Gait and function in patients with a femoral endoprosthesis after tumor resection

18 patients evaluated 12 years after surgery

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ABSTRACT – We performed gait analysis in 18 patients with a femoral endoprosthesis: 12 distal, 3 proximal and 3 total. Follow-up after surgery was mean 12 (0.6–19) years. The gait parameters measured were walking velocity, step length, duration of stance phase and swing phase. Goniometry of the hip, knee and ankle in both legs was determined during free-paced walking. The functional outcome score of the Musculoskeletal Tumor Society (MSTS) and the Ambulation score were also assessed in all patients.

The mean free-paced walking velocity was 88% of normal. The step length of the uninvolved leg was longer than that of the involved one. The swing phase of the involved leg was longer than that of the uninvolved leg, and the stance phase of the involved leg was shorter than that of the uninvolved leg. Goniometry showed three abnormal patterns in the involved leg: a stiff knee gait in 10 patients, a flexed knee gait in 6, and an abnormal flexion-extension pattern in the hip in 9. Goniometry of the uninvolved leg was normal. The mean MSTS score was 22 points (72%). This showed a significant positive correlation to the Ambulation score, but no correlation to any of the temporal variables.

Our findings indicate that the time of load on the involved leg, whether conscious or not, is reduced. Follow-up studies are needed to evaluate the effects of the asymmetrical gait pattern observed and the abnormal goniometric results on the development of endoprosthesis-related complications.

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Tumor resection and reconstructions have replaced amputation in about 70–80% of patients with sarcomas of the extremity (Veth et al. 1995). This treatment gives good oncological results with the same disease-free survival rate as after amputation (Simon 1988, Rougraff et al. 1994). In the lower extremity, modular or custom-made endoprostheses are frequently used (Ham et al. 1998). Since most of the patients are young, the long-term functional results are important. For this purpose, the Musculoskeletal Tumor Society (MSTS) developed a system for subjective functional evaluation. This system scores pain, function, emotional acceptance, use of supports, walking ability, and gait cosmetics (Enneking 1993). At present, however, there is no validated standard method for the objective functional outcome measurements in limb salvage patients, and only a few studies have reported gait analysis in these patients. Therefore, the first objective of this study was to evaluate gait pattern as an objective functional outcome measurement in a group of patients who underwent endoprosthetic reconstruction after resection of a tumor located in the femur. The second aim was to compare the subjective functional outcome with the objective parameters obtained by gait analysis.

Material and methods

Patients

We examined 18 patients treated between 1979 and 1998 with tumor resection and endoprosthetic reconstruction of the femur (Table 1). Mean age at time of surgery was 23 (10–41) years, 12 were males. 13 patients had an osteosarcoma, 3 a chon-

Table 1. Patient data

A	B	C	D	E	F	G	H	I	J	K
1	M 23	OS, IIB	L tot	165	total	Waldemar-Link			SKG, TFEH	83 / 61
2	F 24	OS, II	R dist	7	140	Kotz			SKG, TFEH	90 / 88
3[a]	M 10	OS, III	L dist	210	170	Howmedica	74	74	SKG, TFEH	77 / 88
4[b]	F 28	CS, IA	R prox	7	140	Kotz			SKG	43 / 29
5	M 11	OS, IIB	L dist	201	200	Link	24	168	FKG, TFEH	83 / 97
6	F 16	OS, IB	L dist	108	190	Link			NP	93 / 100
7[c]	F 41	CS, IIA	R dist	202	120	Link	18		SKG, TFEH	57 / 41
8[b]	M 32	GCT	R dist	69	120	Kotz	25		SKG	60 / 74
9	F 17	OS, IIB	R tot	231	total	Howmedica	92	92	SKG, TFEH	57 / 62
10	M 14	OS, IIA	L dist	225	280	Link	142	142	SKG, TFEH	70 / 65
11	M 20	OS, IIB	R dist	141	200	Link			FKG	87 / 82
12[b]	M 35	CS, IA	R prox	119	130	Link			FKG	67 / 50
13	M 14	OS, IIB	R dist	124	180	Link			FKG, TFEH	77 / 76
14	M 35	OS, IIB	L dist	181	230	Link	37		SKG, TFEH	77 / 53
15[b]	F 31	OS, IIB	L tot[d]	126	250	Link			SKG	63 / 59
16	M 10	OS, IIB	L dist	138	220	Link			FKG	63 / 71
17	M 26	OS, IIB	R dist	132	160	Link	111		FKG	80 / 91
18	M 34	SV	R prox	159	90	Link	120		NP	73 / 62

