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ORIGINAL STUDY

Gait analysis in tumor patients after distal femoral resection and implantation of a megaprosthesis

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We analysed nine patients who had had a megaprosthesis implanted into the distal femur and knee joint for treatment of sarcomas. Data obtained from the leg operated on were compared with those from the contralateral side and healthy volunteers.
Gait data, kinematics, ground reaction forces and the EMG from five muscles around the knee joint were analysed by means of a video-based analysis system recording data from reflection markers ; a Kistler-plate recorded the GRF and a ten channel surface EMG the muscle activity.
Muscle around the knee showed a cocontraction between the extensor and flexor muscles in the thigh and the calf in the operated leg as well as contralaterally.
Gait characteristics exhibited a reduced speed, cadence, and a shorter step. This correlated with a reduced flexion in the hip and knee joint.
The GRF exhibited significant changes in the data representing the reduced gait dynamic.

Keywords : sarcoma of bone ; gait analysis ; distal femur ; megaprosthesis.

INTRODUCTION

The distal femur is the region where primary malignant bone tumors most frequently occur (*3,4,8 13,15,16*). Implantation of a megaprosthesis after a "wide resection" of the tumor is the standard procedure (*3,4,8,13,15,16*). Depending on the extension of the tumor and location of the biopsy, either an antero-medial or an antero-lateral incision will be necessary. Thus, important proprioceptive structures have to be sacrified (*2,6,7,15,22,24*).

Besides the oncological necessity of a wide resection, preservation of the knee function is a major goal in limb-sparing surgery.

Computer-aided gait analysis is an important tool in orthopaedic diagnosis and treatment, particularly in limb-saving tumor surgery (*6*). The aim of this study was to ascertain to what extent the implantation of a megaprosthesis into the distal femur changes the pattern of gait.

MATERIAL & METHODS

Gait analysis was performed in patients in whom a distal femoral resection and implantation of a cementless megaprosthesis (KMFTR, Howmedica, Kiel, Germany) had been performed after resection of a primary malignant

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bone tumor located there with a minimum postope-rative time interval of one year. Data from the operated leg were compared with data obtained from the contralateral healthy leg and from healthy volunteers matched in sex and age.

The VICOM-system (3-D-Gait-analysis-System Vicom-System, Oxford Metrics, Oxford, UK) was used for analysis.

Three-dimensional ground reaction forces (GRF) were recorded using a Kistler-plate (Kistler Instruments Ltd., Hook, Hampshire, UK) which was integrated into a plain walking area stage measuring about 25 m. In order to analyse muscular activity, a simultaneous EMG (Motion Lab. Systems Baton Rouge, LA, USA) with ten channels was used to bilaterally record activities of five muscles : the quadriceps femoris (QF), tensor fascia lata (TFL) and the biceps femoris muscle (BF) in the thigh and the tibialis anterior muscle (TA) and triceps surae muscle (TS) in the lower leg.

Data were analysed by means of the Vicom-computer-programm which meant that kinetic, kinematic and electromyographical data and ground reaction forces (GRF) could be recorded simultaneously.

Before measurements, the patients and control persons were allowed a 20-minute preparation period to adapt to the examination. For the trials each patient or control person walked at his/her own pace. At least seven measurements were recorded for each patient.

Statistical analysis

For each single variable, the univariable ANOVA-test and the Scheffé-test were used.

RESULTS

Nine patients and five volunteers were analysed. Clinically, the mean Enneking-score for the patients was 21 (11-25) pts.

Kinetic data

Kinetic data revealed that the gait shows significant changes following implantation of a megaprosthesis : the gait velocity of the leg operated on and the contralateral side was, significantly, greatly reduced as was the double-step length and stance-phase vs. swing-phase-ratio. In addition, the cadence was significantly reduced and the duration of the double support was significantly longer (Table I).

