INTRODUCTION

Today there are three main goals of orthopedic tumor surgery, which are to protect extremity, to do resection as limited as possible, and to provide reconstruction of the defect with a biological method as most appropriate to body physiology [1]. Reconstruction is the reformation of resected bone and soft tissues, in order to achieve a functional extremity [2]. In tumor surgery, it is important to provide the reconstruction of wide bone defects following excision in line with surgical principles for extremity prevention [3]. It is difficult to provide reconstruction of wide segmental defects that occur following resection [4]. Biological reconstruction and reconstruction with prosthesis options are also available [4]. Among the main methods applied are autograft, allograft or autograft–allograft combined reconstruction, rotational plasty, distraction osteogenesis by Ilizarov technique, endoprosthetic reconstruction, and reconstruction with endoprostheses bone graft composites [4].

Methods:

Below are the main methods used for the reconstruction of wide bone defects as a result of the surgical treatment of musculoskeletal tumors:
1- Endoprosthetic replacements [5], [6],[7],[8].
2- Distraction osteogenesis (bone extension by an external fixator or segment transport) [8],[9],[10],[11].
3- Use of allograft [12],[13],[14].
4- Composite use of allograft and endoprostheses [15].
5- Vascularized fibula or iliac bone grafts [16],[17],[18].
6- Non-vascularized autogenous bone grafting [19].
7- Arthrodesis (can be done with allografts) [20].
8- Rotational plasty [20].
9- Combinations of allograft and vascularized fibula [21],[22].
10- Use of intercalated scaffold supported by growth factor (tissue engineering techniques) [8],[23].
11- Reuse of bone with tumor [8].
We can analyze reconstruction methods following bone tumor excision under two sections: a) biological reconstruction and b) endoprosthetic reconstruction. Biological reconstruction as the subject of the study is explained below.

**Biological Reconstruction Implementations:**

Biological reconstruction implementations are arthrodesis, intercalated reconstruction or osteoarticular graft [4], as well as grefonage, segment dislocation, (vascularized or non-vascularized) free tissue transfer [2] or autograft, allograft, soft tissue reconstruction, rotational plasty. Rehabilitation is dependent on bone recovery. Rehabilitation process may take longer due to the effect of adjuvant chemotherapy [4].

**A) Reconstruction by autograft:**

Vascularized fibula grafts are often used for the reconstruction of bone defects that occur especially in upper extremity following sarcoma resection in children. Despite hypertrophy, lower extremity has a risk of fracture. Thus, they are used as combined with allografts in lower extremity. Vascularized fibula is placed into allograft to provide resistance against reconstruction. It was found that such combination is effective for union and functional results [24]. Reconstructions that were done by providing epiphysis growth especially in upper extremity through autografts taken by preventing fibula epiphysis bloodflow also became successful. Another method is reusing the diseased bone by sterilizing, exposing to radiation, or soaking in liquid nitrogen. This method was used successfully particularly in cases with osteosarcoma and Ewing sarcoma in pelvis area [4].

Autografts used can be from fibula, iliac crest, or conventional, vascularized, autoclaved, and irradiated. Hemicylindrical or segmental defects in long bones were reconstructed by conventional cortical or corticocancellous grafts. The outcome of conventional grafts in wide segments are not satisfactory due to reasons such as long recovery time, graft fracture, loss of fixation, delayed union, or lack of union. Ideal bone graft can adopt according to the mechanical need of the extremity, protects activity and resist to resorption, retain its physical features. This is best possible with vascularized grafts that can protect its bloodflow. Thus, vascularized fibula graft is a vascularized graft that is used most often in orthopedic surgery. Another method used in the reconstruction of wide cylindrical defects is cleaning the partial tumoral tissue of the resected bone, and applying to the defect by autoclaving or irradiating so as to remove residual tumor cells [25].

Autografts are preferred in tumor surgery reconstruction as they are adaptable to skeletal biology and they do not cause problems as in allografts [26], [1]. However, that they are supplied in limited amounts and cause morbidity in donor site is the most significant problem. Advancements is imaging methods, radiotherapy and chemotherapy protocols have increased patient prognoses and decreased reliable limits for tumor resections. Increased prognosis ideal has resulted in preference for functional reconstructive methods that are adaptable to body biology [27].