[a] Patient used a knee brace
[b] Patient used 1 cane
[c] Patient used 2 canes
[d] Push-through prosthesis, functionally considered as a total femoral endoprosthesis

A Case
B Sex and age at time of surgery
C Type and stage of tumor
- CS chondrosarcoma
- GCT giant cell tumor
- OS osteosarcoma
- SV synovitis villonodularis

D Side and location of prosthesis
- R right
- L left
- dist distal femoral endoprosthesis
- prox proximal femoral endoprosthesis
- tot total femoral endoprosthesis

E Follow-up (months)
F Length of resection (mm)
G Type of prosthesis
H Months to first revision
I Months to first total revision
J Type of goniometric gait pattern in affected leg
- FKG flexed knee gait
- SKG stiff knee gait
- TFEH translated flexion extension hip
- NP normal patterns

K MSTS score (%) / Overall Ambulation Score (%)

drosarcoma, 1 a giant cell tumor, and 1 patient a synovitis villonodularis with invasion of the proximal femoral shaft. The surgical staging of the 16 bone sarcomas was determined using the Musculoskeletal Tumor Society (MSTS) classification: 10 were stage IIB, 2 stage IIA, 1 stage IB, 2 stage IA, and 1 stage III. The giant cell tumor was classified as a stage III benign tumor.

After resecting the tumor, we used a distal femoral endoprosthesis for reconstruction in 12 patients, and a proximal femoral endoprosthesis in 3; the mean length of resection was 18 cm and 12 cm, respectively. Total femoral resection and endoprosthetic replacement was performed in 2 patients, and in 1 patient, a push-through endoprosthesis was used to replace both the knee and the hip. On analysis, this was considered to be a total femoral endoprosthesis.

Cementless fixation of the femoral components was used in all cases, and the tibial component was cemented in case of replacement of the knee (Ham et al. 1998). The original acetabulum was kept intact when possible, and the patella was not routinely resurfaced. The gluteal muscles were sutured to the tensor and vastus lateralis remnants in proximal and total femoral reconstructions; this was considered essential to conserve active abduction and avoid dislocation of the artificial hip. In all other areas, adaptation of remaining muscles was performed only when the function of the endoprosthesis, including the patello-femoral joint, was guaranteed.

The mean follow-up at the time of examination was 12 (0.6–19) years after tumor resection and endoprosthetic reconstruction. None of the patients had had a local or distant recurrence. In 9

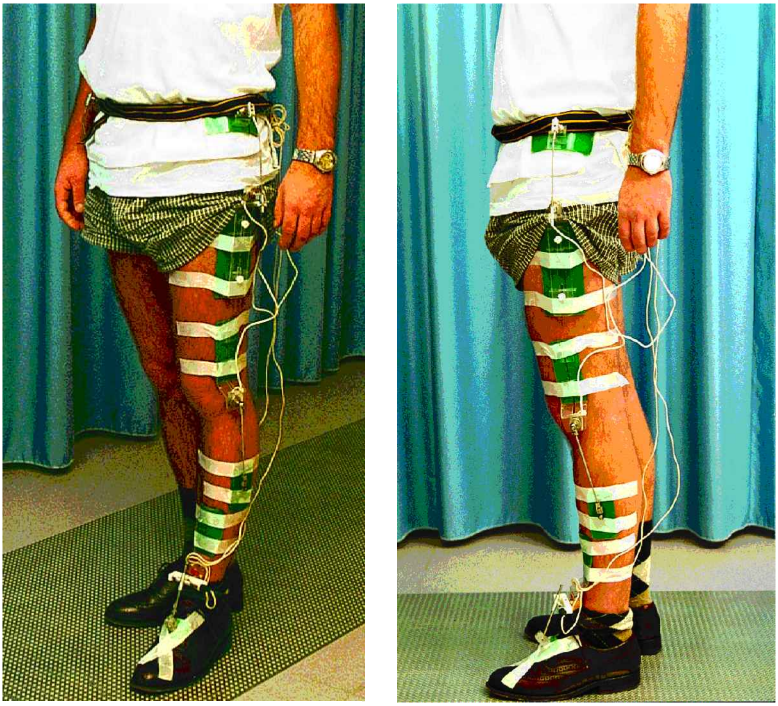

Figure 1. An example of the gait analysis set-up.

patients, at least one revision procedure had been performed. In 4 of these, the total endoprosthesis had been revised after a mean of 10 (6–14) years; the mean follow-up after total revision was 8 (3–12) years.