Ground reaction forces (GRF)

In all three dimensions the GRF exhibited that tumor patients had a more cautious tread. They walked with reduced GRF particularly at heel-strike and toe-off. This was most evident in the vertical direction and less in the anterior-posterior direction distinctly less in the medial-lateral direction (Fig. 1a-c) ; even the velocity of increase in the vertical GFR was significantly reduced (Fig. 1c).

In comparison to the contralateral legs (conlegs) and the controls, the GRF in the operated legs (oplegs) were lowest ; in the contralateral leg they were between that of the operated legs and the

Table I. – Gait-characteristics

	Operated side	Contralateral side	Controls
Gait velocity (cm/sec)	81.15# (range, 50.9-107.0)	90.04# (range, 59.4-118.7)	121.23 (range, 114.6-146.9)
Double-step time (sec)	1.35+ (range, 1.32-1.39)	1.30 (range, 1.27-1.33)	1.21 (range, 1.17-1.25)
Double-step lenghth (cm)	107.78# (SD 18.9)	115.35# (SD 16.1)	147.10 (SD 34.4)
Cadence (steps/minute)	93.40+ (SD 18.3)	103.29 (SD 8.2)	104.96 (SD 26.2)
Stance-phase ration Stance-phase : swing-phase	0.46# (SD 1.7)	0.57# (SD 1.6)	0.56 (SD 0.4)

= $p < 0.001$; + = $p < 0.05$.

