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ORIGINAL ARTICLE

LIMB SALVAGE SURGERY WITH CRYOTREATED AUTOGRAFT FOR OSTEOSARCOMA WITH AND WITHOUT VASCULAR RECONSTRUCTION: A CASE SERIES

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ABSTRACT

Background: Osteosarcoma is the most common primary malignant bone tumor in children and young adults. Limb-salvage surgery (LSS) has largely replaced amputation as the preferred surgical approach when adequate oncologic margins can be achieved. However, major vascular involvement remains a challenge in extremity osteosarcoma. This case series aimed to evaluate the feasibility and early outcomes of limb-salvage surgery using cryotreated autograft reconstruction with and without vascular reconstruction in patients with osteosarcoma around the knee.

Case presentation: This retrospective case series included four patients with non-metastatic osteosarcoma around the knee treated between 2024 and 2025. All patients underwent limb-salvage surgery with wide tumor excision and reconstruction using a liquid nitrogen–treated autograft. Two patients required vascular reconstruction because of major arterial encasement, while two patients underwent reconstruction without vascular repair. Functional outcomes were evaluated using Karnofsky Performance Status (KPS), while perioperative laboratory parameters and postoperative complications were also assessed. All patients achieved successful limb preservation and remained ambulatory at follow-up. Patients requiring vascular reconstruction had longer operative times and hospital stays. At a median follow-up of 10 months, no local recurrence, distant metastasis, secondary amputation, graft failure, or major postoperative complications were observed.

Conclusion: Limb-salvage surgery using cryotreated autograft reconstruction demonstrated acceptable early oncologic and functional outcomes in selected osteosarcoma patients, including cases requiring vascular reconstruction. Major vascular involvement should not be considered an absolute contraindication to limb salvage when adequate oncologic margins and vascular reconstruction can be achieved through multidisciplinary management. However, these findings should be considered preliminary and longer follow-up are needed.

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KEYWORDS
Cryosurgery, limb salvage surgery, osteosarcoma, vascular reconstruction, functional outcome

INTRODUCTION

Osteosarcoma is the most common primary malignant bone tumor in children and young adults, accounting for the majority of malignant bone sarcomas in the pediatric population[1,2]. The introduction of multi-agent chemotherapy combined with aggressive surgical resection has significantly improved survival outcomes, with current 5-year survival rates for non-metastatic disease reaching approximately 65-80%[2,3]. Surgical management remains a cornerstone of treatment, and limb-salvage surgery (LSS) has largely replaced amputation as the preferred approach for extremity osteosarcoma when adequate oncologic margins can be achieved[1,4].

Advances in imaging, surgical techniques, and multidisciplinary oncology care have expanded the indications for limb-sparing procedures. Several studies have demonstrated that limb salvage provides oncologic outcomes comparable or superior to amputation while offering better functional and psychosocial outcomes, particularly in adolescents and young adults[3,5-7]. Consequently, limb preservation is currently feasible in approximately 80-90% of patients with appendicular osteosarcoma[1].

Various reconstructive techniques have been developed following tumor resection. Among these, cryotreated autograft reconstruction using liquid nitrogen has emerged as an attractive biological reconstruction option. This technique devitalizes tumor cells while preserving the osteoconductive and osteoinductive properties of the bone matrix, allowing reimplantation of the patient's own bone with preservation of anatomical congruity and soft-tissue attachment sites[8,9]. Previous studies have reported favorable oncologic and functional outcomes using this method in limb-salvage surgery for bone tumors.

Despite these advances, major vascular involvement remains one of the greatest challenges in limb-salvage surgery. Historically, radiologic evidence of vascular encasement was considered a contraindication to limb salvage because of concerns regarding incomplete tumor resection, increased local recurrence, and technical difficulties associated with vascular reconstruction[10-12]. However, recent studies have demonstrated that en bloc tumor resection combined with vascular reconstruction may allow successful limb preservation without compromising oncologic safety in selected patients[10-13].

This case series aimed to evaluate the feasibility and early outcomes of limb-salvage surgery using cryotreated autograft reconstruction with and without vascular reconstruction in patients with osteosarcoma around the knee. By presenting these cases, we sought to illustrate that limb preservation may remain a viable option even in selected patients with major vascular involvement.