12 patients used no support at the time of examination, 4 walked with a cane, 1 patient walked with two canes, and 1 used a knee brace. 4 patients needed a built-up shoe on the involved side because of a leg-length discrepancy of more than 2 cm.

Gait analysis

The patients walked two sessions on a 7-meter long straight walkway at their preferred walking speed wearing their ordinary shoes. During the first session, the patients walked without measuring or goniometric equipment to get used to walking in a laboratory setting. Each patient walked 7 meters 8 times, and only the preferred walking velocity was measured at this time. After 3 or 4 times, patients seemed to become accustomed to the setting and walked the following times at a constant velocity. During the second session, the patients walked with electrogoniometers placed on both hips, knees and ankles, that measured angular displacement in a sagittal plane (Figure 1). Footswitches on heel and toe made it possible to distinguish between stance and swing phase. Patients were instructed to walk at their preferred walking speed. In this second session, all patients walked 7 meters at least 8 times with the equipment. The correctness of the measurements was assessed immediately after each time. When the measurement was incorrect—e.g., due to failure of the equipment, the patient had to walk again. Therefore, some patients walked more than 8 times.

We measured angular displacement of the hip, knee and ankle of both legs. The calculated variables were duration of stance and swing phase, step length and walking velocity. All data were processed by The Walk software. International validated normal data for walking (Winter 1991) were available from the software.

Subjective evaluation

Overall function was scored in accordance with the system for subjective functional evaluation of the MSTS (Enneking et al. 1993). The patient's score for the various parameters was expressed as a percentage of the total possible score of 30 points. We

Table 2. Ambulation scores A1 and A2

	Score
Questions for comfortable ambulation score A1	
I am able to walk without rest	
less than 50m	1
between 50 and 500 m	2
between 500 and 2000 m	3
between 2 and 5km	4
more than 5km	5
I have to be careful not to fall while walking outside	
never	5
only while walking a long distance, or uneven ground and such	4
usually	3
always	2
I never walk outside	1
I am able to walk without rest	
less than 5 min	1
between 5 and 15 min	2
between 15 and 30 min	3
between 30 and 60 min	4
longer than 60 min	5
I use a stick or crutch or support myself on pieces of furniture or some other support while walking inside	
never	4
sometimes	3
usually	2
always	1
I use a stick or crutch or other support or I walk supported by somebody else while walking outside	
never	5
sometimes	4
usually	3
always	2
I never walk outside	1
Questions for fast ambulation score A1	
Fast walking	
without any difficulty	5
with some difficulty	4
with fairly great difficulty	3
with very great difficulty	2
is impossible	1
If I walk with a healthy person of about my own age, I am able to keep his/her speed	
without any difficulty	5
with some difficulty	4
with fairly great difficulty	3
with very great difficulty	2
is impossible	1
Questions for comfortable ambulation score A2 (0 means impossible, 7 means excellent)	
Walking is	0 1 2 3 4 5 6 7
Sauntering is	0 1 2 3 4 5 6 7
Walking on fresh-cut grass is	0 1 2 3 4 5 6 7
Question for fast ambulation score A2	
Fast walking is	0 1 2 3 4 5 6 7

Maximum score A1 for comfortable ambulation is 24.
Maximum score A1 for fast ambulation is 10.
Maximum score A2 for comfortable ambulation is 21.
Maximum score A2 for fast ambulation is 7.
Overall ambulation score is 62.

also used a modification of the Ambulation score developed by Boonstra et al. (1996) for subjective functional evaluation of transfemoral amputee patients (Table 2). The items in the original Ambulation score that specifically involved amputation patients were omitted. Ambulation scores A1 and A2 rated walking distance and ease of walking in different and more demanding circumstances, like fast walking, strolling and walking on rough ground. In each patient, the score was expressed as a percentage of the total possible score, which was 24 points for A1 comfortable ambulation, 10 points for A1 fast ambulation, 21 points for A2 comfortable ambulation, 7 points for A2 fast ambulation and 62 points for the overall ambulation score, obtained by adding all subscores A1 and A2.

