Gait Analysis in Patients with Wide Resection and Endoprosthesis Replacement Around the Knee

Abstract

Background: Limb salvage surgery with endoprosthesis for bone tumor around the knee is reported to have good functional and oncological outcomes. However, the functional assessment using musculoskeletal tumor society (MSTS) and Toronto extremity scoring system remains subjective. We performed gait analysis as an objective assessment of their functional outcome. **Materials and Methods:** Gait analysis was performed in 20 patients with endoprosthesis replacement around the knee. The temporal parameters assessed during gait analysis were walking velocity, stride length, duration of stance, and goniometry of the knee. These parameters were compared with the functional outcome score of the MSTS. **Results:** The mean free-paced walking velocity was 0.91 m/s (normal is 1.33 m/s), which was 68% lower than normal gait. The stride length and stance phase were shorter for the affected limb compared to normal ($P < 0.05$). However, the gait was symmetrical with no difference in stride length ($P = 0.148$), velocity ($P = 0.918$), knee flexion ($P = 0.465$), and knee extension ($P = 0.321$) between the affected and unaffected limbs. Sixteen patients demonstrated stiff knee gait, two had a flexed knee gait, and only two patients had normal gait during the stance phase. The mean MSTS score was 21. There was significant correlation between overall MSTS scores ($P = 0.023$), function ($P = 0.039$), and walking scores ($P = 0.007$). **Conclusion:** Limb salvage surgery with endoprosthesis reconstruction around the knee gives good functional outcome, both objectively and subjectively, as evidenced by the symmetrical gait pattern and significant correlation with MSTS score. Despite decreased walking velocity, stride length, and stance phase of the operated limb, the patient still has a symmetrical gait.

Keywords: *Bone sarcoma, gait, knee prosthesis, musculoskeletal tumor, endoprosthesis, limb salvage*
MeSH terms: *Gait, knee prosthesis, sarcoma, tumor*

Vivek Ajit Singh, Chan Wei Heng, Nor Faissal Yasin

Department of Orthopaedic Surgery, Faculty of Medicine, University of Malaya, Kuala Lumpur, Malaysia

Introduction

Primary benign and malignant bone tumors are commonly located around the knee, either at the distal femur (DF) or proximal tibia (PT).[1] Amputation was the mainstay of treatment for musculoskeletal sarcoma of the extremities such as osteosarcoma (OS) before the 1970's. The introduction of chemotherapy has made limb salvage surgery a treatment of choice in about 70%–80% of patients with sarcomas of the extremity.[2] This has become the standard treatment and it does not compromise the oncological results, with similar disease-free survival rate as compared to limb amputation.[3,4] Limb salvage surgery in musculoskeletal sarcoma is also reported to give good functional and psychological outcome.[5,6]

Limb salvage surgery with either modular or custom-made endoprosthesis reconstruction is frequently used in bone tumors around the knee. Endoprosthesis reconstruction in this condition provides joint stability, mobility, and thus better functional outcome to patients.[7]

In 1993, Enneking *et al*. developed the musculoskeletal tumor society (MSTS) scoring system for a subjective assessment of the functional evaluation in patients diagnosed with musculoskeletal sarcoma of the extremities.[8] Currently, most of the reported functional outcomes for musculoskeletal sarcoma patients are based on MSTS scores which is a subjective assessment by the physician.

At the moment, there is no validated standard method for the objective functional outcome assessment in limb salvage surgery of the extremity. There are only a few studies which reported gait analysis in patients after musculoskeletal tumor resection and reconstruction of the lower extremity.[9-12] The objective of this study is to evaluate gait pattern as an

How to cite this article: Singh VA, Heng CW, Yasin NF. Gait analysis in patients with wide resection and endoprosthesis replacement around the knee. Indian J Orthop 2018;52:65-72.

Address for correspondence:
Prof. Vivek Ajit Singh, Department of Orthopaedic Surgery, Faculty of Medicine, University of Malaya, 50603 Kuala Lumpur, Malaysia.
E-mail: drvivek69@gmail.com

Access this article online

Website: www.ijoonline.com

DOI: 10.4103/ortho.IJOrtho_188_17

Quick Response Code:

objective functional outcome assessment for patients with tumor resection and endoprosthesis reconstruction around the knee. This study will also compare the subjective functional outcome (MSTS scores) with the objective parameters obtained from the gait analysis.

