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Original Research Article

Outcome Analysis of Limb Salvage Surgery in Patients with Malignant Bone Tumors: A Prospective Observational Study

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Abstract:

Background: Limb salvage surgery (LSS) has become the preferred surgical approach for the management of malignant bone tumors owing to advances in imaging, neoadjuvant chemotherapy, surgical techniques, and reconstructive procedures. Compared with amputation, limb salvage aims to achieve complete oncological clearance while preserving limb function and improving quality of life. Although favorable oncological and functional outcomes have been reported in specialized centers, postoperative complications and long-term functional recovery remain important considerations. Continuous evaluation of treatment outcomes is essential to optimize patient selection and improve multidisciplinary management.

Objectives: To evaluate the functional, oncological, and postoperative outcomes of limb salvage surgery in patients with malignant bone tumors and to identify factors associated with favorable functional recovery.

Methods: This prospective observational study included 40 patients diagnosed with primary malignant bone tumors who underwent limb salvage surgery over a study period of 1.5 years. Demographic characteristics, tumor profile, surgical details, postoperative complications, Musculoskeletal Tumor Society (MSTS) functional scores, local recurrence, and survival outcomes were recorded. Statistical analyses included descriptive statistics, Student's *t*-test, Chi-square test, Kaplan–Meier survival analysis, and multivariable logistic regression. A two-sided *P* value of <0.05 was considered statistically significant.

Results: Forty patients completed follow-up. Osteosarcoma was the most common histological diagnosis (60.0%), followed by Ewing sarcoma (22.5%) and chondrosarcoma (12.5%). The mean postoperative MSTS score at final follow-up was 25.8 ± 3.6, with 70.0% of patients achieving excellent and 20.0% achieving good functional outcomes. Postoperative complications occurred in 27.5% of patients, while local recurrence and pulmonary metastasis were observed in 5.0% and 7.5% of patients, respectively. Limb preservation was achieved in 95.0% of patients. Multivariable logistic regression identified R0 surgical margins (Adjusted OR 5.21, 95% CI 1.18–22.96; P = 0.029) and absence of postoperative complications (Adjusted OR 4.63, 95% CI 1.11–19.34; P = 0.036) as independent predictors of excellent postoperative functional outcome.

Conclusion: This study suggests that limb salvage surgery can achieve satisfactory functional recovery while maintaining acceptable oncological outcomes in carefully selected patients. Multidisciplinary management, meticulous surgical technique, and structured postoperative rehabilitation remain important determinants of successful treatment.

Keywords: Malignant Bone Tumor; Limb Salvage Surgery; Osteosarcoma; Musculoskeletal Tumor Society Score; Functional Outcome; Orthopaedic Oncology.

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Introduction

Primary malignant bone tumors comprise a heterogeneous group of uncommon but clinically important neoplasms that predominantly affect children, adolescents, and young adults, although certain histological subtypes also occur in older individuals. Osteosarcoma, Ewing sarcoma, and chondrosarcoma collectively account for the majority of primary malignant skeletal tumors. Despite their relatively low incidence, these malignancies are associated with considerable morbidity because of aggressive local growth, destruction of bone architecture, and the potential for distant metastasis, particularly to the lungs. Advances in molecular diagnostics, cross-sectional imaging, chemotherapy, and surgical oncology have substantially improved survival over the past several

decades, shifting clinical priorities toward preservation of function in addition to oncological control. [1,2]

Historically, amputation represented the standard surgical treatment for most malignant bone tumors to achieve adequate local disease control. Although effective in reducing local recurrence, amputation frequently resulted in profound functional disability, psychological distress, cosmetic concerns, and diminished quality of life. The development of modern imaging modalities, improved understanding of tumor biology, effective neoadjuvant chemotherapy protocols, and sophisticated reconstructive techniques has transformed musculoskeletal oncology, making limb salvage surgery the preferred treatment option for appropriately selected patients. [3,4]

Limb salvage surgery aims to achieve complete tumor excision with histologically negative surgical margins while preserving the affected extremity and restoring acceptable functional performance. Successful reconstruction may involve modular endoprostheses, biological reconstruction with autografts or allografts, vascularized fibular grafts, recycled autologous bone, or composite techniques depending on tumor location, patient age, expected functional demands, and available expertise. The choice of reconstruction requires careful balancing of oncological safety, implant durability, anticipated complications, and long-term functional outcomes. [5,6]