Data analysis

The statistical analysis was done with SPSS for Windows, release 9.0.1. The Student's t-test for paired samples was used to compute differences between mean temporal variables of the involved leg, the uninvolved leg and normal values. The α-value was set at 0.05. Correlations between variables were assessed with Pearson and Spearman rho correlation tests. The Spearman rho correlation was used because the item "gait" of the MSTS score is an ordinal measurement.

Results

In the group of 18 patients, the mean free-paced walking velocity without equipment was 69 m/min, which is 88% of normal individuals' walking velocity. The mean free-paced walking velocity with equipment was 60 m/min.

The step length of the involved leg did not differ significantly from the normal value. The step length of the uninvolved leg was longer than that of the involved leg ($p < 0 .001$) and of the normal value ($p = 0.006$) (Table 3). The duration of the swing phase in the involved leg was longer ($p < 0.001$) than of the uninvolved leg and also of the normal value ($p < 0.001$). The duration of the stance phase of the involved leg was shorter than that of the uninvolved leg ($p < 0.001$) and also of the normal value ($p < 0.001$).

On goniometric examination, 10 patients showed

Table 3. Mean (SD) temporal parameters

	Involved leg	Uninvolved leg	Normal value
Step length (in meters)	0.628 (0.08)	0.678 (0.08) [a, b]	0.577 (0.16)
Duration of swing phase (in seconds)	0.461 (0.05) [a]	0.407 (0.03) [a]	0.399 (0.05)
Duration of stance phase (in seconds)	0.783 (0.11) [a]	0.838 (0.13) [a]	0.843 (0.12)

Temporal parameters of involved leg compared to uninvolved leg and comparison of temporal variables in patients to normal values, available from the software. Data concern all 18 patients. Normal values available from the software.
[a] Significant difference from involved leg ($p < 0.05$)
[b] Significant difference from normal value ($p < 0.05$)

a stiff knee gait pattern, that was defined as continuous hyperextension of the knee during loading response and mid-stance (Table 1). Because of this gait pattern, there is no shock absorption at the beginning of heel-strike (Figure 2). Shock absorption at the onset of the stance phase is visualized in the normal knee as a small increase in knee flexion (loading response). 6 patients showed a flexed knee gait pattern, that is characterized by continuous flexion during the mid-stance phase (Figure 3). A shift in the flexion-extension pattern of the hip towards more extension during the entire gait cycle was found in 9 patients (Figure 4). Normal gait patterns of the knee and hip were found in only 2 patients.

The overall MSTS score was 72%. The highest MSTS and Ambulation scores were seen in the group of patients with a distal femoral endoprosthesis (Table 4).

Correlation analysis showed that the overall MSTS score or one of the items on the MSTS score was not significantly correlated to one of the temporal variables measured during gait analysis. The mean walking velocities with or without

Figures 2–4 show examples of the patterns observed. Each figure concerns one patient, the different lines are the different steps the patient took during the gait analysis session. In each figure, the vertical hatched area denotes the normal flexion-extension range.The horizontal axis denotes % of gait cycle, heel strike is at 0% of gait cycle; beginning of stance phase.The software uses auto-scaling for the vertical axis, which is why the range in degrees of flexion and extension differs in Figures 2–4.

