REVIEW ARTICLE

Is there an ideal method of reconstruction for proximal humerus osteosarcoma? A review of different reconstruction techniques

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Abstract

Osteosarcoma is the commonest primary bone malignancy occurring in patients aged <20, and humerus is the third most common site affected by it. In the past, ablative surgery with poor functional outcomes was the only option, but due to advances in chemotherapy, medical imaging and surgical techniques, patient survivorship and the rate of limb salvage surgery has increased significantly. Over the decades many treatment options have been proposed for the reconstruction of the defect following extirpation of the tumour in the proximal humerus, with every procedure having its merits and demerits. However, there is no agreement on the preferred treatment even in similar age groups, and the best way to reconstruct the proximal humerus remains debatable because the restoration of the function of the shoulder girdle remains primarily dependant on the extent of muscle-loss during tumour resection, available surgical expertise and financial constraints in different health systems. The current narrative review was planned to discuss the various reconstruction techniques with their advantages and disadvantages, and a present general review of the relevant literature.

Keywords: Osteosarcoma, Humerus, Limb salvage, Neoplasms, Sarcoma surgery, Reconstructive surgery.

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Introduction

Osteosarcoma is the commonest primary malignant bone tumour in young patients among whom there is a 15-30% survival rate if the tumour has metastasised. Proximal humerus is a common site for primary and metastatic tumour accounting for 15% of osteosarcoma locations[1].

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Historically, before the advent of chemotherapy and modern imaging and surgical techniques, ablative surgery was the only surgical option and it had dismal outcomes.

The introduction of multi-agent chemotherapy changed the whole concept of the management of patients with osteosarcoma, and 5-year survivorship jumped from a dismal 20% to 70%[2,3]. With advances in surgical techniques, imaging, biomaterials and better understanding of the disease, limb salvage surgery became the norm[4,5]. Multiple trials have shown that the survivorship is independent of whether limb salvage surgery was performed or amputation, and that limb salvage surgery leads to better physical, functional and psychological outcomes[6]. Arias Vázquez et al. revealed that the rate of depression in amputees was 92.5% while 27.5% had suicidal tendencies[7]

Numerous options have been proposed for the reconstruction of the defect following the resection of proximal humerus, and every procedure has its merits and demerits. However, there is no agreement on the preferred treatment even in similar age groups and the best way to reconstruct the proximal humerus remains debatable because the restoration of the function of the shoulder girdle remains primarily dependant on the size of the tumour[8](Figure1), extent of muscle-loss during tumour resection, integrity of axillary nerve, available surgical expertise, and financial constraints in different

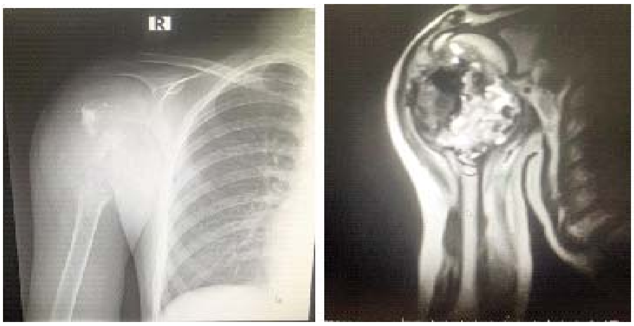

Figure: (a) Plain radiograph showing a destructive lesion (Telangiectatic osteosarcoma) involving the proximal humerus. (b) T1-weighted coronal view of magnetic resonance imaging (MRI) scan showing the involvement of meta-epiphyseal region of humerus, and with the involvement of all rotator cuff muscles, approximately 50% of deltoid and sparing of gleno-humeral joint.

health systems[9,10]. The current narrative review was planned to discuss and review the reconstruction options available for the proximal humerus after the extirpation of tumour.

Presentation and pre-operative management

Patients with osteosarcoma usually present in the teen ages, and the commonest symptoms are pain, swelling, deformity, fracture and loss of function[11]. The first line of investigation is a plain radiograph which shows an aggressive, destructive lesion usually in the meta-epiphyseal region of the proximal humerus.

After local and systemic staging and confirmation of diagnosis with biopsy, the patient is referred for multi-agent neoadjuvant chemotherapy. The preferred technique is a core needle biopsy which has a high positive yield and is minimally invasive[12]. Following re-staging after the completion of the neoadjuvant chemotherapy, surgical planning is done for the extirpation of tumour and reconstruction of the defect. Any reconstruction that is undertaken should cause minimum morbidity, be durable, and acceptable to patients and their families.