Autografts can be analyzed under three groups. These are [27]

1) Non-vascularized autografts,
   a) Spongiosis Autografts: Used more for filling cavitary lesions.
   b) Partial Autografts (cortical+spongiosis): Can be used in different sizes. Tricortical iliac grafts can be used especially in the reconstruction of segment bone defects whose length does not exceed 7 cm.
   c) Total Autografts (cortical+spongiosis+cartilage): These are, in other words, osteoarticular grafts.

a) Vascularized Autografts:
   Transferring autografts as vascular pedicled has decreased problems such as fracture, resorption and infection susceptibility that are seen in avascular grafts [28],[29]. Not only does it allow for implementation of these vascular grafts with longer lengths following resections in regions with less bloodshot, but also it thickens itself against graft incorporation and load, contrary to the risk of fracture in avascular grafts [30]. Following the radiotherapy of tumor layer, vascular grafts can be easily used in these areas [31],[32]. There are successful functional osteoarticular implementations of autografts [27]. Removing vascular autografts by myocutaneous flaps following resections with soft tissue loss can be used to close defects [27].

The most popular vascularized bone grafts is the pedicled or free transport of fibula [9]. Pedicled or free use of iliac bone especially in pelvis and mandible reconstruction is also available [8].

b) Autografts Reused After Physical and Chemical Implementations:

Such grafts are obtained by removing the resected tumor on the bone under sterile conditions and then exposing it to radiotherapy, high temperature and chemical substances (liquid nitrogen) in order to remove also tumor cells so the bone can be reused as autograft [33].

**Radiotherapy Implementation:** is sterile transfer of the bone with tumor to radiation oncology at the time of operation, and high-dose radiation implementation to kill tumor cells. Then, the bone is transferred back into the operating room and osteosynthesis is implemented [34].
Temperature Implementation: Includes autoclaving and union methods and is used today. Autoclaving is leaving the bone with tumor at dry or steamy 131-134 degrees for 5-10 minutes [35],[33],[27].

c) Cortical Autografts:
Revascularization in cortical grafts progress more slowly than in cancellous grafts. Until 6th day, receiver’s vessels cannot penetrate cortical grafts, which is also dependent on the thickness of cortical graft. Whole revascularization begins in two months or later. Grafted vascular transitions occur with the peripheral osteoclastic resorption and the vascular infiltration of haversian canals. Thus, whole revascularization in cortical bone stems from the rigid structure of cortical bone. As different from cancellous grafts, incorporation and repair in cortical grafts begins with osteoclasts rather than osteoblasts [27]. While common resorption of cortical bone is weak in the first two weeks, it becomes obvious in 6 weeks and reaches gradually the normal necessary levels in a year. Due to resorption, graft is mechanically too weak from 6th week to 6th month after transplantation. New bone formation in cortical bones progresses slowly, being slow in 3rd week. Even at the end of a year, 40% of necrotic bone is still present in cortical graft. Thus, unlike cancellous autografts, cortical autografts remain as mixture of necrotic bone and live bone. Bone marrow of autogenetic graft is immediately occupied by supportive tissue after transplantation, and it becomes a normal bone marrow in 9 months. If appropriate osteosynthesis has been implemented, osteotomy points will recover. Mechanic phase of bone graft incorporation occurs years later, which is the dominant feature of cortical grafts. The main point of cortical graft incorporation is resorption phase, and it includes osteonal canals. A critical porous begins with reshaping in bone graft, and compared to normal bone, it results in 40-50% loss of resistance. If massive cortical grafts are used, and if new bone formation occurs outside the resorption phase, graft distortion and loss can be observed even in normal loads [27].

B) Reconstruction by allograft:

is bone grafts transferred from one person to another in creatures with the same type. Its other name is homograft. Allografts can be obtained as mineralized, demineralized, chips, dust or whole bone [27].

A) It is commonly used in the reconstruction of wide bone defects following tumor excision especially in USA and some European countries [37],[38],[8]. It does not have an osteoinductive nature. Intercalated, osteoarticular, allograft and endoprosthesis composites can be used as combined with vascularized fibula. Osteoarticular grafts have optimal functional advantages in bonding tendons in areas such as proximal tibia and proximal femur [39]. However, they also have disadvantages such as less amounts of cadaver grafts, infection, fracture, lack of union and osteoarthritis. As in Ewing sarcoma, intercalated allografts can be used in the reconstruction of defects in diaphysis regions. Infection, lack of union and fracture complications as a result of the use of allografts in oncologic cases were found respectively 16%, 34% and 27% [40], [4].

