Background: The aim of the present study was to objectively assess the physical activity levels of patients after tumor prosthesis implantation with two objective measurement devices.

Methods: The DynaPort ADL monitor permitted up to 24 hr monitoring of lower-extremity physical activities in daily life with respect to posture and locomotion. The step activity monitor (SAM) was worn for a whole week to collect the daily number of gait cycles. The devices were worn during the waking hours by 22 patients with knee prostheses after wide tumor resection.

Results: In the MSTS and TESS scores the patients achieved over 80% of the maximum score indicating a good clinical outcome. The most prominent activity was sitting which accounted for 54 ± 18% of the recorded time, followed by standing (27 ± 16%), locomotion (10 ± 6%), and lying (8 ± 6%). During locomotion, the average walking activity accumulated to 4,786 ± 1,770 step cycles per day (range 2,045–8,135) corresponding to a yearly 1.75 million steps. There was no significant correlation between clinical scores and step count measures.

Conclusions: Even though this activity level was lower than for a group of healthy adults it was comparable to the activity level for other patients, for example, with hip arthroplasty as reported in the literature.

Key Words: physical activity assessment; ambulatory monitoring; quality of life; limb salvage; bone tumors

INTRODUCTION

Limb salvage surgery is considered as the treatment of choice for malignant bone tumors if no oncologic considerations exclude this option. In combination with adjuvant chemotherapy limb salvage treatment has been shown to lead to successful functional restoration. It has been reported that current treatment achieves long-term, disease-free survival rates around 60% [1,2]. Tumors that affect the distal femur or the proximal tibia require a resection of the knee joint. In limb-salvage surgery, the defect may be reconstructed with endoprostheses. Current developments led to different concepts of modular prostheses that can be adapted to the level of resection.

The clinical outcome has been amply described in previous reports with the potential limitation that it was based on subjective or semi-objective questionnaires. Functional outcome has only rarely been evaluated, for example, with laboratory based computer assisted gait analyses [3]. These investigations have helped to shed a light on the functional capabilities of a patient under optimal walking conditions. While this approach indicates at which functional level a patient should be able to perform, it does not describe how this translates into patients’ physical activity levels in daily life. However, since younger adults are mostly affected, the physical activity level is of great importance for the overall well-being and subjective satisfaction of the patients.

Previous research has shown that physically demanding jobs cannot be carried out after limb salvage surgery so 25% of the patients do not return to their previous jobs after treatment [2]. Only little is known about the patients’ physical activity levels which may remain limited after treatment. Up to now, quality of life after implantation of tumor prostheses has been generally assessed with questionnaires which do not necessarily provide objective and quantitative information about the physical activity level that the patients are able to achieve in daily life [4]. New technologies nowadays allow obtaining objective information about daily activity profiles of patients under real life conditions [5,6]. These devices are based on accelerometers and/or gyroscopes and can been worn for extended periods of time. A comprehensive description of this patient population with established clinical scores as well as novel objective physical activity assessments would help to better understand the functional capabilities after this type of treatment. Therefore, the aim of the present study was to objectively assess the physical activity levels of patients after tumor prosthesis implantation with portable measurement devices that permitted 24 hr monitoring of lower-extremity activities of daily living with respect to posture and locomotion. Additionally, a step activity monitor (SAM) was worn for a whole week. These objective results were compared with standard clinical scores. This information will be helpful to determine the level of re-integration of patients and should furthermore be beneficial for manufacturers of tumor prostheses in order to better estimate and evaluate the durability of their products, for example in biomechanical wear tests.