Materials and Methods

We identified and recruited patients diagnosed with OS and giant cell tumor (GCT) around the knee, treated with wide resection and endoprosthesis reconstruction in our medical center. The tumor is located either at the DF or PT, and replaced with either modular or custom-made expandable knee endoprosthesis after wide resection surgery.

The following patients were excluded from the study; patients with a neurological deficit of the affected limb, infected implant and had underwent multiple operations, local recurrence, and distant metastasis at the time of examination. Patients with fixed flexion contracture of the affected knee and significant limb length discrepancy of >2 cm were also excluded because these patients will require further management to treat the deficits.

All patients who were included underwent wide resection of the tumor and achieved clear oncological margin. In patients with tumor at the DF, vastus intermedialis was removed with the tumor. In patients with tumor at the PT, a reconstruction of the extensor mechanism was done using the medial gastrocnemius muscle flap.

All endoprosthesis used in this study had a rotating hinge knee mechanism and cemented prosthesis.

Subjective assessment with musculoskeletal tumor society score

Patients were reviewed and evaluated using MSTS scores before the gait analysis was performed. The six criteria included in MSTS scores are pain, function, emotional acceptance, supports, walking ability, and gait. Each criterion has six sub-categories which is scored between 0 and 5, thus the maximum score will be 30. The higher the score, the better the functional outcome of the patient. A score between 23 and 30 (75%–100%) is considered to be an excellent functional outcome, whereas a score between 0 and 14 (<50%) is considered to be poor functional outcome.[8]

Objective assessment with gait analysis

Gait analysis[13] was conducted at Motion Analysis Laboratory, Biomedical Engineering Department, University Malaya. Written consent was obtained from each patient or the patient's guardian before the analysis. All patients were briefed on the procedures involved during the gait analysis.

Sixteen retroreflective markers were placed on various anatomical bony landmarks. The bony landmarks include anterior superior iliac spine, posterior superior iliac spine, femoral shaft, lateral knee joint line, tibial shaft, lateral malleolus, posterior aspect of the ankle, and second metatarsal bone [Figure 1].

Static calibration was done before the gait analysis was started. The patient walked at a preferred speed along a 15 m runway into a calibrated length of 2.5 m during gait analysis. Three-dimensional kinematic data were recorded during the gait analysis using six different cameras at different projection along the runway (60-Hz Vicon system from Vicon, Oxford, United Kingdom).

Each patient walked along the runway a minimum of 20 times. During the first few trials, the patients walked along the runway to get used to walking in a laboratory setting. The data collected was then processed at a laboratory computer using the Vicon Nexus system. Once the data were processed, the best five trials with complete gait cycles were selected from the 20 trials made by each patient. Incomplete gait cycles due to the failure of equipment were excluded. The selected five trials were processed further, which involved averaging the mean kinematic values during swing and stance phases for one complete gait cycle.

The data collected from the gait analysis are as follows: (a) Temporal parameters-preferred walking velocity, stride length, and duration of stance phase (b) Goniometry of the knee during walking

Normal values of temporal parameters according to patients' age and sex were obtained from the data published in gait analysis: An introduction by Whittle.[14]

The data collected were then analyzed using the SPSS version 22 (IBM, NY, US). The student's *t*-test for paired samples was used to analyze the differences between mean temporal variables of the involved limb, the uninvolved limb, and normal values. The statistical significance was set at $P < 0.05$. ANOVA test was used if three or more groups were compared. Correlations between variables were assessed with Pearson correlation test.

Figure 1: A clinical photograph showing placement of the sensor probes at the lower limbs for gait analysis

Results

Demographic data

A total of 20 patients were recruited into the study [Table 1]. There were eight males and twelve female patients. Twelve patients were diagnosed with OS, whereas another eight patients were diagnosed with GCT. Fifteen tumors were located at the DF and five tumors at the PT. Eighteen patients (90%) were diagnosed at the age of <30. Only two patients were diagnosed and treated after 40 years of age. Both patients were diagnosed with GCT, at the age of 44 and 54 years old, respectively.