Reconstruction options

The reconstruction method for the defect after the extirpation of tumour depends on numerous factors, including patient age, surgeon's experience, availability of bone bank for allografts, and financial issues. Patient preferences and social and religious factors also play an important role in the decision-making process for reconstruction. The reconstruction options can be broadly classified into biological and non-biological (Table 1). A summary of merits and demerits of these reconstruction options has also been shared for the readers (Table 2).

Table-1: Reconstruction options for proximal humerus osteosarcoma.

Biological	Non-biological	Hanging shoulder
1. Autograft: a. Vascularised and non-vascularised fibula autograft. b. Intercalary autograft, joint sparing. c. Clavicle pro humerus. **2. Allograft:** a. Osteoarticular allograft. b. Structural/Intercalary allograft. c. Allograft prosthetic composite. **3. Recycled bone.** a. Radiation. b. Autoclaving. c. Liquid nitrogen. d. Pasteurisation.	1. Modular & custom-. made prosthesis 2. Nail, cement spacer.	1. Tikhoff Linberg type reconstruction

Table-2: Types of reconstruction options, their benefits, availability and disadvantages

Options.	Microvascular surgery skills.	Availability.	Morbidity, donor site.	Non-union.	Range of motion.
Endoprosthesis	No.	Yes.	NA.	NA.	Depends on loss of muscle and nerve, prosthesis type.
Nail cement spacer	No.	Easily.	NA.	NA.	Depends on loss of muscle and nerve
Allograft.	No.	No.	No.	Yes.	Minimal, unless intercalary.
Vascularised autograft.	Yes.	Yes.	Yes.	Yes.	Yes, on scapulothoracic joint if arthrodesis performed.
Non-vascularised autograft.	No.	Yes.	Yes.	Yes.	Yes, on scapulothoracic joint if arthrodesis performed.
Recycled bone.	Only if vascularised fibula used in between.	Yes.	If fibula used.	Yes.	Yes, on scapulothoracic joint if arthrodesis performed.
Clavicle pro humerus.	No.	Yes.	Yes.	Yes.	Some.
Allograft.	Only if vascularised fibula used in between.	No	Only if vascularised fibula used in between.	Yes	Depends on type of reconstruction.

A. Biological reconstruction:

1. Fibula autograft

Fibula is the workhorse of oncoplastic surgeons for biological reconstruction, and this is the commonest type of autograft used for proximal humerus osteosarcomas. It can be used either as a vascularised or non-vascularised graft, depending on the size of the defect and available surgical expertise. There is a general consensus that to bridge any defect >5cm, one should consider a

Figure-2: Vascularised fibula autograft with fibuloglenoid arthrodesis, showing solid union at both sites.

vascularised fibula as a larger defect size is considered a high-risk factor for non-union. Vascularised fibula after implantation retains it's biological and mechanical properties, which is why it can easily heal by primary union and, in response to load, can also undergo hypertrophy[13]. Along with better union rates, vascularised fibula graft also offers better resilience to infection in a hostile environment[14]. However, a surgeon skilled in microvascular surgery is needed on the team for a vascularised fibula autograft.

The fibular graft can be used in different ways, depending on the location of the defect, and, to an extent, the age of the patient. The commonest mode is to use the fibula graft and fuse it distally at the fibula-humeral site and proximally either an arthrodesis at the fibuloglenoid junction (Figure 2) or suspensory arthroplasty at the glenoid. With fibula glenoid arthrodesis, patient can utilise the scapulothoracic joint for movements with intensive physiotherapy and can attain an abduction and flexion of almost up to 90 degrees. This form of reconstruction is very advantageous, particularly if the rotator cuff has been sacrificed completely due to the involvement in the tumour. There is no cut-off age limit for this type of reconstruction, but they perform well in younger patients[13,15]. This, in the opinion of the authors, is the preferred option for all patients aged <20, unless otherwise.

Another way to use the fibula in very young patients is to harvest the autograft with the fibula head, and reconstruct a shoulder capsule around the gleno-fibular joint. The function and stability of this type of reconstruction, however, relies on the integrity of muscles around the shoulder. This type of reconstruction is ideal for very young patients[13].

In rare cases when the humeral head with its tuberosities is spared from the tumour, one can reconstruct the defect using the fibula as an intercalary graft. This, however, is rare, as patients mostly present late and the tumour size is large enough not to spare the humeral head[16]. The advantage with this type of reconstruction is that the function of the glenohumeral joint is well preserved.