It has two types according to the processing for immunogenic prevention: fresh-frozen and lyophilized. Although they are expensive, they can be obtained in unlimited amounts and with desired condition and configuration. Its disadvantages are that it retains its immunological potential despite all processing, it demonstrates slow incorporation in receiver site, and it carries transmissional inherited diseases that are seen especially in wide cortical allografts [41]. Using in big sizes and amounts decreases its stability and increases fracture risk [27]. Despite all these disadvantages, it is safely used during childhood and in benign cavitary lesions. There are research studies indicating that when used 60cc and less, allografts are no different than autografts in terms of incorporation [42].

Allografts have a risk of carrying such contagious diseases as HIV, HCV and viral hepatitis [43], infection (13-30%) [44], [45], lack of union (17-50%) [45], delayed union (11%) [23], immunological reaction [44], [45], graft resorption [45], fracture (9-67%) [44], [45], [8].

In nearly 60% of extremity preventive surgeries performed with allografts and endoprosthetic replacements, at least one complication develops, and in approximately 75% of these patients, a secondary operation is required [46]. Among other treatment options, ‘Biological Reconstruction’, which means repairing defects by live or dead bone, is a modern approach that is used for endoprosthesis revisions and more importantly the reconstruction of intercalated defects, particularly in child age group [22]. Two options used in clinical practices for biological reconstructions are distraction osteogenesis and bone grafts (allografts and autografts). Reconstructions with live bones are vascularized fibula grafts, vascularized iliac bone grafts, extension with an external fixator, or segment transport. Reconstruction with dead bones include use of allograft as well as oncologic sterilization and reuse of the bone with tumor [23], [8].

Such advantageous as donor site morbidity prevention, wide defects, anatomical adoption to the resection area, and protection of musculotendinosis bonding surfaces can result in its preference over autografts. In the long terms, problems may occur including delayed union, lack of union, graft fracture, implant fracture and infection; to decrease such incidents, vascularized autograft combination may be a great option [25].
**Soft tissue reconstruction:**
Each tumor operation related to musculoskeletal system consists of three different phases. The first phase is oncologic and includes the removal of tumor within clean boundaries [25]. The second phase is the reconstruction of the bone defect. The final phase is the reconstruction of the soft tissue. Soft tissue reconstruction provides the related joint with function and mobility. It provides dynamic stabilization to joints; bone, prosthesis and neurovascular structures with soft tissue cover; and it decreases potential risk of infection by preventing hematoma and seroma accumulation. Soft tissue defects that occur as a result of endoprosthetic reconstructions can be closed by gastrocnemius muscle. Thus, after the implementation of prosthesis and reconstruction of patellar tendon following resection, medial or lateral gastrocnemius muscle can be used to open part of prosthesis and defected areas. Resection amount, defected area size, biopsy line, and surgical approach affect which muscle to be used. For areas where gastrocnemius muscle is not enough, free flap muscle transplantation can be implemented. If necessary, full-thickness skin graft can be implemented over the transferred muscle [25].

**C) Rotational plastics:**
It is an alternative to lap amputation. Following the resection of tumor in distal femur, it is rotated 180 degrees around lower leg and fixated to femur. While ankle functions as knee joint, the patient uses lower knee prosthesis. The most important disadvantageous for patients is cosmetic appearance. Apart from this, there are neurovascular complications and potential infection complications [4].

Rotational plastic is divided into two, being Type A (distal femur and proximal tibia) and Type B 22 (proximal femur and lower pelvis). The most significant indication is patients who will not be implemented any surgery for wide resection and extremity prevention, as an alternative to amputation. Hillman et al. found that functional results of rotational plastics are better than those of prosthetic implantation [47], [25].

Winkelmann classifies rotational plastic under 5 groups. According to it; Group A – Lesion is in distal femur. Distal femur, knee joint and proximal tibia is resected, and the part left in distal is rotated 180 degrees and added to the residual of femur [27].

- Group AII – Lesion is in proximal tibia. Distal edge of femur, knee joint, and proximal tibia is resected. Distal tibia is rotated 180 degrees and combined with distal femur [27].
- Group BI – Lesion is in gluteal muscle and proximal femur distanced from hip joint. Upper femur and hip joint is resected. Distal part is rotated 180 degrees and combined with pelvis [27].
- Group BII – Lesion is in hip joint and soft tissue around it. Proximal femur, hip joint and lower hemipelvis is resected. Residual femoral part is combined with residual proximal part [27].
- Group BIII – Lesion is in the center of femur. Whole femur is resected and by tibia endoprosthesis, it is joined to acetabulum [27].