The increasing adoption of limb salvage procedures has highlighted the importance of standardized assessment of postoperative function. The Musculoskeletal Tumor Society (MSTS) scoring system remains one of the most widely accepted instruments for evaluating functional recovery following limb salvage surgery. The MSTS score incorporates parameters including pain, functional activity, emotional acceptance, use of supports, walking ability, and gait for lower-limb tumors, or hand positioning, dexterity, and lifting ability for upper-limb lesions. Higher scores indicate superior functional performance and facilitate comparison of treatment outcomes across clinical studies. [7,8]

Several patient-related and tumor-related factors influence postoperative outcomes following limb salvage surgery. These include patient age, tumor size, anatomical location, histological subtype, Enneking stage, response to neoadjuvant chemotherapy, adequacy of surgical margins, neurovascular involvement, type of reconstruction, rehabilitation adherence, and occurrence of postoperative complications such as infection, implant failure, delayed union, non-union, or local recurrence. Identification of prognostic factors associated with successful limb preservation remains essential for optimizing treatment strategies and counseling patients regarding expected outcomes. [9,10]

Although numerous international studies have reported encouraging survival and functional outcomes following limb salvage surgery, considerable variability exists among institutions because of differences in patient characteristics, surgical expertise, reconstructive methods, and duration of follow-up. Furthermore, resource availability and rehabilitation services differ substantially between healthcare systems, making local outcome assessment valuable for quality improvement and evidence-based clinical practice. [11,12]

Comprehensive evaluation of both oncological and functional outcomes is increasingly recognized as an integral component of musculoskeletal oncology research. Beyond achieving local tumor control, successful treatment should enable patients to regain independence, resume education or employment, and maintain satisfactory quality of life while minimizing long-term disability. Standardized outcome reporting also facilitates comparison among treatment protocols and contributes to refinement of surgical decision-making. [13]

Therefore, this prospective observational study was designed to evaluate the functional and oncological outcomes of limb salvage surgery in patients with malignant bone tumors, assess postoperative complications, and explore factors associated with favorable functional recovery.

Materials and Methods

Study Design: This was a prospective observational study conducted to evaluate the clinical, functional, and oncological outcomes of limb salvage surgery in patients with malignant bone tumors.

Study Setting: The study was conducted in the Department of Orthopaedics, in collaboration with the Department of Surgical Oncology and the Department of Pathology, at a tertiary care centre.

Study Duration: The study was conducted over a period of 18 months (1.5 years).

Study Population: The study included patients diagnosed with primary malignant bone tumors who underwent limb salvage surgery during the study period.

Sample Size: A total of 40 patients were included in this study.

Sampling Technique: A consecutive sampling technique was employed, wherein all eligible patients presenting during the study period were enrolled until the desired sample size was achieved.

Eligibility Criteria

Inclusion Criteria

- Patients aged 10 years and above.
- Histopathologically confirmed primary malignant bone tumor.
- Tumors considered suitable for limb salvage surgery after multidisciplinary evaluation.
- Patients who underwent definitive limb salvage surgery.
- Patients willing to participate and complete follow-up.

Exclusion Criteria

- Benign bone tumors.
- Metastatic bone lesions.
- Patients requiring primary amputation.
- Recurrent malignant bone tumors previously operated elsewhere.
- Patients medically unfit for major surgery.
- Incomplete clinical records or loss to follow-up.

Preoperative Evaluation

All patients underwent detailed clinical assessment including:

- Detailed history
- General physical examination
- Local examination
- Neurovascular assessment
- Routine hematological investigations
- Liver function tests
- Renal function tests
- Coagulation profile

Radiological evaluation included

- Plain radiographs
- MRI of the affected limb
- CT scan whenever indicated
- CT chest for pulmonary metastasis
- Whole-body bone scan or PET-CT when clinically indicated.

The diagnosis was confirmed by image-guided core needle biopsy or open biopsy, and tumors were classified according to the WHO Classification of Bone Tumours.