All 20 patients had a wide resection of the tumor and achieved clear surgical margin.

The average followup for the patients in this study is 7 years (range 6-136 months).

Subjective functional outcome

The study participants had a good to excellent subjective functional outcome assessment using the MSTS scores, with a mean score of 21 out of a total of 30. Sixteen patients (80%) had an overall MSTS score of 21–25 [Figure 2].

Four patients (20%) had moderate scores, ranging from 13 to 20. All four patients scored lower in the walking component. Two of them had a perception of gait alteration causing a major cosmetic defect, but the minor functional deficit. They also required to use of support such as a walking stick during outdoor activities. Furthermore, they had moderate pain when walking. For this group of patients, the criteria of pain, walking, support, and gait scores were the three main factors that reduced the overall MSTS score.

Only two patients felt their gait was normal after the surgery. They gave a score of five for gait criteria. One was diagnosed with GCT of DF, whereas the other one had OS of PT. They had excellent overall MSTS scores of 25 and 24, respectively.

Objective functional outcome

Gait analysis of the 20 patients showed a mean free-paced walking velocity without support at 0.91 m/s [Figure 3], which was 68% lower than the normal individuals' walking velocity. Mean normal velocity for normal individuals was 1.33 m/s.

The analysis also showed that stride length, walking velocity, and stance phase in this group of patients were reduced after the surgery [Table 2]. The stride length, walking velocity, and stance phase of the affected limb were significantly reduced ($P < 0.05$) compared to the normal value published by Whittle.[14] However, there were no significant differences in the stride length ($P = 0.148$) and velocity ($P = 918$) between the affected and unaffected limb when the patients walked. The duration of stance phase was significantly reduced ($P = 0.000$) between the affected and unaffected limb. The gait appeared symmetrical in the stride length and velocity, but not in the stance phase [Table 3]. This analysis showed that the unaffected limb could compensate for the affected limb, and patients still can walk with an acceptable symmetrical gait.

On goniometric examination, only two patients exhibited normal gait pattern of the knee during the gait cycle. Sixteen patients (80%) had stiff knee gait, and two patients (10%) had flexed knee gait. All the patients in the study had normal knee flexion and extension, both actively and passively. The mean active range of motions was 2.25^{o}–105^{o}, and passive range of motions was 0^{o}–105^{o}.

In normal gait, there was a physiological 10^{o}–15^{o} knee flexion during a stance phase [Figure 4]. In stiff knee gait, the knee flexion was $<15^{o}$ during a stance phase [Figure 5] whereas in flexed knee gait, the knee flexion was $>15^{o}$ during a stance phase [Figure 6].[9] Although patients had different patterns of clinical gait during the analysis, the mean range of motion of the knee, between the affected and unaffected limb was not statistically significant ($P > 0.05$) [Table 4].

