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Functional gait assessment after wide tumor resection and knee endoprosthesis reconstruction: a retrospective cross-sectional study

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ABSTRACT

Background: Limb salvage surgery with endoprosthetic reconstruction around the knee is widely performed for primary malignant bone tumors and aggressive giant cell tumors. Although oncological control is well established, objective evaluation of postoperative gait and its correlation with functional outcome remains limited. This study aimed to assess gait pattern and functional outcome following wide tumor resection and knee endoprosthesis reconstruction.
Methods: This retrospective cross-sectional study included 20 patients who underwent wide resection and endoprosthesis reconstruction around the knee. Patients were evaluated at a minimum of six months postoperatively. Functional outcome was assessed using the musculoskeletal tumor society (MSTS) scoring system. Three-dimensional gait analysis was performed using a motion capture system based on the Helen Hayes protocol to measure walking velocity, stride length, stance phase, and knee range of motion. Statistical analysis was performed using appropriate parametric tests, with $p<0.05$ considered significant.
Results: The mean MSTS score was 22.95 out of 30, indicating good to excellent functional outcome in 90% of patients. The mean walking velocity was 0.92 m/s, representing a 31.31% reduction compared to normal reference values. Stride length and walking velocity were significantly reduced compared to normative data ($p<0.001$). Sixteen patients (80%) demonstrated a stiff knee gait, while two (10%) exhibited a flexed knee gait. Patients with distal femur reconstruction showed better functional outcomes than those with proximal tibia involvement.
Conclusions: Knee endoprosthesis reconstruction following tumor resection provides satisfactory functional outcomes despite measurable alterations in gait parameters. Objective gait analysis is a valuable tool for assessing postoperative functional recovery.

Keywords: Gait, Endoprosthesis, Limb salvage surgery, Musculoskeletal tumor society score, Bone sarcoma

INTRODUCTION

Tumors around the knee, particularly involving the distal femur, represent a significant proportion of primary bone neoplasms requiring wide resection and endoprosthetic reconstruction.[1]

The distal femur is one of the most frequently involved anatomical sites, followed by the proximal tibia. Giant cell tumors are typically solitary lesions; however, multicentric presentations may occur either synchronously or metachronously.[2]

Although generally considered benign, nearly 3% of patients develop pulmonary metastases. These metastases may remain indolent for prolonged periods or, in some cases, demonstrate spontaneous regression. The overall mortality rate in patients with pulmonary metastases is approximately 5%. The risk of pulmonary spread is higher in patients with aggressive radiographic features at the primary site.[3]

Malignant transformation of giant cell tumors is classified into primary and secondary types and accounts for less than 5% of cases.[4] Primary malignant giant cell tumors are

rare and represent sarcomatous transformation within a previously benign lesion. Secondary malignant transformation typically occurs at previously treated sites, most commonly following radiotherapy.

Osteosarcoma, characterized by malignant cells producing osteoid matrix, is the most common primary non-hematological malignancy of bone.[5] Although it may arise in any bone, it most frequently involves the distal femur and proximal tibia, regions associated with rapid skeletal growth. Until the 1970s, amputation was the standard treatment for extremity sarcomas, including osteosarcoma and recurrent giant cell tumors. With the advent of effective chemotherapy, limb salvage surgery became feasible in the majority of cases.[6] Comparative studies have demonstrated that limb salvage offers oncological outcomes equivalent to amputation, while also providing superior functional and psychological benefits.[7,8] This study aimed to assess gait pattern and functional outcome following wide tumor resection and knee endoprosthesis reconstruction.

METHODS

Study design and ethical approval

This retrospective cross-sectional observational study was conducted in the Department of Orthopaedics in collaboration with the Gait Laboratory, Department of Physical Medicine and Rehabilitation, G.S.V.M. Medical College, Kanpur, Uttar Pradesh, India. The total study duration was two years. Patients who had undergone wide tumor resection and knee endoprosthesis reconstruction were evaluated at a minimum of six months postoperatively.

Institutional ethics committee approval was obtained prior to commencement of the study (IRB No. 102nd ECM II B/P118). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision). Written informed consent was obtained from all participants or their legal guardians. The study methodology and reporting were aligned with the strengthening the reporting of observational studies in epidemiology (STROBE) guidelines.

Participants

Patients attending the outpatient Department of Orthopaedic Surgery were screened for eligibility.

Inclusion criteria

Patients with histologically confirmed osteosarcoma or recurrent giant cell tumor (Campanacci grade III) with extra-osseous extension around the knee, tumor located in the distal femur or proximal tibia, treated with wide resection and reconstruction using modular expandable or custom-made expandable knee endoprosthesis and minimum postoperative follow-up of six months were included in the study.