METHODS

Twenty-two patients (14 male, 8 female) who had been treated between 1987 and 2003 in the Orthopaedic Department of the University Hospital Münster for malignant bone tumors in the distal femur or proximal tibia with tumor prosthesis for the knee joint

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volunteered to participate and provided informed consent (Table I). The procedures were approved by the local ethics committee (Arztekommision Westfalen-Lippe AZ 1XI RödL1). The mean age of the patients was 35 ± 18 years (range 16–76 years) with a mean follow-up of 7.8 ± 7.9 years (range 2–39 years). An average body mass index of 24.0 ± 3.4 kg/m² (range 19–31 kg/m²) indicated a fairly normal body weight in the patient group. The tumor was located in the distal femur (n = 18) or proximal tibia (n = 4). In 9 patients the left, in 13 patients the right leg was affected. There were 14 patients with an osteosarcoma, four patients with chondrosarcoma, three patients Ewing’s sarcoma, and one patient with a malignant fibrous histiocytoma. After intraarticular resection of the tumor the majority of the patients were reconstructed with a MUTARS prosthesis (n = 20), two received a Kotz prosthesis. The modular MUTARS prosthesis consists of titanium and is implanted with a non-cemented HA-coated stem in the majority of cases. It is a rotating hinge prosthesis, which allows a rotation of 5°. In contrast, the Kotz prosthesis is a fixed hinge prosthesis. All patients underwent chemotherapy and aftercare according to prescribed regimens for their respective tumor entity. Since the main interest was focused on the activity assessment of a diverse group of subjects with tumor prosthesis we did not inquire about the complications experienced by the patients so that we cannot provide this information.

Clinical outcome was assessed with the MSTs score of the Musculoskeletal Tumor Society [7] and the TESS score (Toronto Extremity Salvage Score [8]). The daily life activities of the subjects were assessed during a week that reflected the subject’s normal life and job conditions and excluded special conditions such as holidays.

Two measurement systems were applied based on the experience and following the recommendations of a previous project [9]: The first device was the DynaPort®: ADL monitor (McRoberts, Den Haag, The Netherlands). This device uses three uniaxial accelerometric sensors; two orthogonally mounted sensors are worn around the waist in a belt. The third sensor is worn in a strap around the left thigh. The device measures precisely the time spent in different activity categories such as locomotion (walking, bicycling), standing, sitting and lying as well as movement intensity [10]. Technical specifications can be found elsewhere [9].

The second system is the SAM®: Step Activity Monitor (Cyma Inc., Seattle, OR), a light-weight accelerometer that counts step activities in daily profiles and is able to store data of several weeks in 1-min intervals. Thus, the SAM offers also an analysis of gait data in terms of intensity if the minutes spent in a defined interval of step cycles per minute are considered. Furthermore, intensity can be expressed in terms of absolute time (in minutes) and relative time (in percent) spent in each intensity interval. This system was adapted to the individuals’ gait dynamics. With this procedure it has been shown to be more reliable than simple pedometers [11] and to detect the number of steps with an accuracy of 99% across a wide range of gait styles [12]. The values of the step-activity-monitoring were compared to 26 healthy subjects of similar age (34 ± 8.4 years) that were free of musculoskeletal disorders or other mobility-limiting health conditions. Because only the SAM was used in the control group, the DynaPort data was compared with literature-reported values [10].

Patients who were living farther away were personally instructed how to handle and wear the devices before taking them home. Patients from the vicinity of the institution were visited at home and received instructions in order to ensure appropriate use of the instrumentation. These efforts minimized the patient-reported technical problems. In two subjects data from the ADL monitor was missing or incomplete so that twenty complete data sets were available for comparative analysis. On the first measurement day, both devices were worn simultaneously for a whole day from getting up until going to bed (excluding the time needed for hygiene). For the following 6 days, the SAM was worn alone in order to evaluate a reliable step activity profile of a whole week.

Data was read out from the storage media and analyzed for each patient with regard to the time spent in the different activity modes, movement intensity and the physical activity index for 1 day (DynaPort) as well as the number of step cycles for each of the 7 days (SAM). Correlations between clinical and functional parameters were determined with commercially available software using Spearman’s rank correlation coefficients (StatView 5.0, SAS Institute Inc., Cary, NC).