CASE PRESENTATION

This retrospective case series included four consecutive patients with non-metastatic high-grade osteosarcoma around the knee treated at our institution between 2024 and 2025. The cohort consisted of three males and one female aged 15-20 years. Tumor location involved the distal femur in three patients and the proximal tibia in one patient. All patients underwent standard neoadjuvant chemotherapy prior to surgery *(Fig 1 and 2)*.

Preoperative assessment included plain radiography, magnetic resonance imaging (MRI), and computed tomography (CT) scans to evaluate tumor extent and neurovascular involvement. Two patients demonstrated radiologic evidence of major arterial encasement involving the femoral or popliteal artery and therefore underwent planned vascular resection and reconstruction during limb-salvage surgery *(Fig. 3 and 4)*.



Figure 1. *Case 1: 20-year-old female with distal femur osteosarcoma treated by limb-salvage surgery with popliteal artery reconstruction. A) Preoperative radiographs. B) Intraoperative appearance. C) Postoperative appearance showing well-healed incision and preserved limb contour. D) MRI of the femoral region.*

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Wide en bloc tumor resection was undertaken with the aim of achieving adequate surgical margins while preserving uninvolved bone whenever oncologically feasible. Major neurovascular structures were preserved unless directly involved by the tumor.

Following tumor resection, the resected bone segment was prepared for cryotreatment. Gross tumor tissue and remaining tumor were meticulously removed by curettage. The bone was then thoroughly irrigated with normal saline to reduce residual tumor burden before cryotreatment.



Figure 2. *Case 2: 15-year-old male with distal femur osteosarcoma undergoing limb-salvage surgery with femoral artery reconstruction. A) Preoperative clinical and radiographic images. B) Intraoperative and MRI images showing tumor extent, cryosurgery-treated autograft, and reimplantation.*

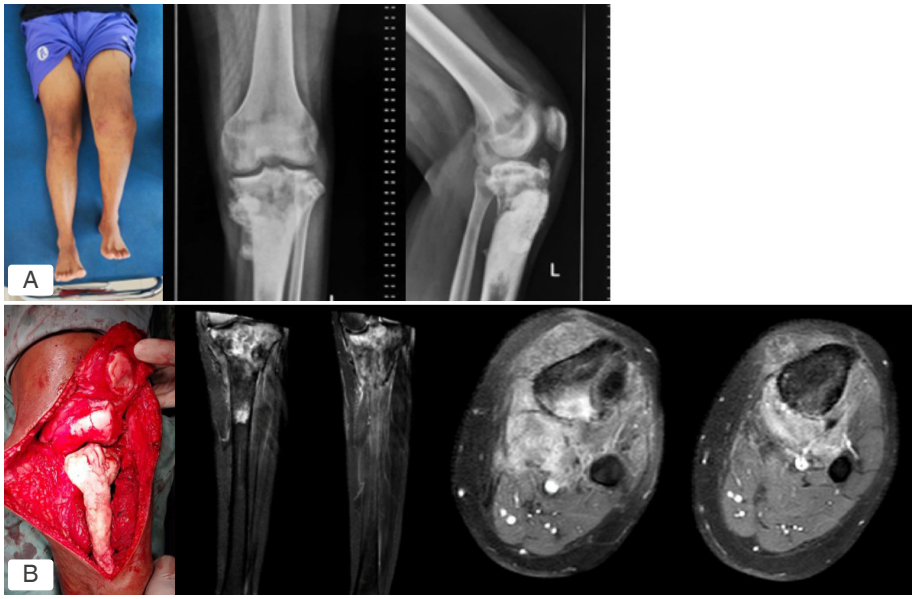


Figure 3. *Case 3: 17-year-old male with proximal tibia osteosarcoma treated without vascular reconstruction. A) Preoperative clinical and radiographic images. B) Intraoperative, and MRI images demonstrate wide resection and cryosurgery-treated autograft.*