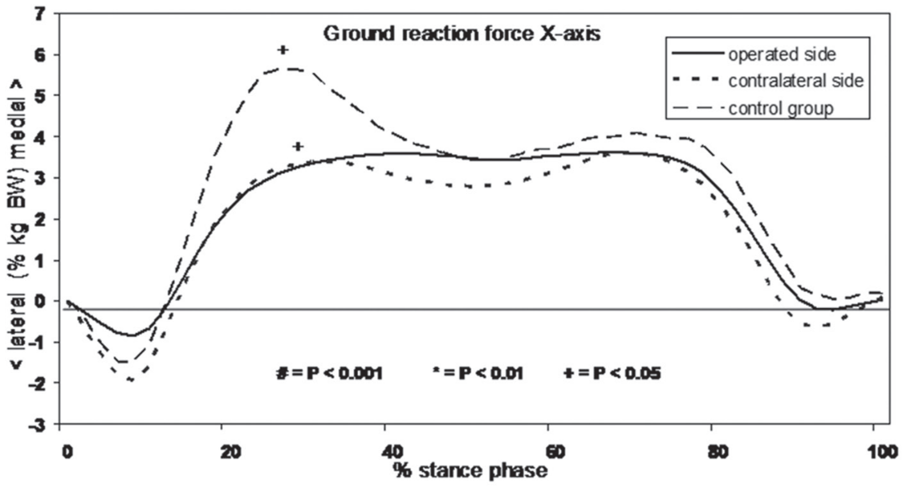

Fig. 1a. — Ground reaction forces in the lateral-medial direction

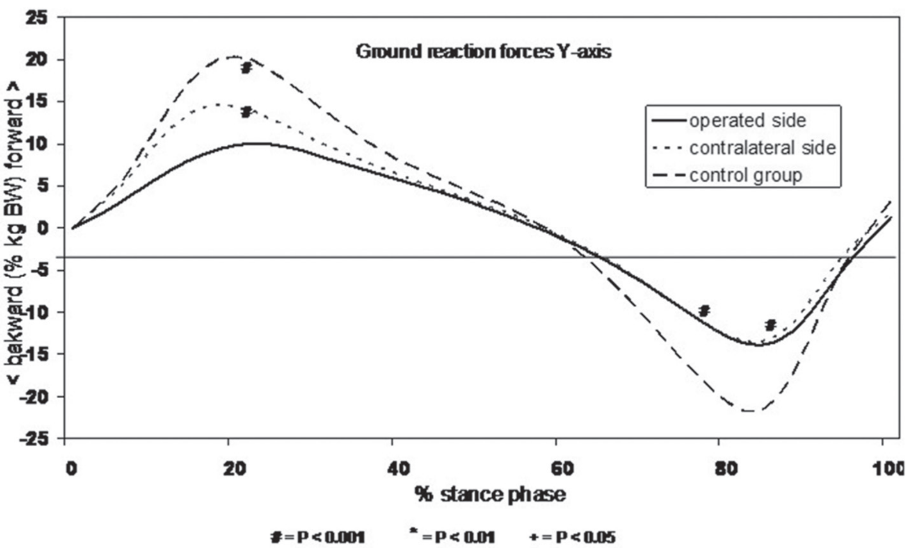

Fig. 1b. — Ground reaction forces in the forward-backward direction

controls (Fig. 1a-c). During heel-strike and toe-off, the GRF in the oplegs were significantly reduced. In the mid-stance phase, the GRF in the vertical direction were significantly higher in the oplegs than in the conlegs and in the controls.

Although the conlegs also showed some differences when compared to controls, the curves of the conlegs showed a greater similarity to those from the controls than to the oplegs. Regarding the lateral-medial direction (Fig. 1), only minor changes were detectable.

Kinematic data

These data were analysed in two different patterns :

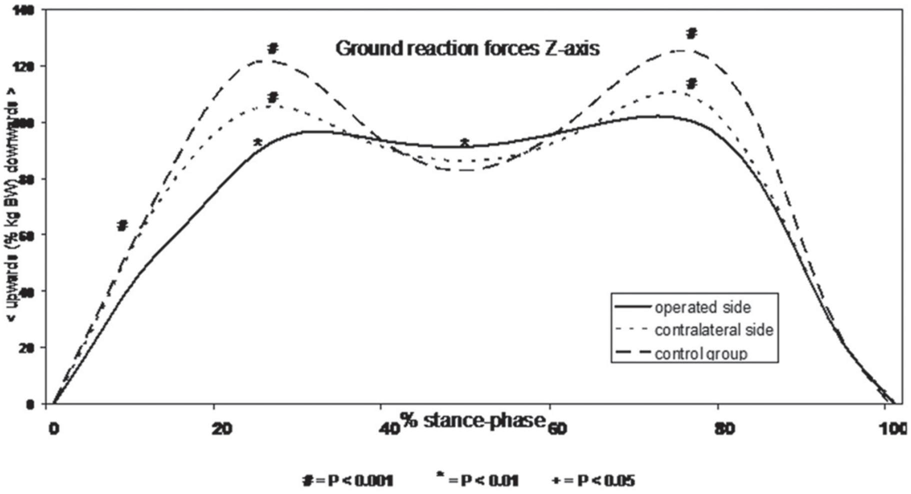

Fig. 1c. — Ground reaction forces in the vertical direction

The ROM in the hip flexion-extension and ab-adduction as well as in knee flexion-extension, and in the ankle for dorsal flexion-plantar extension and supination-pronation was significantly reduced (Fig. 2 a, b).

ROM-analysis alone gives only a rough idea of the difference between the maximum and minimum values and, for this reason, we also analysed the kinematic curves over the gait cycle :

Kinematic curves

Hip joint

The curves indicated a reduced hip flexion at the beginning of the STP and over almost the whole SWP in the oplegs and in the conlegs, in comparison to the controls (Fig. 3a). For the femur ab-adduction, the curves of the oplegs showed a reduced adduction in the middle and at the end of the STP whereas, during the SWP, the oplegs and the conlegs exhibited a distinctly reduced abduction over nearly the whole SWP in comparison to the controls (Fig. 3b).

Knee joint

The reduction of the ROM in knee flexion (Fig. 2b) was due to the knee of the oplegs being steadily flexed during almost the whole STP while, in the middle and at the end of the STP, the contralateral leg and the volunteers exhibited a more extended knee joint. During SWP the oplegs and the conlegs exhibited a higher degree of flexion than volunteers at the end of the SWP towards the heel-strike situation (Fig. 4).