2. Clavicle Pro humerus

This surgical modality was first introduced for filling congenital upper limb deficiencies, which later on was modified for the reconstruction of shoulder girdle after tumour resection[17]. In this form of reconstruction, after the removal of the tumour, the clavicle is freed from the sternoclavicular joint and rotated over the vascular pedicles and ligaments at the coraco-clavicular joint and fused with the remaining part of the humerus (Figure 3). This type of reconstruction effectively works as a vascularised graft, but does not need any micro-vascular anastomosis. The native blood supply to the lateral clavicle is maintained through the thoraco-acromial trunk[17]. The main limitations of this reconstruction are the complex anatomy medial and inferior to the clavicle, and the size of the clavicle itself, because it depends on whether it will be big enough to bridge the defect left after tumour resection. Along with size, the shape of the clavicle also poses major stability concerns at the distal clavicle and humerus interface[18].

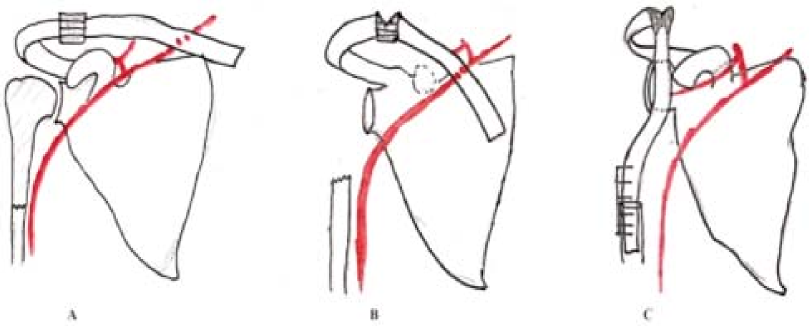

Figure-3: The Clavicle Pro-humerus procedure. (a) resection of the proximal humerus tumor, (b) turning the clavicle with maintained distal blood supply and ligamentous support, and (c) fixation of the clavicle to the remaining humerus and repair of the coracoid process, which is released to facilitate rotation of the flap[34].

However, the humerus can be shortened, if needed, with this type of reconstruction, with no significant compromise apart from cosmetic appearance. With this technique, the reported functional outcomes are comparable to fibula autograft, allograft or prosthesis, but there are numerous reported major complications in the clavicle pro humerus group, mainly due to instability of the construct, requiring surgical revisions[18].

3. Allograft

Allografts can be used to reconstruct the defects, and they can either be used as structural/intercalary or osteoarticular grafts. The main advantage with this technique is the avoidance of donor-site morbidity, matched anatomy and the ability to bridge large defects. However, the main downsides are the non-availability of allografts due to lack of bone banks, risk of disease transmission, degeneration of the joint in the longer run, risk of fracture, as well as social and religious issues[19]. An alternative option is to use this as a composite graft with a humeral prosthesis cemented into an allograft and then fixed in the defect, which provides more stability and better soft-tissue coverage by providing secure tendon and muscle re-insertions[20]. This is generally reserved for weight-bearing bones, and its use is limited in the upper limb.

4. Recycling and replantation of bone

One method of reconstruction, particularly used in developing and resource-constrained setups, is treatment of the involved bone with some modality to kill the tumour cells and then replant that bone in the defect. The tumour-ridden bone can be sterilised using radiation[21,22], pasteurisation[23], autoclaving or liquid nitrogen[24]. The main advantage is that one uses the patient's own bone to reconstruct the defect; it is cheap and fills the defect anatomically. However, the main disadvantages are the destruction of all the bone cells along with the tumour cells when they are treated, leading to loss of structural integrity of the bone, and to fractures[24]. A higher risk of infection is another common concern associated with these techniques. The other main drawback is that as the same bone is re-used, one is not able to assess the margin status and tumour necrosis after chemotherapy to assess the response and need for adjuvant chemotherapy. There is also a concern about whether live tumour cells are replanted after treatment, but extensive studies have been conducted to assess the safety of each of these methods[21,22].

Whatever treatment type is used, the commonest concerns apart from oncological issues are a risk of fracture, non-union and prolonged immobilisation. To improve the chances of union, a fibula autograft can be used along with the treated bone as a "hot dog" which can be vascularised or non-vascularised. We recommend the use of a vascularised fibula with this technique whenever possible (Figure 4).