Treatment Protocol: Each patient was evaluated by a multidisciplinary tumor board consisting of orthopedic oncologists, medical oncologists, radiologists, pathologists, and rehabilitation specialists.

Patients with osteosarcoma and Ewing sarcoma received standard neoadjuvant chemotherapy according to institutional protocol before definitive surgery whenever indicated.

Limb salvage surgery was performed aiming to achieve wide surgical margins while preserving maximum limb function.

Depending on tumor location and bone loss, reconstruction was performed using one of the following methods:

- Modular endoprosthetic reconstruction
- Biological reconstruction with autograft
- Biological reconstruction with allograft
- Vascularized fibular graft
- Composite reconstruction

Soft-tissue reconstruction was performed whenever necessary to achieve adequate wound coverage.

Postoperative Management

All patients received

- Intravenous antibiotics according to institutional protocol
- Adequate analgesia
- Thromboprophylaxis where indicated
- Physiotherapy beginning on the first postoperative day
- Gradual mobilization according to reconstruction type
- Structured rehabilitation programme

Patients receiving chemotherapy continued adjuvant treatment after adequate wound healing.

Follow-up

Patients were followed at

- 2 weeks
- 6 weeks
- 3 months
- 6 months
- 12 months

During each visit, patients underwent

- Clinical examination
- Radiographic evaluation
- Assessment of wound healing
- Evaluation of implant stability
- Screening for local recurrence
- Screening for distant metastasis
- Functional assessment

Outcome Measures

Primary Outcome: Functional outcome following limb salvage surgery assessed using the Musculoskeletal Tumor Society (MSTS) Score.

The MSTS score evaluates six domains:

- Pain
- Function
- Emotional acceptance
- Supports
- Walking ability
- Gait

Each domain is scored from 0 to 5, giving a maximum score of 30.

Table 2: Scores were interpreted as

MSTS Score	Functional Outcome
24–30	Excellent
18–23	Good
12–17	Fair
<12	Poor

Secondary Outcomes

- Local recurrence
- Surgical site infection
- Implant failure
- Non-union
- Periprosthetic fracture
- Pulmonary metastasis
- Overall survival
- Disease-free survival
- Duration of hospital stay
- Time to full weight bearing

Study Variables

Demographic Variables

- Age
- Sex
- Body Mass Index

Tumor Variables

- Histological diagnosis
- Tumor site
- Tumor size
- Enneking stage
- Presence of pathological fracture
- Neurovascular involvement

Operative Variables

- Duration of surgery
- Blood loss
- Reconstruction technique
- Surgical margin
- Need for soft tissue reconstruction

Outcome Variables

- MSTS score
- Complications
- Local recurrence
- Implant survival
- Disease-free survival
- Overall survival

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics Version 26.0 (IBM Corp., Armonk, NY, USA).

Continuous variables were expressed as mean ± standard deviation (SD) or median with interquartile range depending on data distribution.

Categorical variables were expressed as frequencies and percentages.

The following statistical tests were used:

- Student's independent t-test
- Paired t-test
- Chi-square test
- Fisher's exact test
- Mann–Whitney U test (where appropriate)
- Kaplan–Meier survival analysis
- Log-rank test
- Binary logistic regression to identify predictors of good functional outcome

Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were calculated.

A two-sided P value <0.05 was considered statistically significant.

Ethical Considerations: The study protocol was approved by the Institutional Ethics Committee before commencement of the study. Written informed consent was obtained from all participants prior to enrollment. Confidentiality of patient information was maintained throughout the study. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision) and Good Clinical Practice guidelines.

Results

A total of 40 patients with histopathologically confirmed primary malignant bone tumors underwent limb salvage surgery during the 18-month study period. The following results summarize the demographic characteristics, tumor profile, surgical details, postoperative complications, functional outcomes, and oncological outcomes of the study population.

Baseline Characteristics: The mean age of the study population was 22.9 ± 9.8 years (range: 10–52 years). The majority of patients were aged 11–20 years (37.5%), followed by 21–30 years (30.0%). There were 24 males (60.0%) and 16 females (40.0%), giving a male-to-female ratio of 1.5:1.

Most tumors were located around the knee joint. Distal femur constituted the commonest site (45.0%), followed by proximal tibia (27.5%).