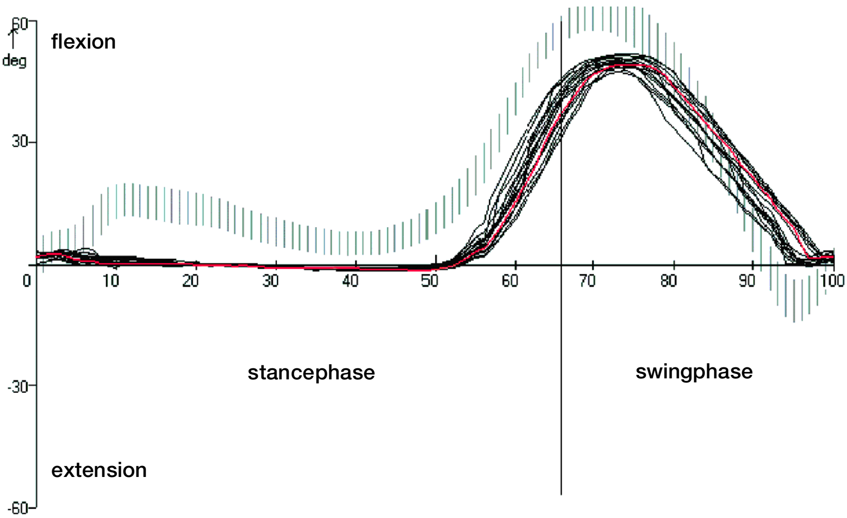

Figure 2. Stiff knee gait. There is no shock absorption at the beginning of heel-strike, the first moments in the stance phase. The knee is in hyperextension during stance phase (0 degrees flexion).

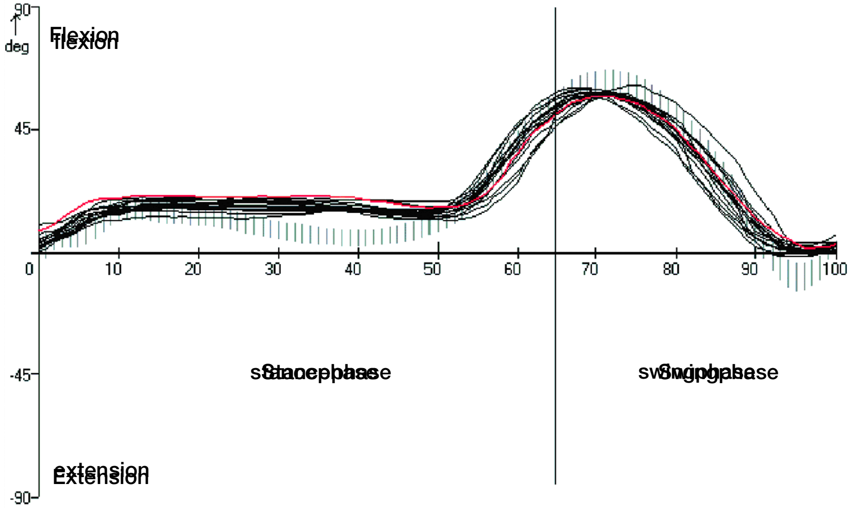

Figure 3. Flexed knee gait. About 15 degrees flexion in the knee during stance phase. Calibration of the goniometer is correct because 0 degrees flexion is measured at the end of the swing phase and very first moments of the stance phase.

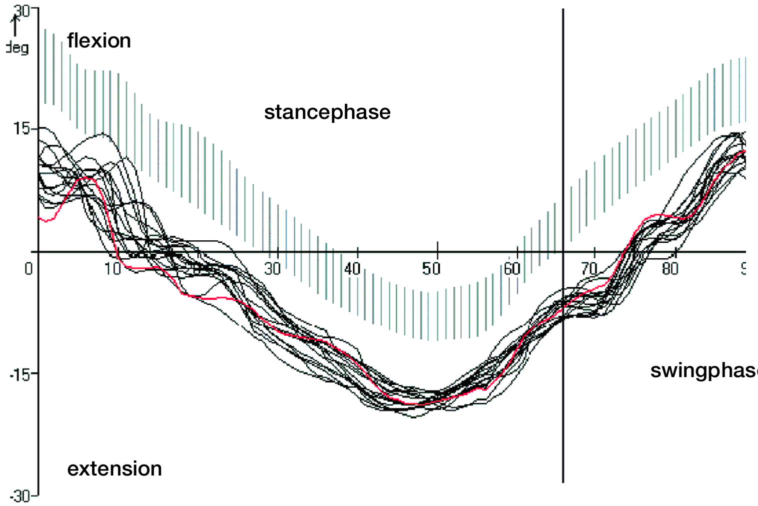

Figure 4. Shifted flexion-extension pattern of the hip. During the entire gait cycle, there is a shift towards more extension.

equipment were positively correlated to the item 'gait' of the MSTS score (with equipment: Spearman rho correlation = 0.58 p = 0.01; without equipment: Spearman rho correlation = 0.57 p = 0.02), but not to the overall MSTS score nor to one of the other items of the MSTS score. The mean walking velocities were not significantly correlated to the overall Ambulation score nor to the A1 or A2 score for fast ambulation. The overall MSTS score was positively correlated to the overall Ambulation score (Pearson = 0.79 $p < 0.001$) and to all subscores of the Ambulation score (A1 for comfortable ambulation: Pearson = 0.86 $p < 0.001$; A1 for fast ambulation: Pearson = 0.57 p = 0.01; A2 for comfortable ambulation: Pearson = 0.70 p = 0.001; A2 for fast ambulation: Pearson = 0.58 p = 0.01). We found no correlation between the Ambulation scores and the temporal variables measured.

