be avoided. Several reports have shown good results using the technique of combining recycled bone with a VBG in the treatment of malignant bone tumors (30). Sunagawa et al. reported that VBGs induce revascularization of necrotic bone and osteogenesis in adult dogs (31). In our case, the tumor bone treated with liquid nitrogen has not been absorbed 4 years after the operation. We inferred that the revascularization and osteogenic ability of the VBG led to this good result.

As mentioned above, a prosthesis is the most common method of shoulder joint reconstruction. In the present case, a prosthesis was the other option considered as a method of reconstruction other than the use of recycled bone, but because the results reported are not very good, this option was not selected. A systematic review and meta-analysis revealed that the postoperative range of motion of the shoulder joint after prosthesis surgery was 82.2 ± 33.9 degrees of anterior flexion and 22.0 ± 20.6 degrees of

external rotation (32), which is not as good as the results achieved in our case.

In recent years, a number of good results have been reported from the use of reverse shoulder prostheses in patients with massive rotator cuff tears. Bacle et al. reported good results of 131 ± 29 degrees of anterior flexion and 43 ± 30 degrees of external rotation of the shoulder joint at an average of 150 months after arthroplasty using reverse shoulder prostheses (33). In the present case, the subscapularis tendon and supraspinatus nerve (supraspinatus and infraspinatus muscles) were sacrificed at the operation. Therefore, only the deltoid muscle is currently moving the shoulder joint. A reverse shoulder prosthesis could have been used to achieve relatively good results. However, half of the glenoid was resected at surgery, so there was no foundation for the prosthesis, which may have necessitated supplementation such as with an iliac autograft. Consequently it may have been difficult to fix the prosthesis in place.

There are limitations to this technique. As noted above, since the articular cartilage is treated with liquid nitrogen, there is a risk of developing arthritis in the future. Therefore, this method would be difficult to use in weight-bearing joints such as knee, hip and ankle joints. Hayasi et al reported that irradiated osteoarticular bone grafts in the knee joint were not recommended because collapse of irradiated joints was inevitable in the long term (34). This method is also technical demanding. The microsurgery technique is

required to perform vascularized bone graft. This will inevitably result in a longer operative time, and this procedure may be difficult to adapt to older patients or those with a serious history of disease.

In conclusion, shoulder joint preservation surgery using a tumor-bearing frozen autograft combined with a VBG was successful and resulted in satisfactory functioning of the shoulder joint.

Conflict of interest

No benefit in any form has been or will be received from any commercial entity related directly or indirectly to the subject of this manuscript.

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359

Figure captions

Figure 1

a, b. Plain radiographs showing ballooning tumor of the right coracoid.

c, d. Coronal and oblique sagittal CT scan images. The bone tumor was located from the base of the coracoid to the proximal half of the glenoid.

Figure 2

a, b. T2-weighted magnetic resonance imaging (MRI) of the right shoulder. The tumor was located at the base of the coracoid. There was no joint fluid accumulation. a: axial image. b: coronal image.

Figure 3

Histological examination of the tumor revealed chondrocytes with clear lacunae and mildly enlarged nuclei. The substrate constitutes the vitreous cartilage. These characteristics indicate chondrosarcoma grade 1.

a. Hematoxylin Eosin stain ×40

b. Hematoxylin Eosin stain ×100

Figure 4

Intraoperative photograph showing the shoulder joint after tumor resection. The humeral head and glenoid with the proximal half resected can be seen.

Figure 5

a. The resected chondrosarcoma together with surrounding bone margins, removed by the biopsy route.

b. The specimen after treatment with liquid nitrogen. The cartilage of the glenoid was also treated with liquid nitrogen.

Figure 6

The vascularized iliac bone was inserted into the tumor cavity of the recycled bone after treatment with liquid nitrogen.

Figure 7

The recycled bone combined with the vascularized iliac bone was fixed in position with two cortical screws. The artery of the donor bone was anastomosed to the

thoracoacromial artery, and the veins were anastomosed to the thoracoacromial vein and the cephalic vein.

Figure 8

The schema of this surgical procedure.

Figure 9

Plain radiograph (a) and CT image (b) at four years after operation. a. The screws and anchors are not loosened. b. The bone union between recycled bone and donor site can be recognized.