Ankle joint

At the beginning of the STP, the ankle joint of the oplegs exhibited a distinctly greater plantar flexion than the conlegs and of the controls. For almost the rest of the STP, no differences could be seen (Fig. 5). During the whole SWP, the oplegs and the conlegs showed a distinctly reduced dorsal extension. The controls exhibited a greater dorsal extension with only a slight degree of plantar flexion at the beginning of the SWP.

Regarding the supination-pronation movement oplegs showed over nearly the whole gait cycle a distinctly reduced pronation (no graph shown) in comparison to the conlegs and to the controls resulting in a significantly reduced ROM (Fig. 2b).

EMG-data

EMG-data are analysed in the on-off mode, e.g. showing muscle activity over time with minimum myo-electrical activity over 50% of the maximal

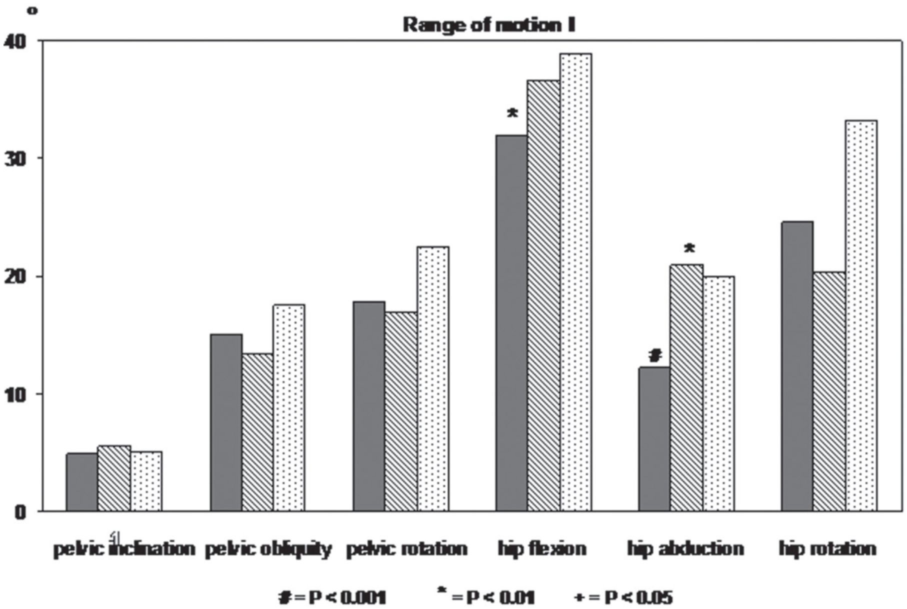

Fig. 2a. — Range of motion in the hip joint and pelvis

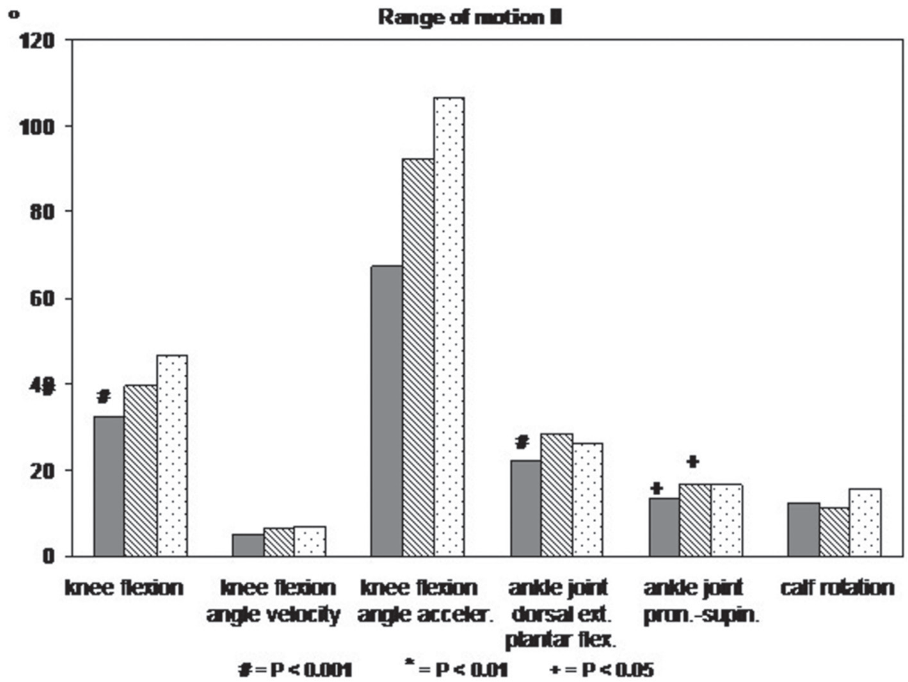

Fig. 2b. — Range of motion in the knee joint and ankle joint