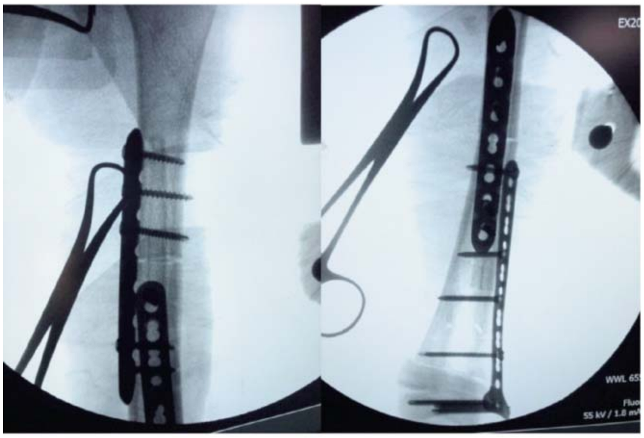

Figure-4: Per-operative radiographs of fibula autograft used as a "hot dog" in an inter-calary liquid nitrogen-treated femoral bone segment in a patient of Ewing's sarcoma.

Radiation of the tumour bone is one of the commonest treatment types used, and relies on the availability of radiotherapy unit at the site, as otherwise it takes a long time for the transfer of the bone to and from the facility[24]. In autoclaving technique, the bone is treated at 132 degrees Celsius for 8-12 minutes (Figure 5). In pasteurisation, the bone is treated in slow heat for 45 minutes at temperatures up to 62 degrees Celsius[23]. The proposed advantage of this technique is the lesser degree of destruction of the bone architecture.

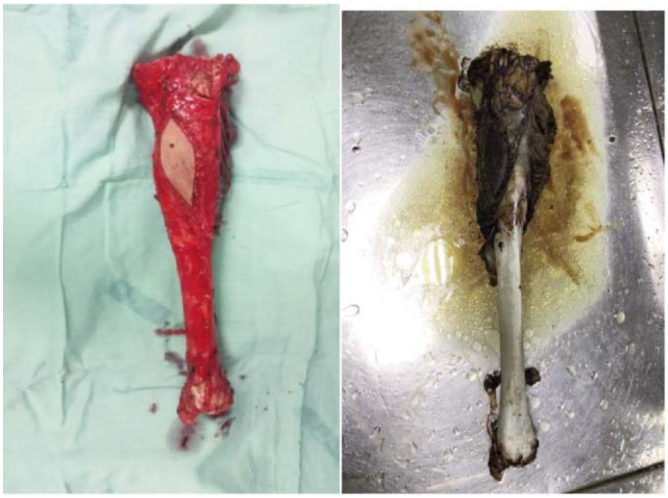

Figure-5: (a) Tumour specimen (whole tibia) with biopsy scar after extirpation. (b) Tibia after autoclaving and treatment in vancomycin-loaded fluid.

Liquid nitrogen is also a well-described treatment modality for biological reconstruction in which the resected bone is left in a container filled with liquid nitrogen for 20 minutes and the temperature goes down to -192 degrees Celsius[25,26]. This is followed by a thawing phase at room temperature for 15 minutes as the bone becomes very brittle because of the treatment and is at risk of fracture. As there is shifting of bone into different containers, there is an associated increased risk of infection with all recycling techniques. This is why these bone segments are always washed in antibiotic loaded fluid (usually vancomycin) for at least 10 minutes before re-plantation. This is the preferred technique for bone recycling as far as the current authors are concerned.

B. Non-biological reconstruction:

1. Modular endoprosthesis

An off-the-shelf, modular endoprosthesis, used as a hemiarthroplasty, is the commonest mode of non-biological reconstruction. This is a quick and reliable method of reconstruction and is freely available, working essentially as a spacer. However, the functional outcome depends on the amount of rotator cuff and deltoid left, and whether the axillary nerve has been spared after tumour resection[10].

Many studies have reported satisfactory outcomes of these endoprosthesis[20], with some claiming up to 91% overall survival rate using such mega prosthesis systems[27]. However, the major issue in the developing countries is the exorbitant cost of this type of reconstruction and the availability of endoprosthesis.

2. Custom-made endoprosthesis

A custom-made prosthesis to bridge the defect left after tumour extirpation is another commonly used reconstruction technique, particularly in the developed world where technology and finances are not the constraints. In contrast, in a country like Pakistan, where patients have to bear the cost of these implants out of their own pocket, it becomes a high-priced management modality[28]. The advantage is a customised prosthesis and that it saves time (Figure 6). However, customisation means they take at least 3-4 weeks to be ready, and if the tumour progresses despite the patient being on chemotherapy, it cannot be used, leading to a huge financial loss to the patient or to the health system.

3. Reverse polarity endoprosthesis

Figure-6: A cemented custom-made endoprosthesis following extra-articular resection of proximal humerus osteosarcoma.