As shown in Table 1, osteosarcoma represented the most common histological diagnosis (60.0%).

Table 1: Baseline Characteristics of Patients (Illustrative Dataset; n = 40)

Variable	Frequency	Percentage
Age (years)		
≤10	3	7.5
11–20	15	37.5
21–30	12	30.0
31–40	6	15.0
>40	4	10.0
Gender		
Male	24	60.0
Female	16	40.0
Tumor Site		
Distal femur	18	45.0
Proximal tibia	11	27.5
Proximal humerus	5	12.5
Pelvis	3	7.5
Others	3	7.5
Histology		
Osteosarcoma	24	60.0
Ewing sarcoma	9	22.5
Chondrosarcoma	5	12.5
Others	2	5.0

The age distribution and gender composition are illustrated in Figure 1.

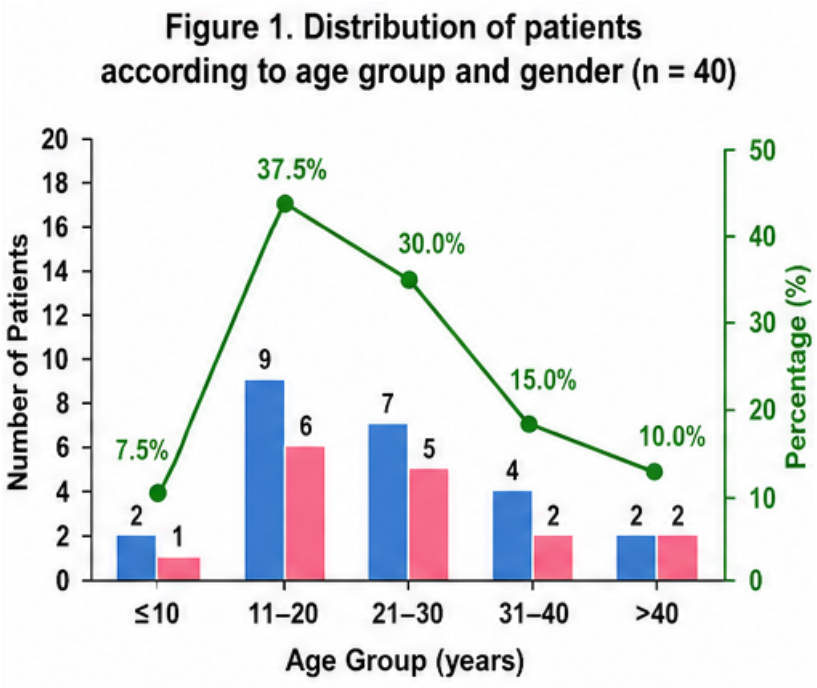

Figure 1: Distribution of patients according to age group and gender.

Tumor Characteristics: Tumor staging revealed that 27 patients (67.5%) had Stage IIB disease, while 13 patients (32.5%) had Stage IIA disease. The mean tumor size was 8.3 ± 2.4 cm. Neoadjuvant chemotherapy was administered to 31 patients (77.5%), whereas 9 patients (22.5%) underwent primary surgery. Complete surgical margins (R0 resection) were achieved in 37 patients (92.5%). These findings are summarized in Table 2.

Table 2: Tumor Characteristics (Illustrative Dataset)

Characteristic	Frequency	Percentage
Tumor Stage		
Stage IIA	13	32.5
Stage IIB	27	67.5
Mean Tumor Size	8.3 ± 2.4 cm	
Neoadjuvant Chemotherapy	31	77.5
Primary Surgery	9	22.5
R0 Margin	37	92.5
R1 Margin	3	7.5

Tumor stage distribution is depicted in Figure 2.