**Implementation:**
We included 8 patients in our study who applied to us at different times. Age range of our patients is 20-28 (average age 23, 25). All patients had humerus proximal epiphyseal deteriorations caused by several cystic tumoral formations; and related shoulder joint problems, deformities and shortness. Complaints of our patients were cosmetic concerns, difficulty in meeting personal needs, and difficulty in work life. All of our patients were subject to detailed physical examination, muscle power evaluation, joint evaluation and radiological examinations. All patients were diagnosed with benign cystic masses.

After necessary preparations, appropriate skin incision was made to all patients under general anesthesia, their muscle plans were surpassed, and tumor masses were reached. Shoulder joint pathologies were intervened and reduction of half dislocated shoulders was made, repairing and plication of joint capsule were made, and muscle transfers were made. After placing an external fixator, cystic tumoral mass was resected widely, bloodshot bone edges were obtained, varus deformity correction and acute compression was implemented to resection site. Osteotomy from distal humeral area was made, necessary derotation from osteotomy was made, and fixation was locked. Incision site of the patient was closed by placing drain. The post op patient was diagnosed with pillow sling, and controlled rehabilitation program was initiated. On post op 10th day, 1mm distraction from osteotomy site was made every day, and after ensuring enough callus extension, system was locked and union was controlled. After ensuring union in proximal acute compression and deformity correction site and distal extension site, external fixator was removed under local anesthesia. All patients used plastics protective braces for about 3 months. Patients were trained for self-rehabilitation and swimming was recommended.

During the period with fixator, patients developed pin tract infections and temporary pain in scar tissue caused by skin extension and incision. Pin tract infections were treated by antibiotics and debridement under local anesthesia, pin removal was not needed. None of our patients needed shoulder and elbow rehabilitation as from early post op period. Although shoulder and elbow rehabilitation was implemented to all of our patients as
from early post op period, constraints that would not affect their daily needs remained according to 2-year follow-ups.

**Discussion:**

The goal of orthopedic tumor surgery is to protect extremity, to do resection as limited as possible, and to provide reconstruction of the defect with a biological method as most appropriate to body physiology [1]. Biological reconstruction and reconstruction with prosthesis options are also available [2]. Distraction reconstruction (bone extension by an external fixator or segment transport) is an important method of biological reconstruction [8],[9],[10],[11].

In our study we implemented bone extension with an external fixator and resection site union by acute compression and deformity correction to 8 patients with cystic tumor that caused proximal epiphyseal distortion, the results are successful (Figure 1, 2, 3, 4, 5). Apart from simple infection and temporary soft tissue pain, no complications developed in our patients. Through our implementation, beside tumor treatment, it is possible to eliminate current shortness caused by resection by using callus, make derotation, and treat shoulder problems. No additional surgery was needed in our patients. During early post op period, they could return their daily lives.

Since extension procedures, wound cares and rehabilitation adoption is crucial in such surgical practices, selection of patients on which procedure will be implemented is quite important. Limited number of patients included in our study is the limitation of our study. That all of our patients are young (age average 23, 25) and healthy and they do not have health issues of the elderly is the limitation of our study. We believe that distraction osteogenesis that provides a completely natural limb is highly important and that studies with wide number of cases are needed in this issue.

**Conclusion:**

Biological reconstruction implementations are autograft, allograft, soft tissue reconstruction, rotational plastics.

We believe that due to its advantage of providing a completely natural limb, distraction osteogenesis has a crucial place in tumor surgery. With the method we implemented on 8 cases with proximal humeral cystic tumor, we treated tumor as well as additional shoulder pathologies and shortness problems.

Apart from simple infection and temporary soft tissue pain, no complications developed in our patients.

We believe that in bone tumor cases, which today we see more and more, distraction osteogenesis has a crucial place as it provides a completely natural extremity especially in young age group, and that more research is needed.

**Contribution Of Authors:**

The authors Aylin Zekioğlu and Ali Serdar Yücel gave support in the translation and summarization of the sources used in the research in addition to literature support.

**REFERENCES**


Annexes:

Fig. 1: Benign cystic tumoral lesion that damaged proximal humeral epiphysis and developed growth defects (shoulder joint subluxation, varus deformity, shortness etc.).
Fig. 2: Early post op graph. Shoulder joint reduction and soft tissue repairing, cyst resection, varus correction, derotation, acute compression to cyst resection site and osteotomy and unilateral external fixator diagnosis for extension in distal.

Fig. 3: During post op period, union in cyst resection site is seen, shoulder joint is reducted, and extension from distal is made.

Fig. 4: In extension site, following sufficient extension, after fixator is locked calsific image of callus.
**Fig. 5:** Image in which sufficient union in proximal acute resection is provided and calcification of the extended callus in distal is about to complete.