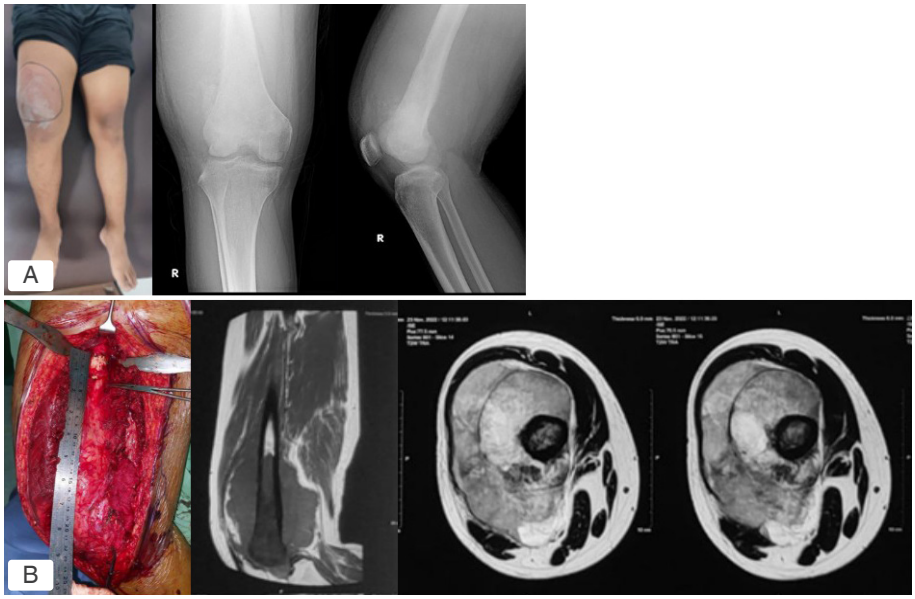


Figure 4. *Case 4: 18-year-old male with distal femur osteosarcoma treated without vascular reconstruction. A) Preoperative clinical and radiographic images. B) Intraoperative images, and MRI scans demonstrate tumor extent, surgical resection, and postoperative reconstruction outcome.*

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Case	Sex	Age (y)	Tumor location	Type	Huvos classification	Vascular reconstruction?	Operative time (min)	Hospital stay (days)
1	F	20	Right distal femur	Conventional osteosarcoma, chondroblastic type	-	Yes (popliteal artery bypass)	160	9
2	M	15	Left distal femur	Conventional osteosarcoma, osteoblastic type	IV	Yes (femoral artery bypass)	200	8
3	M	17	Left proximal tibia	Conventional osteosarcoma, osteoblastic type	II	No	60	6
4	M	18	Right distal femur	Conventional osteosarcoma, osteoblastic type	II	No	150	7

Table 1. *Patient characteristics and perioperative data (N = 4 cases).*

The prepared bone segment underwent cryotreatment using a standardized liquid nitrogen protocol. The specimen was immersed in liquid nitrogen for 20 minutes, followed by thawing at room temperature for 20 minutes and subsequent thawing in sterile distilled water for an additional 20 minutes before reimplantation. This process was intended to achieve complete tumor cell devitalization while minimizing thermal stress to the bone.

Reconstruction was performed using the cryotreated autograft. Internal fixation was achieved with locking plates and screws. In selected cases, fixation was augmented with an intramedullary nail to enhance stability. In patients with vascular involvement, the involved arterial segment was resected en bloc and reconstructed using an autologous saphenous vein graft by the vascular surgery team immediately following tumor excision.

The rehabilitation steps included pain control, edema reduction, joint mobility, and prevention of deep vein thrombosis in the first 2 weeks. Between 2 and 6 weeks, protected ROM exercises and muscle strengthening were initiated without bearing weight. Partial weight-bearing was gradually introduced between 6-12 weeks according to radiographic and clinical assessment, followed by gait training and balance exercises. Return to unrestricted functional activities was generally permitted between 6-12 months depending on graft union and functional recovery.