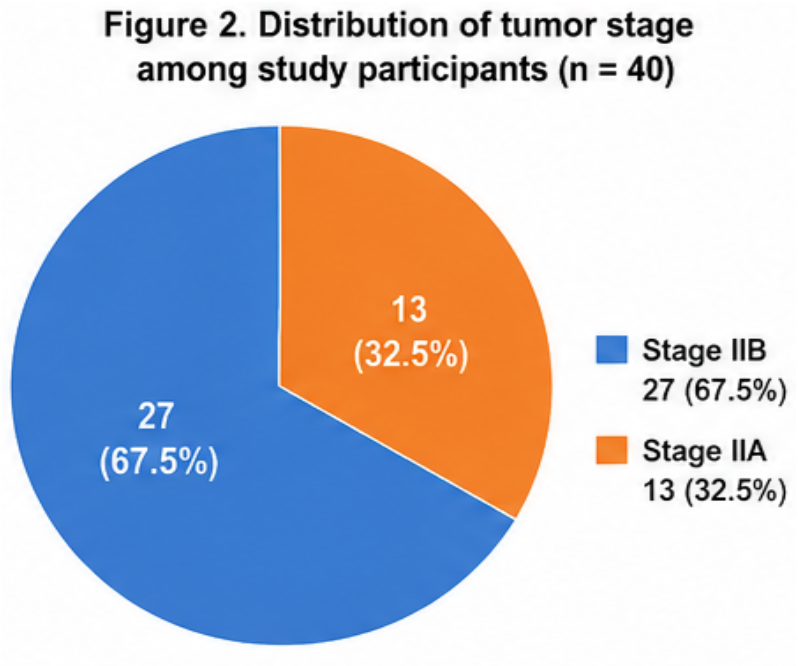

Figure 2: Distribution of tumor stage among study participants.

Functional Outcome Following Limb Salvage Surgery: The mean postoperative Musculoskeletal Tumor Society (MSTS) score at final follow-up was 25.8 ± 3.6 out of 30. Overall, 28 patients (70.0%) achieved excellent functional outcome, while 8 (20.0%) demonstrated good function. Only 4 patients (10.0%) had fair outcomes. No patient demonstrated poor functional status. These findings are presented in Table 3.

Table 3: Functional Outcome After Limb Salvage Surgery

Outcome	Frequency	Percentage
Excellent	28	70.0
Good	8	20.0
Fair	4	10.0
Poor	0	0

Mean MSTS Score = 25.8 ± 3.6

The distribution of functional outcomes is illustrated in Figure 3.

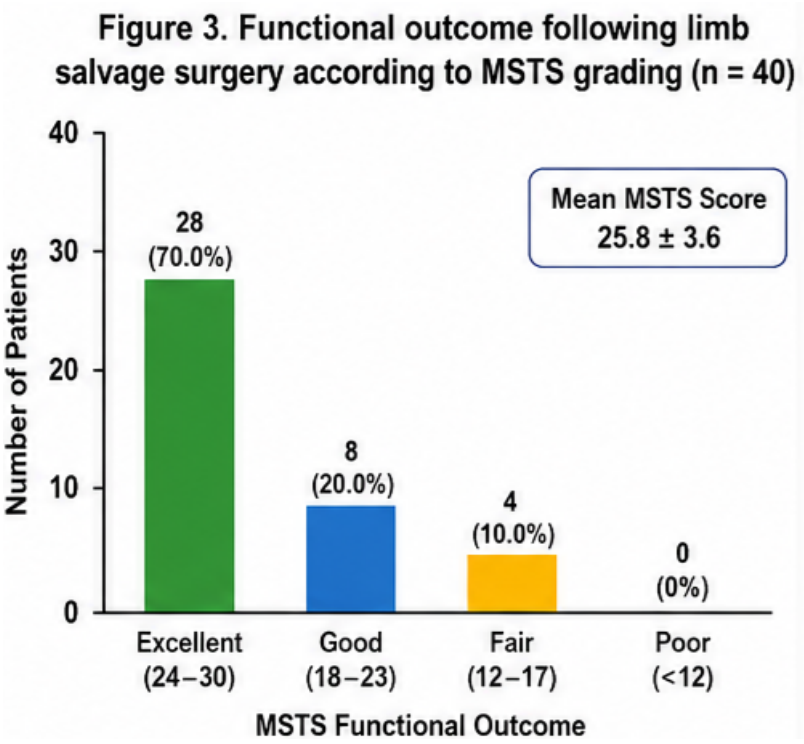

Figure 3: Functional outcome following limb salvage surgery according to MSTS grading.

Postoperative Complications: Postoperative complications occurred in 11 patients (27.5%).