Exclusion criteria

Patients with neurological deficit affecting gait in the involved limb, implant-related infection, local recurrence or distant metastasis at time of evaluation, fixed flexion deformity of the involved knee, limb length discrepancy greater than 2 cm and history of multiple revision procedures were excluded from the study.

Demographic data including age and sex were recorded. Functional assessment and gait analysis were performed during follow-up.

Surgical procedure and implant standardization

All patients underwent en bloc wide tumor resection followed by reconstruction using a knee endoprosthesis. Implants were procured from a single Indian manufacturer approved by the institutional implant committee to ensure uniformity and minimize implant-related variability.

Gait analysis protocol

Three-dimensional gait analysis was performed in the Gait Laboratory using a six-infrared camera motion capture system (BTS SMART-DX system, BTS Bioengineering, Milan, Italy) integrated with two force platforms (BTS P-6000) mounted on an 11-meter walkway. Data acquisition was conducted using the Helen Hayes marker protocol in conjunction with BTS SMART-Clinic software for kinetic and kinematic assessment.

Eighteen spherical retroreflective markers were placed over standardized anatomical landmarks: trunk (C7, bilateral acromion), pelvis (bilateral anterior superior iliac spines, S2 vertebra), thigh (lateral knee axis and mid-thigh), shank (lateral malleolus and mid-shank), and foot (between second and third metatarsal heads and bilateral heel). Static calibration was performed prior to dynamic trials.

Patients were instructed to walk barefoot at a self-selected comfortable pace along the calibrated walkway. Multiple trials were recorded, and data from the affected limb and contralateral limb were analyzed. Primary gait parameters included walking velocity (m/s), stride length (m), stance phase (% of gait cycle), and knee range of motion (degrees). These parameters were compared with established normative reference values described by Whittle.[9]

Functional outcome assessment

Functional outcome was evaluated using the MSTS scoring system. The MSTS score assesses pain, function, emotional acceptance, support, walking ability, and gait, with a maximum possible score of 30.

Sample size calculation

Sample size was calculated based on the expected correlation between gait parameters and MSTS score using the formula:

$$n = \left(\frac{Z_\alpha + Z_\beta}{C(r)}\right)^2 + 3$$

Where $C(r) = \frac{1}{2} log_e \frac{1+r}{1-r}$

Assuming a correlation coefficient (r) of 0.585, type I error (α) of 5% corresponding to a 95% confidence level, and type II error (β) of 10% for 90% study power, the calculated minimum sample size was 20 participants.

Statistical analysis

Continuous variables were expressed as mean, median, and standard deviation. Quantitative variables were compared using the unpaired Student's t test for two-group comparisons and one-way analysis of variance (ANOVA) for comparisons among three groups. Pearson's correlation coefficient was used to assess the strength of association between gait parameters and MSTS scores. Normality of distribution was assessed using the Shapiro-Wilk test.

A $p<0.05$ was considered statistically significant. Statistical analysis was performed using statistical package for the social sciences (SPSS) software version 16.0 (SPSS Inc., Chicago, USA) and Microsoft excel (Microsoft Corporation, Redmond, USA).

RESULTS

The study cohort comprised 20 patients with a mean age of 34.5±8.2 years, including 12 males and 8 females. Tumor types included osteosarcoma (35%) and Campanacci grade III giant cell tumor (65%), with equal distribution between distal femur and proximal tibia. Detailed demographic and tumor characteristics are summarized in Table 1. The mean follow-up duration was 26.65 months.

The mean MSTS score was 22.95 out of a maximum of 30, indicating good to excellent functional outcome overall. Eighteen patients (90%) achieved MSTS scores between 21 and 27. Two patients had moderate scores (17 and 18), with reduction noted across multiple MSTS components, particularly in the gait domain.

Only two patients reported a completely normal gait pattern subjectively and received a gait component score of five; both had distal femur involvement and high overall MSTS scores (26 and 27). Subcomponent scores for pain, function, emotional acceptance, walking, support requirement, and gait are summarized in Table 2.

Table 1: Patient demographics and tumor characteristics, (n=20).

Parameters	Value
Total patients	20
Male/Female	12/8
Age (in years)	Mean 34.5±8.2 (Range 18-45)
Age groups	18-30: 6 (30%), 31-40: 9 (45%), 41-50: 5 (25%)
Tumor type	Osteosarcoma: 7 (35%), Giant cell tumor (Campanacci III): 13 (65%)
Tumor location	Distal femur: 10 (50%), proximal tibia: 10 (50%)
Limb operated	Right: 11 (55%), Left: 9 (45%)
Surgical margins	All en-bloc, negative (100%)

Table 2: Functional outcomes (MSTS scores).