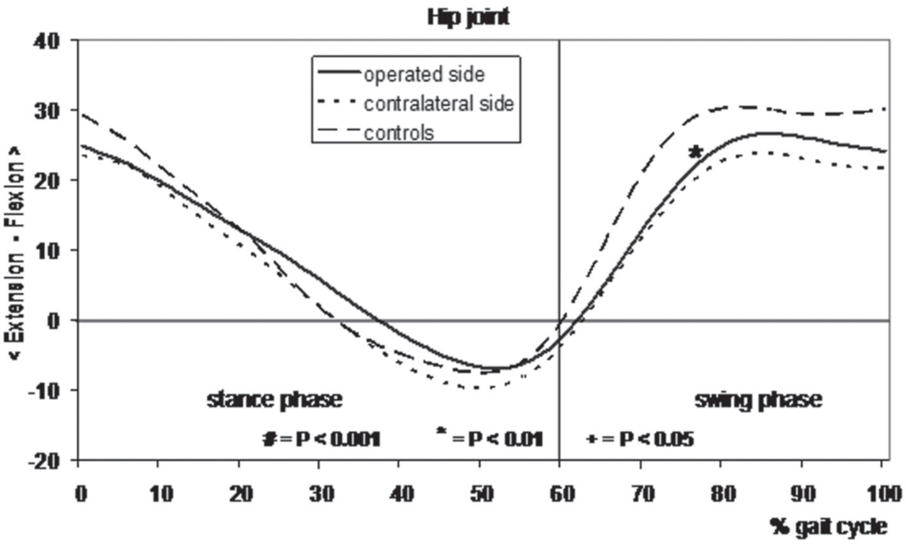

Fig. 3a. — Kinematic data of hip flexion-extension

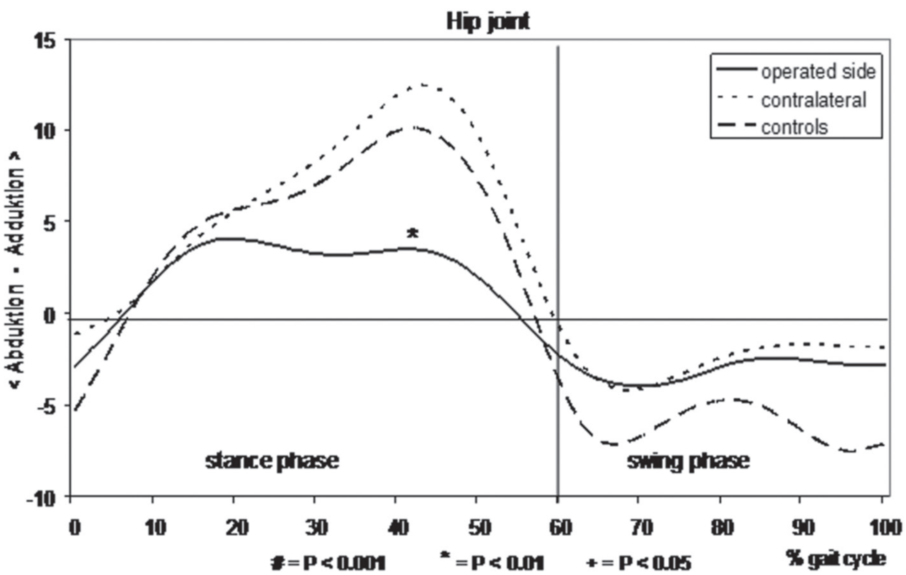

Fig. 3b. — Kinematic data of hip adduction-abduction

activity, since this is more reliable than the direct EMG-data type.

Thigh

During STP all patients exhibited more muscle activity in all of the detected thigh muscles in the operated leg than the controls. The amount of myoelectrical activity of the contralateral side was mostly between those amounts measured for the operated legs and the controls.

Lower leg

Both analysed muscles (AT and TS) exhibited distinctly altered activity : that of the AT in the

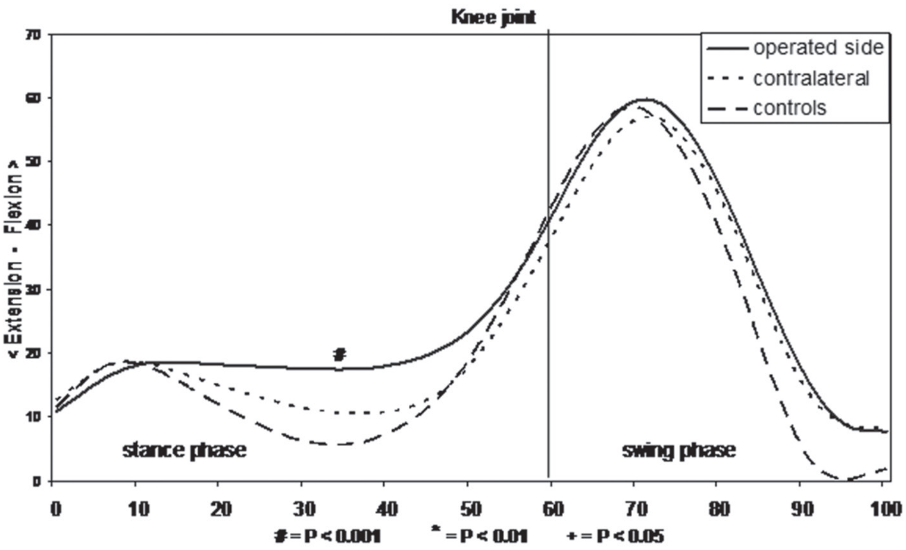

Fig. 4. — Kinematic data of knee flexion-extension

oplegs was clearly increased during the first half of the STP but was less in the conlegs and minimal in the controls. During SWP, the AT was activated in all groups whereas, in the oplegs and in the conlegs activity was detectable at the beginning and end of the SWP. Controls exhibited AT activity during the whole SWP.

In the TS, differences between the oplegs and the conlegs, as well as the controls, were less obvious. This muscle exhibited activity in the oplegs, and in the conlegs, during almost the whole STP. In the controls, TS activity was recorded only during the second half of the STP. During the SWP, no significant activity could be detected in any of the three groups (Fig. A).

DISCUSSION

After a wide tumor resection regain of function is the second most important goal in limb-saving surgery (*2*). Modern techniques for analysing gait allow simultaneous recording of kinematic, kinetic and electromyographical data (*1,5,9,10,14,18*).

For years, it has been well-known that even implantation of a standard joint replacement in an osteoarthritic joint may significantly change the gait pattern (*1,14,25*). This is thought to be an effect of the damage to proprioceptive structures. However, with the special rehabilitation programmes, the gait pattern usually improves with time (*1,7,14,20,21*).