Table 4. Mean (%) MSTS scores and mean Ambulation scores

	Overall	Distal prosthesis	Proximal prosthesis	Total prosthesis
MSTS score	72	76	61	68
A1, comfortable ambulation score	75	83	50	67
A1, fast ambulation score	59	66	40	53
A2, comfortable ambulation score	60	68	33	57
A2, fast ambulation score	27	37	0	14

Mean MSTS scores and mean Ambulation scores for the various types of prostheses as percentage of maximum score.

Discussion

Gait patterns are important parameters in the functional outcome of lower extremity reconstructions. These patterns have been studied by various authors (Otis et al. 1985, McClenhaghan et al. 1989, Harris et al. 1990, Tsuboyama et al. 1994, Catani et al. 1996, De Visser et al. 1998, Kawai et al. 1998, De Visser et al. 1999). In 1988, Simon noted that patients who had had a limb salvage procedure differed greatly in gait compensation, which made interpretation of gait analysis difficult. In our patients, gait compensation was quite uniform. We observed two abnormal patterns of knee flexion-extension during walking, a stiff knee gait and a flexed knee gait, and one abnormal pattern of hip flexion-extension, a shifted flexion-extension pattern. A stiff knee gait was also described by Catani et al. (1996) and De Visser et al. (1998) in patients with a distal femoral endoprosthesis. This phenomenon of a stiff knee gait has also been described after total knee arthroplasty in which patients did not use their quadriceps muscles during stance because of knee pain (Winter 199§). Patients with a femoral endoprosthesis after tumor resection probably walk with a stiff knee because of loss of quadriceps strength. It is not known whether these abnormal gait patterns reduce the longevity of the prosthesis. It is also not known whether the functional outcome, as defined by the MSTS score, would be better if patients developed more natural gait patterns during rehabilitation.

Knee extensors control the rate of knee flexion induced by ground reaction force during early stance and the early swing phase (McHugh 1993). Patients with loss of quadriceps strength avoid uncontrolled knee flexion by increasing hip extension to prevent the ground reaction force from passing behind the knee joint. 7 of our 10 patients who had a stiff knee gait also had a translated flexion-extension pattern in the hip joint.

The pattern of flexed knee gait is not entirely understood. The patients with this gait pattern underwent the same procedure and also had loss of quadriceps strength. A flexed knee during stance phase, however, requires quadriceps strength.

In our study, temporal variables also yielded relatively uniform results, all indicating that patients reduce time of load on the involved leg. Kawai et al. (1998) showed that the shorter support time of a single limb in patients with a distal femoral endoprosthesis correlated with the percentage of the femur that had been resected and the extent of the excision of the quadriceps muscle. However, Catani et al. (1996) found no significant correlations between type and length of resection and gait in 19 patients with a distal femoral endoprosthesis. In our study of 18 patients, no gait variable was significantly correlated to the percentage of femur that had been resected. However, with a larger number of patients such a correlation may exist. Tsubuyama et al. (1994) also found relatively uniform results after gait analysis in 20 patients with a distal femoral endoprosthesis after tumor resection, and concluded that patients were, consciously or not, cautious about using their operated leg. De Visser et al. (1998) suggested that a stiff knee gait could reduce the survival of the prosthesis and patients were encouraged to develop a more natural gait pattern during functional gait exercises.

We used the latest MSTS score for the subjective functional evaluation which was valued for its simplicity, emphasis on more global aspects of limb and patient function and its reproducibility and reliability, irrespective of the expertise of the observer (Enneking et al. 1993). In this latest paper, the mean functional score of 133 patients with a lower extremity reconstruction was 73%, and the mean range 3%. More recently, Rougraff et al. (1994) found an average score of 77% in a group of 73 patients who had had a limb salvage procedure. We found a mean overall score of 72%.