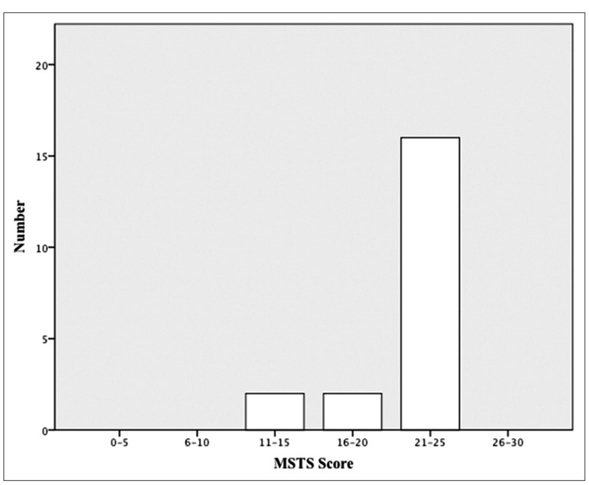

Figure 2: A bar diagram showing musculoskeletal tumor society score of patients

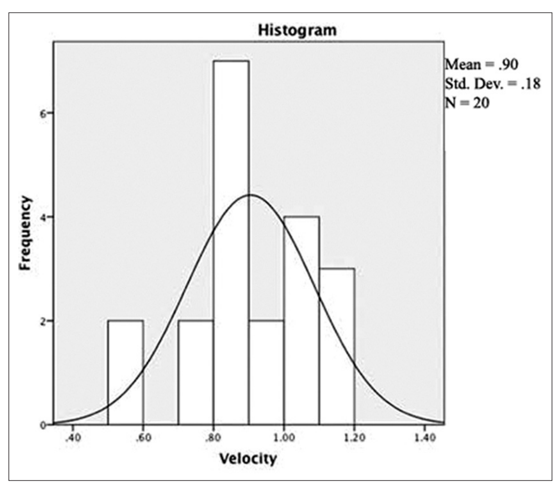

Figure 3: A histogram showing distribution of walking velocity of subjects in gait analysis

Table 1: Clinical details of the patients

Subject	Sex	Age at diagnosis (Years)	Diagnosis	Side	Site	Postoperative period (months)	LLD (cm)	MSTS (30)	Stride length	Velocity	Stance	Gait pattern
1	Male	10	OS	Right	DF	52	4	21	A: 1.09 UA: 1.09 N: 1.35	A: 0.9 UA: 0.93 N: 0.52	A: 57.22 UA: 61.81 N: 60	Stiff
2	Female	10	OS	Left	DF	60	0	23	A: 1.04 UA: 1.08 N: 1.3	A: 0.88 UA: 0.9 N: 1.28	A: 54.84 UA: 59.37 N: 60	Flexed
3	Female	8	OS	Left	DF	21	0	20	A: 0.71 UA: 0.67 N: 1.27	A: 0.53 UA: 0.52 N: 1.26	A: 58.44 UA: 62.46 N: 60	Stiff
4	Female	10	OS	Left	DF	48	4	22	A: 1.04 UA: 1.08 N: 1.35	A: 1.03 UA: 1.05 N: 1.31	A: 53.25 UA: 64.02 N: 60	Stiff
5	Female	14	OS	Right	DF	33	0	22	A: 1.13 UA: 1.16 N: 1.3	A: 1.05 UA: 1.06 N: 1.28	A: 56.15 UA: 60.14 N: 60	Stiff
6	Female	44	GCT	Left	DF	74	0	13	A: 1.12 UA: 1.15 N: 1.3	A: 0.84 UA: 0.87 N: 1.27	A: 59 UA: 64.48 N: 60	Stiff
7	Male	31	GCT	Left	DF	47	0	14	A: 0.9 UA: 0.86 N: 1.5	A: 0.54 UA: 0.52 N: 1.46	A: 59.61 UA: 81.26 N: 60	Stiff
8	Female	27	OS	Right	DF	6	0	21	A: 1.14 UA: 1.07 N: 1.32	A: 0.89 UA: 0.88 N: 1.3	A: 56.38 UA: 62.84 N: 60	Stiff
9	Male	18	OS	Left	DF	136	2	21	A: 0.95 UA: 0.91 N: 1.32	A: 0.78 UA: 0.73 N: 1.3	A: 63.99 UA: 60.83 N: 60	Stiff
10	Female	25	OS	Right	DF	72	3	24	A: 1.07 UA: 1.06 N: 1.32	A: 1.06 UA: 1.03 N: 1.3	A: 58.23 UA: 60.01 N: 60	Stiff
11	Female	23	GCT	Right	DF	30	0	23	A: 1.07 UA: 1.02 N: 1.32	A: 0.92 UA: 0.87 N: 1.3	A: 61.08 61.98 N: 60	Stiff
12	Male	54	GCT	Right	DF	66	2	22	A: 1.32 UA: 1.25 N: 1.52	A: 1.19 UA: 1.16 N: 1.32	A: 55.96 UA: 61.4 N: 60	Stiff
13	Male	27	GCT	Right	DF	6	0	21	A: 1.18 UA: 1.29 N: 1.55	A: 1.11 UA: 1.24 N: 1.46	A: 59.91 UA: 61.84 N: 60	Stiff
14	Female	25	GCT	Left	DF	21	0	25	A: 1.11 UA: 1.11 N: 1.32	A: 0.85 UA: 0.84 N: 1.3	A: 63.61 UA: 61.23 N: 60	Normal
15	Female	17	OS	Left	DF	72	0	22	A: 1.03 UA: 1.05 N: 1.32	A: 0.87 UA: 0.86 N: 1.3	A: 57.19 UA: 62.66 N: 60	Flexed

Contd...