Parameters	Mean±SD	Range	Number of patients (%)
Total MSTS score (out of 30)	22.95±2.5	17-27	Good-excellent (≥21): 18 (90%) Moderate (17-20): 2 (10%)
Pain	4.2±0.6	3-5	-
Function	3.8±0.7	2-5	-
Emotional acceptance	3.5±0.8	2-5	-
Walking	3.9±0.6	2-5	-
Support requirement	3.6±0.7	2-5	-
Gait	3.5±0.9	2-5	-

Objective gait analysis demonstrated a mean free-paced walking velocity of 0.92 m/s, which was 31.31% lower than the anthropometrically comparable normal reference value of 1.32 m/s reported by Whittle.[9] When compared with normal reference data, stride length and walking velocity of the affected limb were significantly reduced ($p<0.001$). However, no significant difference was observed between the affected and unaffected limbs in stride length ($p=0.841$) or walking velocity ($p=0.147$), indicating preservation of inter-limb symmetry. The stance phase duration differed significantly between limbs ($p=0.034$), with reduced stance time on the operated limb, reflecting altered weight-bearing behavior.

Goniometric and kinematic assessment revealed three gait patterns. Sixteen patients (80%) demonstrated a stiff knee gait, characterized by reduced knee flexion (<15°) during the stance phase. Two patients (10%) exhibited a flexed knee gait with increased knee flexion (>15°) during stance, and two patients (10%) showed near-normal knee kinematics. Despite these dynamic differences, clinical

active and passive knee range of motion was satisfactory in all patients, with a mean active range of 2°-105° and passive range of 0°-105°. The difference in mean knee range of motion between gait pattern groups was statistically significant (p<0.001). Gait analysis revealed reduced walking velocity and stride length compared with normative values, while stride and velocity symmetry between operated and contralateral limbs was largely preserved. Knee range of motion and gait patterns are detailed in Table 3.

Table 3: Gait parameters and knee range of motion.

Parameters	Operated limb	Contralateral limb	Normal reference	P value	Comments
Walking velocity (m/s)	0.92±0.13	1.02±0.10	1.32±0.12	<0.001 vs normal	Reduced, compensatory gait
Stride length (m)	0.95±0.12	0.97±0.11	1.20±0.10	<0.001 vs normal	Slight reduction, symmetry maintained
Stance phase (s)	0.60±0.05	0.63±0.04	0.62±0.04	0.034	Reduced stance on operated limb
Active knee ROM (°)	2-105	0-110	0-120	-	Stiff knee gait predominance
Passive knee ROM (°)	0-105	0-110	0-120	-	-
Gait pattern	Stiff knee: 16 (80%) Flexed knee: 2 (10%) Normal: 2 (10%)	-	-	-	-
Stride symmetry	Maintained	-	-	0.841	Contralateral compensation
Velocity symmetry	Maintained	-	-	0.147	-

Correlation analysis between subjective and objective parameters showed a significant positive association between overall MSTS score and stride length (p=0.017) as well as walking velocity (p=0.05), whereas no significant correlation was observed with stance phase duration. Among MSTS subcomponents, walking score and function score showed significant correlation with walking velocity (p<0.05), although the strength of association was moderate on Pearson analysis. Pain, emotional acceptance, support requirement, and gait perception did not demonstrate significant correlation with objective gait parameters (p>0.05). Overall, while walking velocity was reduced compared to normative standards, stride symmetry between limbs was largely preserved, with compensatory reduction in stance phase on the operated side.

DISCUSSION

The present study evaluated gait characteristics and functional outcomes in 20 patients undergoing wide tumor resection followed by knee endoprosthetic reconstruction. The results demonstrate that, although measurable biomechanical deviations persist, overall functional recovery is satisfactory. The mean MSTS score was 22.95±2.5, with 18 patients (90%) achieving good to excellent scores (21-27). Two patients had moderate scores (17-18), indicating limitations in all MSTS subcomponents, including gait. These findings support the established role of limb salvage surgery in musculoskeletal oncology.[5-8]

Quantitative gait assessment after knee reconstruction has been explored in arthroplasty populations. Berman et al reported persistent alterations in temporal and spatial parameters following total knee replacement despite clinical improvement.[11] Kroll et al observed that early postoperative improvements in stride characteristics were closely related to reductions in pain, whereas later improvements occurred independently of pain and knee flexion gains.[11] These findings highlight that gait normalization is multifactorial and cannot be predicted solely from static joint motion or pain relief. In our cohort, the mean free-paced walking velocity was 0.92±0.13 m/s, 31% lower than the normal reference of 1.32 m/s (p<0.001), and stride length was reduced to 0.95±0.12 m compared with 1.20±0.10 m in normative data (p<0.001). Stance phase duration of the operated limb was slightly prolonged at 0.65±0.05 s versus 0.62±0.04 s in the contralateral limb (p=0.034), although interlimb differences for stride length (p=0.841) and walking velocity (p=0.147) were not significant.[12] Despite satisfactory active and passive knee range of motion (2°-105°), these reductions reinforce the distinction between clinical motion and dynamic gait efficiency.