In tumor cases the damage to the proprioceptive structures can be even more extensive (*2,6,19*).

Previous analyses in patients having received a megaprosthesis are not consistent. This is due to the use of different analysis systems and/or analysis of different criteria or to the analysis of different groups of patients within one report, e.g. patients requiring resection of the proximal or distal femoral tumor or where resection of the proximal tibia and distal femur resection was necessary (*2,6,11,12,23,26*).

Our analysis of a clearly-defined group of patients is one of the first of its kind to simultaneously record kinematic, kinetic and EMG-data. Similar to other gait analyses in patients following implantation of a megaprosthesis, we also found significant changes in the gait characteristics, with reduced gait speed, shortened stride length and shortened stance-phase all of which resulted in a lower cadence, at least on the operated side (*1,2,6,11,12,17,18,19, 26*).

Kinematic data exhibited different results depending on the mode of detection, either as ROM or as kinematic curves of the gait cycle. Comparing individual data of the Enneking-score with those

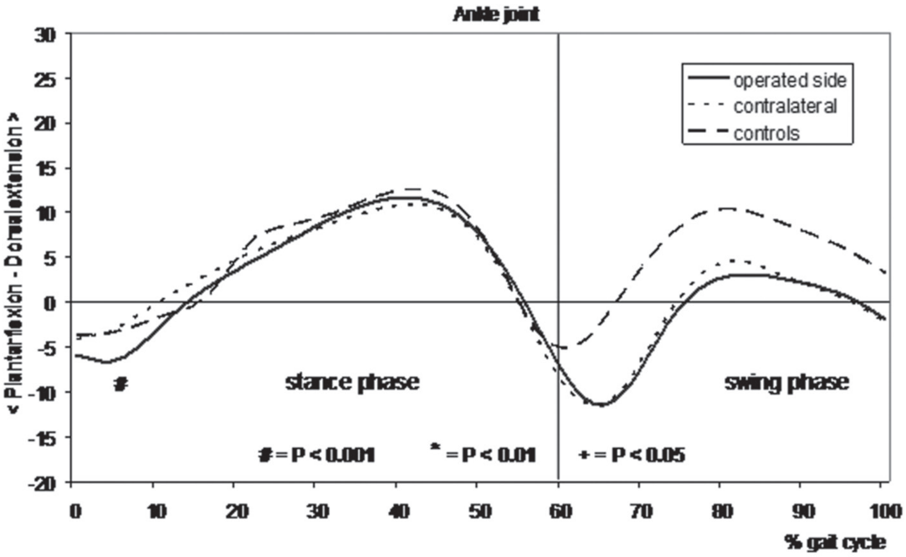

Fig. 5. — Kinematic data of ankle dorsal-extension-plantar-flexion

obtained from the in dividual gait analysis no significant correlation could be detected probably due to the low number of patients. There was only a tendency towards worse data of the gait analysis when the individual Enneking-score was low.

Regarding the ROM, in general we found a significantly reduced flexion-extension and ad-abduction in the hip as well as a significantly reduced flexion-extension in the knee joint and reduced upon plantar flexion-dorsal extension and supination-pronation in the ankle joint.

Kinematic curves indicated the specific reason for the reduction : in the hip joint, the reduced ROM in flexion-extension was due to the reduced flexion at the beginning of the stance-phase, both for the operated legs and the contralateral side. Regarding the ab-adduction movement, the decreased ROM was caused by the distinctly reduced adduction.

In the knee joint we observed a diminished degree of flexion in the first half of the STP which increased during the beginning of the second half, resulting in a significantly reduced ROM of the operated legs.

In the ankle joint the reduced ROM in the operated legs was due to an increased plantar flexion at the beginning of the STP and a reduced dorsal extension during SWP, while the contralateral legs and controls were in a neutral position when the STP was initiated. The difference between the operated legs and the contralateral side, in comparison to the controls, was even more obvious during the SWP : in this phase the controls exhibited a slight plantar flexion only during the very first SWP while, later on, a distinct dorsal extension could be observed. In contrast, the operated leg and the contralateral legs remained in plantar flexion for a longer period of the SWP, later on exhibiting a dorsal extension which was less than that of the controls.