Table 1: Contd...

Subject	Sex	Age at diagnosis (Years)	Diagnosis	Side	Site	Postoperative period (months)	LLD (cm)	MSTS (30)	Stride length	Velocity	Stance	Gait pattern
16	Male	16	OS	Right	PT	56	0	24	A: 1.29 UA: 1.16 N: 1.55	A: 1.16 UA: 1.18 N: 1.46	A: 59.45 UA: 61.89 N: 60	Stiff
17	Male	25	OS	Right	PT	60	0	21	A: 1.04 UA: 0.93 N: 1.5	A: 0.74 UA: 0.78 N: 1.46	A: 65.54 UA: 60.6 N: 60	Stiff
18	Female	29	GCT	Right	PT	75	0	18	A: 1.04 UA: 1.01 N: 1.32	A: 0.83 UA: 0.82 N: 1.3	A: 61.51 UA: 64.24 N: 60	Stiff
19	Female	30	GCT	Right	PT	15	0	23	A: 1.06 UA: 1.07 N: 1.32	A: 0.84 UA: 0.86 N: 1.3	A: 61.03 UA: 64.61 N: 60	Stiff
20	Male	12	OS	Right	PT	36	3	22	A: 1.25 UA: 1.17 N: 1.45	A: 1.09 UA: 1.02 N: 1.39	A: 58.63 UA: 66.14 N: 60	Normal

OS=Osteosarcoma, GCT=Giant cell tumor, DF=Distal femur, PT=Proximal tibia, A=Affected side, UA=Unaffected side, N=Normal, MSTS=Musculoskeletal Tumor Society, LLD=Limb length discrepancy

Table 2: Mean of temporal parameters in gait analysis (standard deviation: 0.181)

Parameters	Affected limb	Unaffected limb	Normal value
Stride length (m)	1.08	1.06	1.38
Velocity (m/s)	0.91	0.91	1.33
Stance phase (%)	59.05	63.19	60.00

Table 3: The paired *t*-test of the temporal parameters between the affected and unaffected limbs

t-test	Stride length	Velocity	Stance phase
Affected			
Unaffected (*P*)	0.148	0.918	0.000
Normal (*P*)	0.000	0.000	0.192

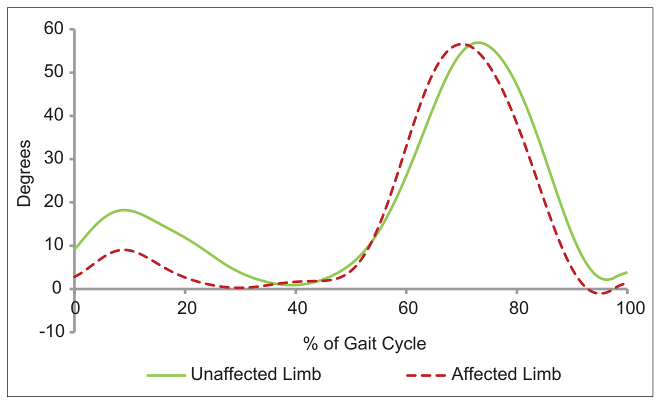

Figure 4: A histogram showing knee movements in normal gait pattern

Correlation of subjective and objective parameters

Correlation between the subjective assessment using MSTS score and objective assessment using the gait analysis was analyzed [Table 5]. It showed that the overall MSTS scores have significant relationship with the velocity of walking in the gait analysis ($P < 0.05$), but not to the stride length and stance phase.

In the sub-categories of MSTS scores, the function score and the walking score also had a significant relationship with the velocity of walking ($P < 0.05$) [Table 5]. However, the relationship was graded as moderate using the Pearson correlation. This suggests that with higher overall MSTS score, function and walking score, the patients were likely to walk at a faster walking velocity. Other parameters in MSTS scoring system (pain, support, and gait) had no significant relationship with velocity, stride length, and stance phase in gait analysis ($P > 0.05$).