RESULTS

The patients of the present study achieved good clinical results with an overall MSTs score of 24.7 ± 3.8 out of 30 points (range 12–30) and an average TESS score of 83.6 ± 15.3% (range 36–100%). The subjects had worn the DynaPort ADL monitor for an average duration of 13.0 ± 2.7 hr during the waking hours of a normal day. Four measurements with the DynaPort had been temporarily interrupted by the subjects for about 30 min for taking a shower or changing clothes. The duration of data collection was negatively correlated with subjects’ BMI (r = −0.6, P < 0.01). The physical activity level did not correlate with the duration of follow-up. An average physical activity index of 1.4 ± 0.2 indicated that overall the subjects had been slightly more active than sitting which would compare to an index of 1 (lying = 0, standing = 2, walking = 2). Nevertheless, the predominant daily activity was sitting which accounted for 54 ± 18% of the recorded time, followed by standing (27 ± 16%), locomotion (10 ± 6%), and lying (8 ± 6%). Only 0.2 ± 0.1% of the activities could not be identified by the algorithms for activity detection (see also Fig. 1). The average movement intensity during walking was 2.4 ± 0.4 m/s² and did not correlate with the subjects’ age, weight or BMI. Upon questioning, three subjects classified the assessed day as not normal, that is, one subject reported less periods of lying, less periods of sitting, more periods of standing, respectively.

The average number of step cycles per day (detected by the SAM) was 4,786 ± 1,770 cycles per day and revealed a highly significant difference as compared to the healthy controls (6,517 ± 1,489 cycles per day, P = 0.01). The number of step cycles did not correlate with subjects’ age but revealed marked inter-
individual differences (range 2,045–8,135, Fig. 2). The control subjects spent more minutes in all absolute intensity categories (Fig. 3) but performed more activities at higher intensities (Fig. 4). For the days without DynaPort measurements, the average percentage of locomotion was estimated based on the step cycles counted [9].

On weekend days, patients achieved only 95% of the weekday steps. Five subjects revealed a similar percentage of locomotion (within 10%), seven subjects were more active (increase of about 31%) and three subjects were less active (decrease of about 69%) as compared to percentage of locomotion assessed by the DynaPort.

The statistical analysis showed only a low correlation between SAM and the MSTS score (0.3; \( P = 0.2 \)) and close-to-zero correlation coefficients for locomotion versus TESS or MSTS score as well as SAM versus TESS score (Table II). Correlation analyses with gait parameters that had been obtained with three-dimensional gait analysis in a sub-group of the patients did not result in significant and clinically relevant relationship between gait performance as evaluated in the lab and mobility as assessed with ADL monitoring.

We analyzed the two groups with different tumor location (distal femur vs. proximal femur) and compared them but did not see statistically significant differences. However, the power of the study may not be adequate to make a definitive statement that no differences exist, particularly considering there were only four subjects in the proximal tibial group.

**DISCUSSION**

The clinical results indicated that the patients achieved good functional recovery with 81% of the maximum MSTS score that was higher than the mean rating of 73% initially described for lower extremity reconstructions [7].

The number of 4,786 step cycles can be extrapolated to an average number of 1.75 million step cycles per year. This was in a similar order of magnitude as the 1.9 million cycles per year reported for patients with well-functioning total hip arthroplasty that had also been assessed with the SAM [11] but revealed a lower activity level as for healthy subjects (about 6,500 step cycles per day or 2.37 million per year) (Fig. 5). Comparable data for total knee arthroplasty patients was not found in the literature so that a comparison with “normal TKA patients” is not feasible. However, the present results appear superior to those reported for patients with bone and soft-tissue tumor with a variety of treatments who revealed only 3,560 cycles per day and had a lower MSTS score of 20.4 points [13]. The relative distribution of activities determined with the DynaPort monitor was comparable to the day-time results of chronic low back pain patients [14] and revealed a higher activity level than for patients after limb salvage or amputation.
that patients may exceed the number of gait cycles frequently cited in the literature. Therefore, the higher number of gait cycles should be taken into account in the design and pre-clinical wear testing of tumor prostheses.

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