To counteract the loss of rotator cuff, a similar reverse polarity principle can be used in tumour prosthesis, utilising the intact deltoid for shoulder abduction[29]. However, if the deltoid is resected or the axillary nerve is lost during resection, this construct will lose its functional advantage.

4. Nail-cement spacer

In resource-constrained environments, the use of a nail cement spacer to reconstruct the defect is also a viable and is a well-published option[30,31]. Generally, a Kuntscher nail or humerus nail of an appropriate size is cemented in the medullary cavity of the humerus and at the proximal end; a humeral head is made of bone cement, of the same size as the contralateral humeral head. This essentially acts as a spacer, like the endoprosthesis, but much less expensive (Figure 7).

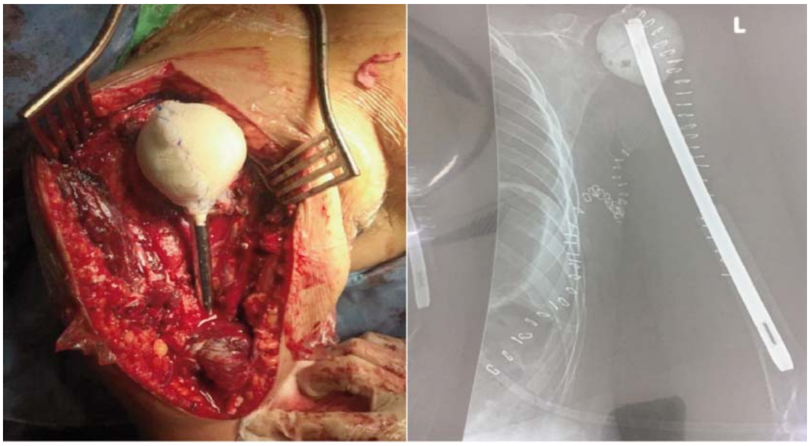

Figure-7: Clinical photograph and post op radiograpgh of a nail cement spacer in situ after tumour extirpation, with a prolene mesh used to stabilise the implant at the joint due to deficiency of rotator cuff and deltoid muscles.

The authors have used this for both primary and secondary tumours, and have good short- to medium-term outcomes in their unpublished series. A prolene mesh is used to suspend the spacer around the glenoid labrum with a purse-string non-absorbable suture to avoid any dislocation in cases where significant deficiency of rotator cuff and deltoid is present.

Comparing it to amputation and the consequent emotional and physical trauma of the patient, this method of reconstruction has shown much better results cosmetically, physically and emotionally[32]. Rafalla A.A. et al. reported comparable functional outcomes and patient satisfaction at mid-term while comparing endoprosthetic replacement versus cement spacer in the reconstruction of proximal humerus after tumour resection[30].

C. Hanging shoulder:

(Tikhoff Linberg type reconstruction)

There are six different types of resection described in this system[33]. Essentially, one can suspend the remnant of the humerus from the clavicle with a prolene, polydioxanone (PDS) suture or merselene tape to avoid traction symptoms. The authors generally reserve and advise this for the elderly patients with compromised fitness (Figure 8).

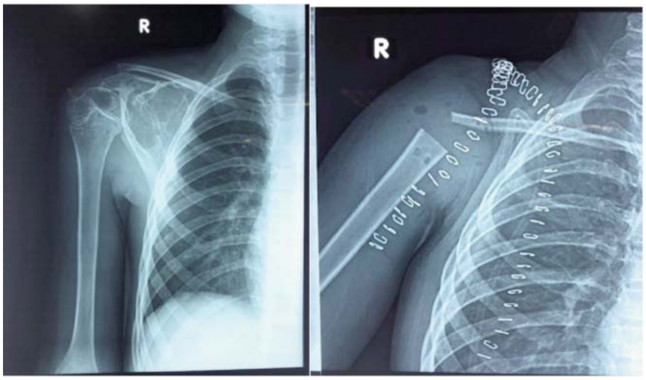

Figure-8: Image of a young boy with tumour involving scapula, shoulder joint and proximal humerus with post-operative X-ray showing Tikhoff Linberg type resection and reconstruction.

Conclusion

The management of extremity bone sarcomas involves a multidisciplinary approach in specialised centres with experienced musculoskeletal oncology and microvascular surgeons, which provides the best outcome. Reconstruction of proximal humerus following tumour resection is a challenging operation due to many reasons, including patient expectations and associated morbidity with these procedures. There are various reconstruction options, and all of them have their benefits and disadvantages. The choice of reconstruction is multifactorial and should be tailor-made depending on the type of defect, patient age, surgical expertise, availability of bone bank or implants and financial issues with the involvement of the patient and family in the final decision-making process (Table 2).

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