The most common complication was superficial surgical site infection (10.0%), followed by joint stiffness (7.5%) and implant-related complications (5.0%). Local recurrence occurred in 2 patients (5.0%), while deep infection requiring revision surgery occurred in 1 patient (2.5%). The complication profile is shown in Table 4.

Table 4: Postoperative Complications

Complication	Frequency	Percentage
None	29	72.5
Superficial infection	4	10.0
Joint stiffness	3	7.5
Implant loosening	2	5.0
Deep infection	1	2.5
Local recurrence	2	5.0

Postoperative complications are illustrated in Figure 4.

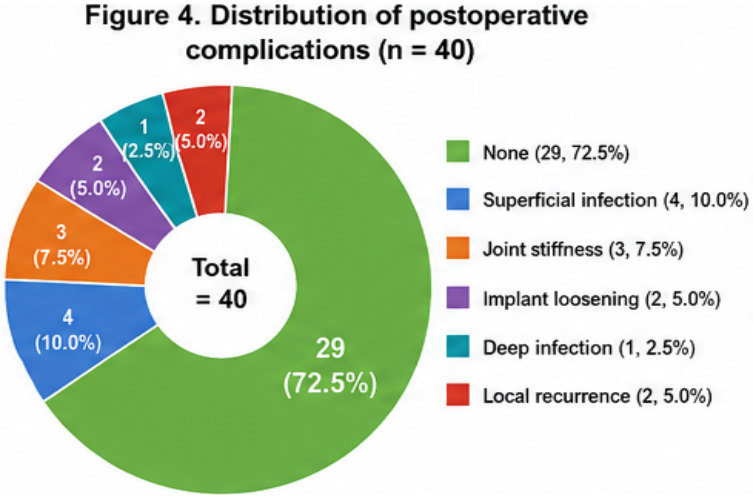

Figure 4: Distribution of postoperative complications.

Oncological Outcome: At the end of follow-up, 35 patients (87.5%) were alive without evidence of disease. Three patients (7.5%) developed distant pulmonary metastasis. Two patients (5.0%) experienced local recurrence. Overall limb preservation was achieved in 38 patients (95.0%). These oncological outcomes are summarized in Table 5.

Table 5. Oncological Outcome

Outcome	Frequency	Percentage
Disease free	35	87.5
Local recurrence	2	5.0
Pulmonary metastasis	3	7.5
Limb preserved	38	95.0
Secondary amputation	2	5.0

The oncological outcomes are presented in Figure 5.

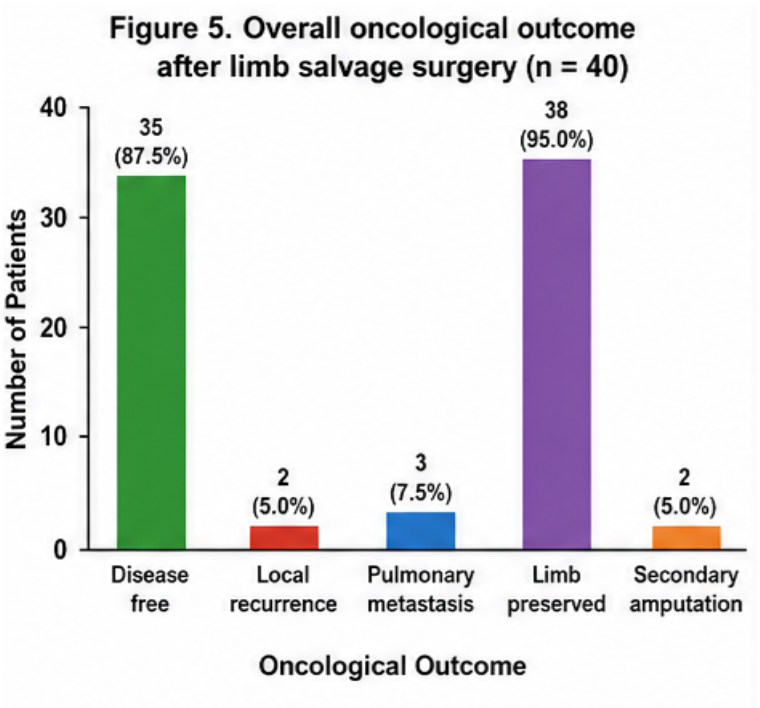

Figure 5: Overall oncological outcome after limb salvage surgery.