Discussion

Gait pattern is an important parameter in the functional outcome assessment of lower extremity reconstruction. It was first described in patients who had undergone knee replacement for degenerative disease.[15-17] The authors showed that gait pattern was correlated with patient's functional outcome after surgery.

Gait is expected to be abnormal after a limb salvage surgery in the lower extremity due to the amount of bone and soft tissue resection, as compared to joint replacement surgery. This gait abnormality or better known as gait compensation was first described by Simon *et al.,* in patients with limb salvage surgery after tumor resection and reconstruction.[4] Following this description, gait analysis in patients with

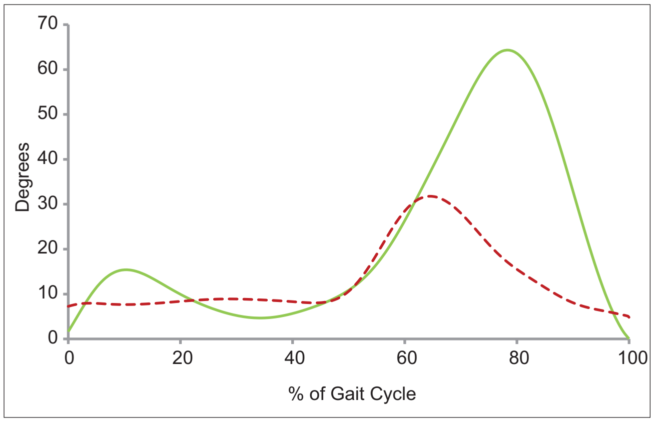

Figure 5: A histogram showing stiff knee gait pattern with reduced knee flexion in stance phase

Table 4: Mean range of motion of knee between affected and unaffected limbs

Motion	Affected limb	Unaffected limb	*P*
Flexion (°)	51.97 (35-62)	55.40 (55-65)	0.465
Extension (°)	0.59 (0-5)	−1.47 (−5-5)	0.321

Table 5: Correlation between Musculoskeletal Tumor Society score and temporal parameters in gait analysis

Parameters	Velocity	Stride length	Stance phase
MSTS			
r	0.505	0.308	−0.043
P	0.023	0.187	0.857
Pain			
r	0.373	0.212	−0.171
P	0.106	0.370	0.470
Function			
r	0.465	0.380	0.097
P	0.039	0.098	0.683
Support			
r	0.235	0.031	−0.010
P	0.319	0.895	0.967
Walking			
r	0.585	0.430	−0.004
P	0.007	0.059	0.988
Gait			
r	0.364	0.185	−0.072
P	0.115	0.434	0.764

MSTS=Musculoskeletal Tumor Society

limb salvage surgery for lower extremity tumor resection and reconstruction was studied by a few authors.[5,9-12,18] Majority of patients with limb salvage surgery around the knee have an abnormal gait, but their functional outcomes are still satisfactory. Limb salvage surgery with endoprosthesis reconstruction for bone tumors around the knee gives good to excellent functional outcome.[1,19-21]

In this study, we found that patients who had knee endoprosthesis reconstruction walked at a slower pace

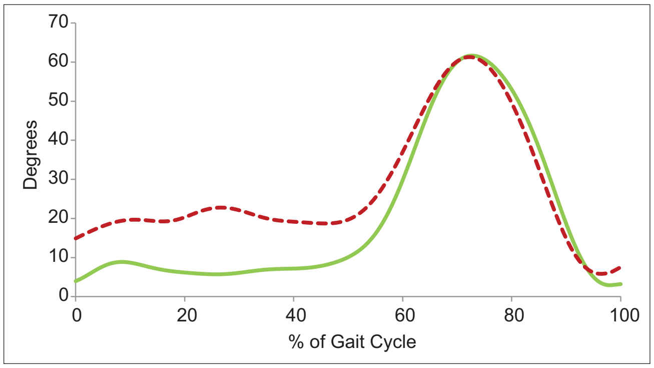

Figure 6: A histogram showing flexed knee gait pattern with increased knee flexion in stance phase