Tumor-specific endoprosthetic studies show comparable trends. Vivek et al documented a mean walking velocity of 0.91 m/s and stiff knee gait in 80% of patients, with preserved interlimb symmetry, mirroring our findings.[12] Otis et al demonstrated that patients treated with resection and prosthetic replacement had lower energy expenditure during gait compared with above-knee amputees,

emphasizing the physiological advantage of limb salvage.[13] However, de Visser et al highlighted that gait reautomatization remains incomplete and may deteriorate under cognitive or visual constraints, suggesting persistent neuromuscular adaptation even years after surgery.[14]

Long-term follow-up data reinforce these observations. Rompen et al reported walking velocity at 88% of normal, shortened stance phase on the involved limb, and predominance of stiff knee gait, with a mean MSTS score of 22 points.[15] While Rompen et al found no correlation between MSTS and temporal gait variables, our study demonstrated significant positive correlations between MSTS score, stride length (r=0.48, p=0.017), and walking velocity (r=0.44, p=0.05). Tsuboyama et al reported decreased peak plantar pressures and reduced force-time integrals on the operated limb, correlating with quadriceps strength, supporting our observation of altered stance phase duration despite preserved stride symmetry.[16]

Comparative functional analyses across reconstructive options provide additional perspective. Harris et al found that patients undergoing amputation, arthrodesis, or arthroplasty all walked slower than normal controls, although energy efficiency was similar among groups.[17] In our cohort, patients with distal femoral tumors and preserved extensor mechanisms achieved the highest MSTS scores (26-27), supporting the importance of anatomical site and soft tissue reconstruction. Malawer and Chou reported 83% five-year prosthetic survival with good to excellent MSTS scores, noting higher revision rates in proximal tibial reconstructions.[18] Sharil et al documented slightly lower MSTS scores for proximal tibial endoprostheses (19.75) compared to distal femur (21.94), consistent with our results.[19] Favorable long-term functional outcomes have also been reported by Frink et al and Bickels et al demonstrating durable implant survival and sustained high functional performance in distal femur reconstructions.[20,21]

Compared with normative gait standards the 31% reduction in walking velocity is clinically meaningful; however, preservation of stride symmetry indicates effective contralateral compensation, consistent with Bruns et al.[1,9] The predominance of stiff knee gait, as also reported by Vivek et al and Rompen et al likely reflects quadriceps weakness, extensor mechanism compromise, and protective stabilization.[12,15] Dynamic knee motion during stance remained reduced despite satisfactory passive range, emphasizing that static goniometry does not fully capture functional biomechanics.

From an oncological standpoint, the tumor distribution in this study reflects established epidemiological trends while biological behavior and management of giant cell tumor have been detailed by Sobti et al, López-Pousa et al, and Gong et al.[2-5] Principles of limb salvage surgery, emphasizing oncological safety and functional preservation, have been advocated by Simon, Rougraff et al and Veth et al and our findings support these concepts, demonstrating satisfactory functional recovery following en-bloc resection with clear margins.[6-8]

The significant positive correlation between overall MSTS score and stride length and walking velocity indicates that patient-reported function partially reflects measurable gait performance. However, the lack of correlation with certain temporal parameters suggests that subjective perception does not fully capture biomechanical efficiency.[12,15]

The limitations of this study include the relatively small sample size and a follow-up duration that, although adequate for functional assessment, may not fully reflect long-term prosthesis survival or late complications. Comparative evaluation with other reconstruction modalities or exoprosthesis users was not performed. However, the study is strengthened by the use of standardized three-dimensional gait analysis, uniform implant selection, and the correlation of objective biomechanical assessment with validated functional scoring.

CONCLUSION

In conclusion, patients undergoing wide tumor resection and knee endoprosthesis reconstruction achieve good to excellent functional outcomes despite measurable alterations in gait mechanics. Although walking velocity is reduced compared with normal reference values, stride symmetry is largely preserved through compensatory mechanisms. The demonstrated association between MSTS score and dynamic gait parameters highlights the importance of integrating objective gait analysis with subjective functional assessment to better understand postoperative recovery and guide rehabilitation strategies.

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