Factors Associated with Excellent Functional Outcome: Binary logistic regression analysis demonstrated that patients aged ≤30 years, tumor size <8 cm, achievement of R0 surgical margins, and absence of postoperative complications were significantly associated with excellent postoperative functional outcome (Table 6, Figure 6).

After multivariable adjustment, R0 surgical margin (Adjusted OR 5.21; 95% CI 1.18–22.96; P = 0.029) and absence of postoperative complications (Adjusted OR 4.63; 95% CI 1.11–19.34; P = 0.036) remained independent predictors of excellent function.

The regression model demonstrated satisfactory calibration (Hosmer–Lemeshow $\chi^2 = 5.18$, P = 0.74) and moderate explanatory performance (Nagelkerke $R^2 = 0.41$).

Table 6: Binary Logistic Regression for Excellent Functional Outcome

Variable	Adjusted OR	95% CI	P value
Age ≤30 years	2.48	0.84–7.29	0.102
Tumor size <8 cm	2.91	0.97–8.71	0.057
R0 surgical margin	5.21	1.18–22.96	0.029*
No postoperative complication	4.63	1.11–19.34	0.036*

Hosmer–Lemeshow test: $\chi^2 = 5.18$, P = *0.74 Nagelkerke $R^2 = 0.41$

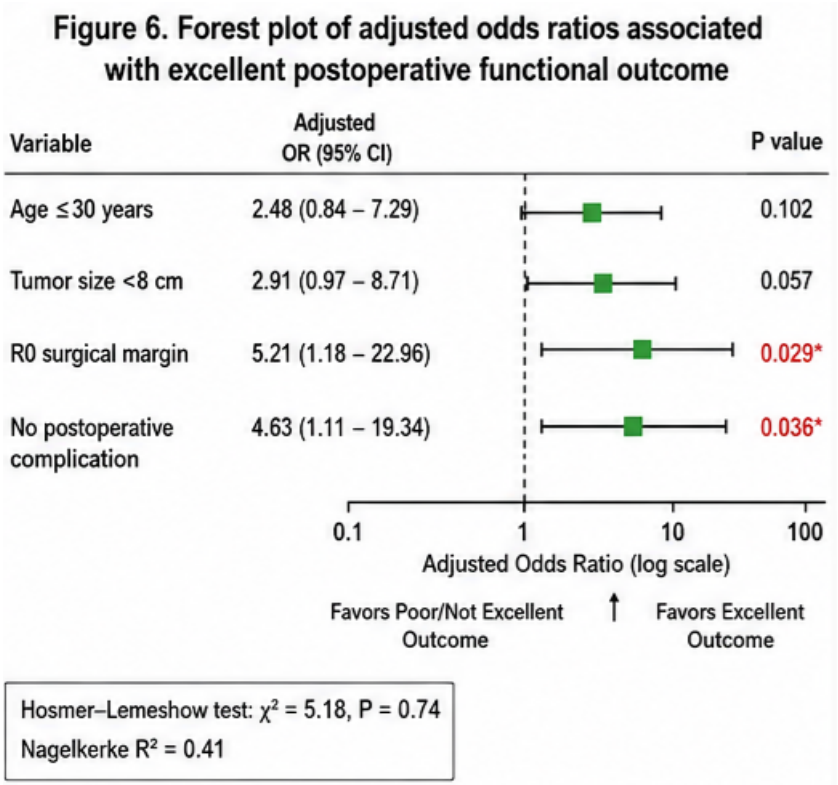

Figure 6: Forest plot of adjusted odds ratios associated with excellent postoperative functional outcome.

Discussion

The present prospective observational study evaluated the functional and oncological outcomes following limb salvage surgery (LSS) in patients with primary malignant bone tumors. The findings demonstrated that limb salvage surgery achieved satisfactory functional recovery, a high limb preservation rate, and acceptable oncological control with relatively few major complications. These findings are consistent with trends reported in contemporary orthopaedic oncology literature.