The cohort consisted of 4 patients with age 15-20 years old. Operative times ranged from 60 to 200 minutes, while hospital stay ranged from 6 to 9 days. Patients requiring vascular reconstruction had longer operative duration and hospitalization compared with patients without vascular repair. Histopathological response to neoadjuvant chemotherapy was evaluated using the Huvos grading system. One patient in the vascular reconstruction group did not undergo Huvos assessment because the specimen was unavailable for pathological evaluation. Among the remaining patients, one demonstrated Huvos grade IV, while two patients demonstrated Huvos grade II. All patients underwent wide oncologic resection with histologically negative surgical margins *(Table 1)*.

Postoperative Doppler ultrasonography confirmed vascular graft patency with preserved distal pulses in both vascular

Case	KPS (pre/post)	CRP (mg/l) pre/post	WBC ($\times 10^9$/l) pre/post	Hb (g/dl) pre/post	Albumin (g/dl) pre/post
1	70/50	>150/0.0	20.7/7.7	12.1/9.0	4.04/4.00
2	50/50	>150/35.6	13.5/7.8	12.4/10.0	4.21/2.53
3	60/60	–/71.3	4.3/5.6	12.1/10.3	4.13/3.29
4	50/70	–/33.3	4.3/14.5	9.8/8.0	4.23/3.27

Table 2. *Preoperative and postoperative functional and laboratory outcomes. Postoperative laboratory values were obtained 2-5 days after surgery.*

Abbreviations: KPS, Karnofsky performance status; CRP, C-reactive protein; WBC, white blood cell count; Hb, hemoglobin.

CRP values >150: measurements exceeding the assay's upper limit (150 mg/l).

"–" : value not assessed.

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reconstruction cases. No intraoperative or immediate postoperative complications were observed. All patients retained the salvaged limb and remained ambulatory during follow-up. Functional outcome was assessed using the Karnofsky Performance Status (KPS), which was routinely recorded during postoperative follow-up at our institution. KPS was selected to evaluate patients' overall functional independence and ability to perform daily activities following limb-salvage surgery. Preoperative KPS ranged from 50-70. Postoperatively, KPS ranged from 50-70, with all patients remaining partially independent and ambulatory. One patient in the non-vascular group demonstrated postoperative functional improvement *(Table 2)*.

Postoperative laboratory evaluation demonstrated expected inflammatory responses following major oncologic surgery. Transient elevation of C-reactive protein (CRP) and white blood cell count (WBC) was observed without evidence of persistent infection or wound complications. Hemoglobin and serum albumin levels decreased postoperatively in all patients, reflecting operative blood loss and perioperative catabolic stress, but stabilized before discharge.

At a median follow-up duration of 10 months (range 6-15 months), no local recurrence, graft failure, secondary amputation, or major postoperative complications were observed. Progressive graft incorporation was observed in all cases, however complete radiographic union was not achieved yet in every patient. All patients remained alive and disease-free at final follow-up *(Fig. 5 and 6)*.

DISCUSSION

This descriptive case series highlights the technical feasibility of limb-salvage surgery using cryotreated autograft reconstruction in carefully selected osteosarcoma patients with and without vascular reconstruction[10,14]. All patients achieved complete limb preservation with acceptable early oncologic and functional outcomes. At a median follow-up of 10 months, no local recurrence, distant metastasis, graft failure, or secondary amputation was observed. These findings should be considered preliminary and longer follow-up is required to evaluate long-term oncological control and sustained limb preservation.

Patients requiring vascular reconstruction experienced longer operative times and hospital stays, reflecting increased surgical complexity. However, all patients remained ambulatory with acceptable postoperative KPS scores. These findings suggest that vascular reconstruction may increase perioperative burden but does not necessarily compromise functional recovery following limb-salvage surgery.

Limb-salvage surgery offers important functional and psychosocial advantages compared with amputation, particularly in children and young adults[6,7,15,16]. All patients in this series retained their native limbs and remained ambulatory at follow-up. Although detailed functional scoring systems such as the Musculoskeletal Tumor Society (MSTS) score were not evaluated, the observed KPS provided a pragmatic measure of patients' overall functional independence and ambulatory capacity. Nevertheless, KPS may not fully capture limb-specific



Figure 5. *Follow-up X-ray results in patients with vascular reconstruction A) Case 1 and B) Case 2.*