compared to the gait parameters published by Whittle.[14] The mean free paced walking velocity was 68% of the normal walking velocity. This finding is consistent with results reported in previous studies, which found that their walking velocity was between 64% and 88% of normal walking velocity after lower limb salvage surgery.[9,11,22] The slower velocity of the affected limb is likely due to muscle weakness after wide resection.[5,9,22] There will be a large amount of muscles resected in tumors located either in DF or PT order to achieve clear surgical margin. The amount of muscles resected will affect the strength of the affected limb. Patients may also tend to avoid straining the operated limb by reducing their walking velocity. A patient who was seen earlier after surgery in this study will have a shorter time for rehabilitation, and thus, it will affect the walking velocity.

In general, we found that the gait pattern after limb salvage surgery around the knee can be divided into two major groups as follows: stiff knee gait and flexed knee gait. Stiff knee gait is described as a continuous extension of the knee during stance phase where knee flexion is <10-15º. This gait pattern was described by de Visser *et al.*[9] in patients with a DF endoprosthesis, who likely walk with a stiff knee gait after tumor resection, due to the loss of quadriceps muscle strength. Knee extension during stance phase in this group of patients provided extra stability to the knee joint when walking. This compensatory mechanism helps to preserve weight-bearing stability during stance phase to the affected limb. However, the loss of knee flexion during stance phase has detrimental effect on the survival of the endoprosthesis. Knee flexion during stance phase is important for shock absorption as it reduces the direct force transmission from the femur to tibia during walking.[9] The flexed knee gait pattern is not well described in the literature and not entirely understood.

Despite these gait patterns, patients with abnormal gait can have acceptable active and passive range of motions. There was also no significant difference in the knee range motions between the affected and unaffected limbs. The patients may have subconsciously avoided vigorous knee motion to the affected limb during walking.

We found that all the patients in this study walked symmetrically. There was no significant difference between walking velocity, stride length, and range of motion of knees. We came to a conclusion that the normal limb has decompensated to compensate for the affected limb. A symmetrical gait is more physiological and gives better functional outcome.

We also noted that patients spent less time on the affected limb during the stance phase. Rompen *et al.,*[11] showed that there was reduced stance phase in patients who underwent endoprosthesis replacement around the knee, and our study concurs with their findings. The reduced stance phase may be due to patients being cautious when walking using the operated limb.

Limitations of the study

The numbers of patients involved in the study are small due to financial limitations to perform the gait analysis and difficulty in recruiting patients to participate in this study.

Other factors such as the site of tumor, postoperative period of recovery and length of total bone resection that may affect the functional outcome were not studied.

Conclusion

In our study, we demonstrated that the patients had good functional outcome using both the MSTS scoring system and gait analysis. This is evidenced by the symmetrical gait pattern in all patients. The gait was symmetrical despite the decreased walking velocity, stride length and stance phase of the operated limb compared to normal limbs. This means that the normal limb could compensate for the affected limb to achieve a symmetrical gait.

In addition, there were significant correlations of the subjective parameters with the objective parameters. The overall MSTS scores, sub-categories of MSTS scores in function and walking scores were moderately correlated with walking velocity in gait analysis, but not in the stride length and duration of stance phase.