Correlation analysis showed that the MSTS score was significantly correlated to the overall Ambulation score and to all sub-scores, indicating that this score could also be used effectively for the functional evaluation of limb salvage patients. The Ambulation score, originally developed for patients who had had an amputation, was modified for patients with an endoprosthetic reconstruction in the lower extremity. In our opinion, it can give additional information about the functional limitations experienced by the patients.

Walking velocity proved to be the only objective parameter which was positively correlated to the item 'gait' of the MSTS score. All other objective parameters showed no correlation to the overall subjective scores or one item of the subjective scores.

We conclude that endoprosthetic reconstructions of the femur after resection of bone tumors yielded good functional results. However, during rehabilitation, patients often develop an asymmetrical gait pattern and have abnormal flexion-extension patterns in the hip and knee on the affected side. Follow-up studies, in which gait analysis is performed periodically, are necessary to evaluate the possible adverse effects of these abnormal gait patterns on the longevity of the reconstruction.

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Boonstra A M, Schrama J M, Eisma W H, Hof A L, Fidler V. Gait analysis of transfemoral amputee patients using prostheses with two different knee joints. Arch Phys Med Rehabil 1996; 77: 515-20.

Catani F, Benedetti M, Donati D, Campanacci D A, Simoncini L, Villani S, Giannini S. Gait in patients with distal femoral prosthesis after bone sarcoma resection. Presented at the 10th conference of the ESB, 1996.

De Visser E, Pauwels J, Duysens J E, Mulder T, Veth R P. 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.

De Visser E, De Witte J, Duysens J E, Mulder T, Veth R P. Gait rehabilitation by functional gait exercise in patients with a distal femoral knee prosthesis. Presented at the Tenth Symposium of the International Society of Limb Salvage, Cairns, Australia, 1999.

Enneking W F, Dunham W, Gebhardt M C, Malawer M, Pritchard D J. A system for the functional evaluation of reconstructive procedures after surgical treatment of tumors of the musculoskeletal system. Clin Orthop 1993; 286: 241-6.

Ham S J, Schraffordt Koops H, Veth R P H, Van Horn J R, Molenaar W M, Hoekstra H J. Limb salvage surgery for primary bone sarcoma of the lower extremities: Long-term consequences of endoprosthetic reconstructions. Ann Surg Oncol 1998; 5: 423-36.

Harris I E, Leff A R, Gitelis S, Simon M A. Function after amputation, arthrodesis, or arthroplasty for tumors about the knee. J Bone Joint Surg (Am) 1990; 72: 1477-85.

Kawai A, Backus S I, Otis J C, Healey J H. 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.

McClenhaghan B A, Krajbich J I, Pirone A M, Koheil R, Longmuir P. Comparative assessment of gait after limb-salvage procedures. J Bone Joint Surg (Am) 1989; 71: 1178-82.

McHugh B. A description of gait. In: Biomechanical basis of orthotic management. First edition. Butterworth Heinemann. Oxford 1993: 38-57.

Otis J C, Lane J M, Kroll M A. 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.

Rougraff B T, Simon M A, Kneisl J S, Greenberg D B, Mankin H J. 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.

Simon M A. Current concepts review. Limb salvage for osteosarcoma. J Bone Joint Surg (Am) 1988; 70: 307-10.

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.

Veth R P H, Van Hoesel Q G C M, Bokkerink J P M, Hoogenhout J, Pruszczynski M. The art of limb salvage in musculoskeletal oncology. Critical Reviews in Oncology/Haematology 1995; 21: 77-103.

Winter D A. Assessment of pathological gait. In: The Biomechanics and Motor Control of Human Gait: Normal, Elderly and Pathological (Ed. Winter D A). Second edition. University of Waterloo Press. Ontario 1991: 95-113.

Equipment

Electrogoniometers: Low-friction potentiometers (10KΩ; linearity, 0.2%) with their mechanical axes perpendicular to the sagittal plane. Electrogoniometers, type P4101, Novotechnik KG. Otterdinger GmbH & Co, 7302 Ostfilderni, Germany.

The Walk software: Developed at the Gait Laboratory, Department of Rehabilitation, University Hospital Groningen, The Netherlands.