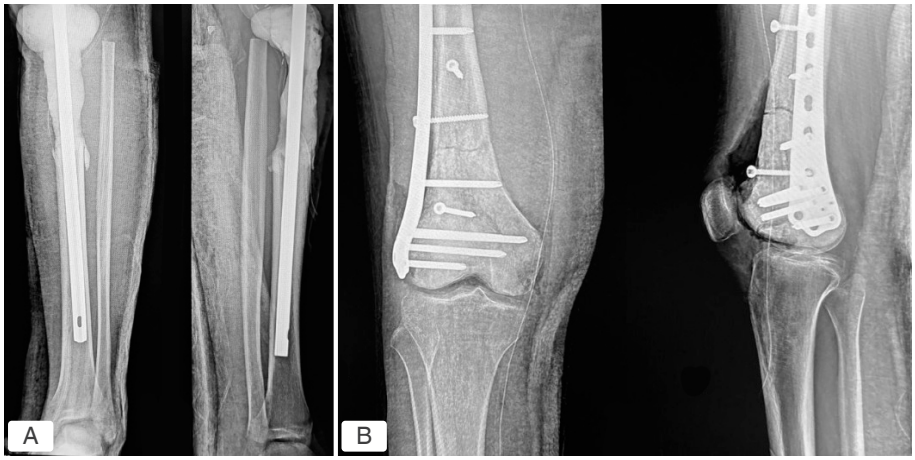


Figure 6. *Follow-up X-ray results in patients without vascular reconstruction A) Case 3 and B) Case 4.*

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function, pain, emotional acceptance, or activity limitations following limb-salvage surgery. Future studies should incorporate validated specific outcome measures to better characterize postoperative functional recovery, such as MSTS and TESS[17].

Cryotreated autograft reconstruction using liquid nitrogen provides several biological advantages after tumor resection. The technique devitalizes tumor cells while preserving the osteoconductive and osteoinductive properties of the extracellular bone matrix, allowing biological incorporation of the graft[8,9]. Previous studies have demonstrated favorable oncologic safety and functional outcomes with this reconstruction method[8,9,189]. In the present series, no graft-related complications such as infection, fracture, or nonunion were observed during early follow-up, suggesting that cryotreated autograft reconstruction can be safely combined with vascular reconstruction when necessary.

Perioperative laboratory findings reflected expected physiological responses following major orthopaedic oncologic surgery. Transient postoperative elevations in CRP and WBC count resolved without evidence of persistent infection. Postoperative decreases in hemoglobin and serum albumin levels were consistent with operative blood loss and perioperative catabolic stress. No patient developed surgical-site infection, wound complications, or vascular graft failure.

Historically, major vascular involvement was considered a contraindication to limb-salvage surgery because of concerns regarding inadequate surgical margins and increased local recurrence risk[10-12]. Consequently, primary amputation was frequently recommended in patients with radiologic evidence of vascular encasement. However, advances in vascular reconstruction techniques and multidisciplinary sarcoma management have expanded the indications for limb-sparing surgery. Several studies have reported high rates of limb preservation following en bloc tumor resection with vascular reconstruction without compromising oncologic outcomes[10-14]. Shah et al. and Tsukushi et al. reported successful limb preservation rates exceeding 90% in sarcoma patients undergoing vascular reconstruction[10,11], while Sheahan et al. emphasized the importance of multidisciplinary management in enabling successful limb salvage in pediatric bone tumors involving major vessels[12].

In this series, two patients with arterial encasement underwent vascular reconstruction using autologous saphenous vein grafts and achieved successful limb preservation without graft failure or oncologic progression during follow-up. Although operative time and hospital stay were longer in these patients, acceptable limb function was maintained. These findings support previous reports indicating that vascular reconstruction can be safely performed during extremity sarcoma surgery when adequate oncologic margins and multidisciplinary expertise are available[10-13].

This study is limited by its small sample size, short follow-up period, limited functional assessment, and lack of some important oncological data, which preclude definitive conclusions regarding long-term oncologic control and graft durability. Nevertheless, this case series highlights the importance of multidisciplinary planning and feasibility of this approach in complex limb-salvage surgery. When major neurovascular structures are reconstructible and oncologic principles can be maintained, limb salvage should still be considered[19,20].

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