Therefore, MSTS scoring system is still a useful assessment for functional outcome in limb salvage surgery of the lower extremity, and we suggest that gait analysis can be used as a complementary tool for an objective assessment in patients with knee endoprosthesis reconstruction.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Malawer MM, Chou LB. Prosthetic survival and clinical results with use of large-segment replacements in the treatment of high-grade bone sarcomas. J Bone Joint Surg Am 1995;77:1154-65.
2. Veth RP, van Hoesel QG, Bökkerink JP, Hoogenhout J, Pruszczynski M. The art of limb salvage in musculoskeletal oncology. Crit Rev Oncol Hematol 1995;21:77-103.
3. Rougraff BT, Simon MA, Kneisl JS, Greenberg DB, Mankin HJ. Limb salvage compared with amputation for osteosarcoma of the distal end of the femur. A long term oncological, functional, and quality-of-life study. J Bone Joint Surg Am 1994;76:649-56.
4. Simon MA. Limb salvage for osteosarcoma. J Bone Joint Surg Am 1988;70:307-10.
5. Otis JC, Lane JM, Kroll MA. Energy cost during gait in osteosarcoma patients after resection and knee replacement and after above-the-knee amputation. J Bone Joint Surg Am 1985;67:606-11.
6. Weddington WW Jr., Segraves KB, Simon MA. Psychological outcome of extremity sarcoma survivors undergoing amputation or limb salvage. J Clin Oncol 1985;3:1393-9.
7. Chen TH, Su YP, Chen WM. Giant cell tumors of the knee: Subchondral bone integrity affects the outcome. Int Orthop 2005;29:30-4.
8. Enneking WF, Dunham W, Gebhardt MC, Malawar M, Pritchard DJ. A system for the functional evaluation of reconstructive procedures after surgical treatment of tumors of the musculoskeletal system. Clin Orthop Relat Res 1993;286 241-6.
9. de Visser E, Pauwels J, Duysens JE, Mulder T, Veth RP. Gait adaptations during walking under visual and cognitive constraints: A study of patients recovering from limb-saving surgery of the lower limb. Am J Phys Med Rehabil 1998;77:503-9.
10. McClenaghan BA, Krajbich JI, Pirone AM, Koheil R, Longmuir P. Comparative assessment of gait after limb-salvage procedures. J Bone Joint Surg Am 1989;71:1178-82.
11. Rompen JC, Ham SJ, Halbertsma JP, van Horn JR. Gait and function in patients with a femoral endoprosthesis after tumor resection: 18 patients evaluated 12 years after surgery. Acta Orthop Scand 2002;73:439-46.
12. Tsuboyama T, Windhager R, Bochdansky T, Yamamuro T, Kotz R. Gait after knee arthroplasty for femoral tumor. Foot pressure patterns recorded in 20 patients. Acta Orthop Scand 1994;65:51-4.
13. Azuan N. Motion Analysis System: An Integrated Approach. 2nd ed. UMpress 2009.
14. Whittle M. Gait Analysis: An Introduction. Elsevier 2007. p. 223-4.
15. Berman AT, Zarro VJ, Bosacco SJ, Israelite C. Quantitative gait analysis after unilateral or bilateral total knee replacement. J Bone Joint Surg Am 1987;69:1340-5.
16. Kroll MA, Otis JC, Sculco TP, Lee AC, Paget SA, Bruckenstein R, *et al.* The relationship of stride characteristics to pain before and after total knee arthroplasty. Clin Orthop Relat Res 1989;239:191-5.
17. Simon SR, Trieshmann HW, Burdett RG, Ewald FC, Sledge CB.

Quantitative gait analysis after total knee arthroplasty for monarticular degenerative arthritis. J Bone Joint Surg Am 1983;65:605-13.
18. Harris IE, Leff AR, Gitelis S, Simon MA. Function after amputation, arthrodesis, or arthroplasty for tumors about the knee. J Bone Joint Surg Am 1990;72:1477-85.
19. Sharil A, Nawaz A, Nor Azman M, Zulmi W, Faisham W. Early functional outcome of resection and endoprosthesis replacement for primary tumor around the knee. Malays Orthop J 2013;7:30-5.
20. Bickels J, Wittig JC, Kollender Y, Henshaw RM, Kellar-Graney KL, Meller I, *et al.* Distal femur resection with endoprosthetic reconstruction: A long term followup study. Clin Orthop Relat Res 2002;400:225-35.
21. Frink SJ, Rutledge J, Lewis VO, Lin PP, Yasko AW. Favorable long term results of prosthetic arthroplasty of the knee for distal femur neoplasms. Clin Orthop Relat Res 2005;438:65-70.
22. Kawai A, Backus SI, Otis JC, Healey JH. Interrelationships of clinical outcome, length of resection, and energy cost of walking after prosthetic knee replacement following resection of a malignant tumor of the distal aspect of the femur. J Bone Joint Surg Am 1998;80:822-31.