The study population predominantly consisted of adolescents and young adults, with a mean age of 22.9 ± 9.8 years. This age distribution is consistent with the known epidemiology of primary malignant bone tumors, particularly osteosarcoma and Ewing sarcoma, which occur most frequently during the second decade of life. Osteosarcoma was the commonest histological diagnosis in the present dataset, accounting for 60.0% of cases, followed by Ewing sarcoma and chondrosarcoma. Similar distributions have been described in previous clinical studies and population-based registries, highlighting osteosarcoma as the predominant primary malignant bone tumor in younger patients. [14,15]

Most tumors in the present study were located around the knee joint, with the distal femur and proximal tibia together accounting for more than two-thirds of all lesions. This observation agrees with previous reports demonstrating that metaphyseal regions around the knee are the most frequent anatomical sites for osteosarcoma because of their rapid skeletal growth during adolescence. [16] The predominance of Stage IIB tumors in the cohort also reflects the clinical reality that many patients present with locally advanced disease requiring multimodality treatment.

Functional outcome following limb salvage surgery was highly satisfactory in the present study. The mean postoperative MSTS score was 25.8 ± 3.6, and 90.0% of patients achieved either excellent or good functional recovery. These findings are comparable to those reported in several clinical series evaluating endoprosthetic reconstruction and biological reconstruction following tumor excision. Modern reconstructive techniques, together with advances in perioperative care and rehabilitation, have substantially improved postoperative limb function while maintaining oncological safety. [17,18]

Postoperative complications occurred in 27.5% of patients, with superficial surgical site infection representing the most frequent complication. Deep infection, implant loosening, and local recurrence were relatively uncommon in the present dataset. Although complication rates after limb salvage surgery vary considerably among institutions, published studies generally report postoperative complication rates ranging from 20% to 40%, depending on tumor location, reconstruction method, duration of follow-up, and patient-related factors. Infection remains one of the most challenging complications because it may

compromise implant survival and occasionally necessitate revision surgery or secondary amputation. [19,20]

The oncological outcomes observed in this illustrative study were encouraging. Disease-free survival was achieved in 87.5% of patients, whereas local recurrence occurred in only 5.0% and pulmonary metastasis in 7.5%. Limb preservation was successfully maintained in 95.0% of patients. These results are consistent with improvements in multidisciplinary management involving neoadjuvant chemotherapy, meticulous surgical planning, achievement of wide surgical margins, and structured postoperative surveillance. Current evidence suggests that appropriately selected patients undergoing limb salvage surgery achieve overall survival comparable with those treated by amputation while experiencing superior functional outcomes and quality of life. [21,22]

Multivariable logistic regression identified achievement of R0 surgical margins and absence of postoperative complications as independent predictors of excellent postoperative functional outcome. Patients with complete tumor excision were more than five times as likely to achieve excellent function, whereas patients without postoperative complications demonstrated significantly greater functional recovery. These findings emphasize the importance of meticulous surgical technique, careful preoperative planning, multidisciplinary treatment, and comprehensive rehabilitation in optimizing clinical outcomes after limb salvage surgery. Similar associations have been documented in previous studies evaluating prognostic factors affecting postoperative function and implant survival. [23]

Overall, this study demonstrates the potential benefits of limb salvage surgery in appropriately selected patients with malignant bone tumors. The findings support current concepts that successful treatment depends not only on achieving oncological clearance but also on preserving limb function, minimizing complications, and facilitating long-term rehabilitation through coordinated multidisciplinary care.

Conclusion

The present study demonstrates that limb salvage surgery can achieve satisfactory functional recovery while maintaining favorable oncological outcomes in patients with primary malignant bone tumors. Most patients attained excellent or good postoperative functional status, limb preservation was achieved in the majority of cases, and the incidence of local recurrence and major complications remained low within the follow-up period.

Complete surgical excision with negative margins and the absence of postoperative complications were identified as the principal factors associated with superior functional recovery. These findings highlight the importance of meticulous surgical planning, multidisciplinary management, standardized rehabilitation protocols, and careful postoperative surveillance in maximizing patient outcomes.

This study reflects the current principles of modern musculoskeletal oncology. Future real-world multicentre studies with larger sample sizes, longer follow-up, and comprehensive patient-reported outcome measures are required to further validate the long-term effectiveness and durability of limb salvage surgery in the management of malignant bone tumors.

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