The GRF data revealed a significantly reduced dynamic during STP, particularly at heel-strike and toe-off. Furthermore, the velocity of increase of the vertical GRF was distinctly reduced in the operated leg as well as in the contralateral legs. This reduced dynamic was also visible in the horizontal GRF in the backward and forward direction at heel-strike and toe-off.

EMG-data revealed noticeably altered muscle activity in the the thigh and lower leg with an uncoordinated activity in both. This resulted in an uneconomical use of these muscles.

As surface EMG data obtained during gait analysis is usually not very reliable owing to technical problems such as movement of the etctrodes during walk and the transcutaneous detection and also to rather poor discrimination between single muscles, the interpretation of these data has been limited (*1*).

However, we also found a distinct cocontraction : this means that there are no coordinated changes between muscle-groups such as the knee extensors and the hamstrings, in particular during STP. Similar changes could be detected in the TA and TS in the lower leg, these muscles also exhibiting an uncoordinated and uneconomic activity in comparison to the controls.

In some of the particular analyses the standard deviation was relatively high. This can be explained also with the relatively small number of patients and the relatively high interindividual differences.

In summary, the implantation of a megaprosthesis into the distal femur significantly alters gait. This is apparent from the reduced ROM and altered kinematic curves in combination with an uneconomical innervation of the controlled muscles. This pattern of gait, known as "stiff legged" pattern, has already been described by after implantation of a "normal" TKR for the treatment of osteoarthrosis of the knee (*1*).

We also observed these characteristics. The "stiff legged" pattern includes a distinctly reduced walking speed, shortened steps and a reduced cadence as well as a slight flexion of the knee at heel-strike ; a limited flexion of the knee during loading response. An inadequate extension during toe-off is also noticeable. Parallel to that, Benedetti *et al* (*1*) noted a limited flexion of the hip and an abnormal flexion at heel strike and a limited flexion during STP in a single case study after implantation of a TKR and stated that this gait pattern could be related to a "quadriceps avoiding pattern" at the knee joint and expected reduced activity of the RF in the EMG. Surprisingly, they found not a reduced but a distinctly elevated activity of the RF (as a part of the QF) with abnormal cocontraction of the RF and hamstrings, at least during STP. We also recorded these characteristics.

De Visser *et al* (*6*) described an analysis of gait from 19 patients who had had a megapro-sthesis implanted into either the distal (n = 9) or the proximal femur (n = 10). Without recording the GRF and contralateral EMG, they defined the beginning and end of the STP and SWP with foot switches and measured the angles of the knee with an external electrogoniometer. Besides the already mentioned reduction of gait velocity, stride length and cadence, they also found a significantly reduced ROM in the knee and in the hip extension-flexion. They also detected a distinct cocontraction of the RF and hamstrings. Furthermore, they described a significant flexion in both the hip and the knee during STP but neither analysed the kinematics nor mentioned any pattern.

Benedetti *et al* (*2*) reported a gait analysis in a well-defined group of 16 tumor patients who had all had a megaprosthesis implanted into the distal femur. They analysed data from the patients divided into two groups and compared patients, in whom a resection of the vastus lateralis and vastus intermedius (n = 9) had been necessary, with those, who needed a resection of the vastus medialis alone or the vastus medialis and intermedius. Their analysis revealed distinct differences between the groups : while patients with resection of the vastus lateralis exhibited less deficits and had a more normal knee flexion-extension load-absorption pattern, those with resection of the vastus medialis demonstrated a tendency towards the "stiff-knee" pattern and had all the previously described criteria already observed in patients after the implantation of a "normal" TKR (*1*).

An analysis of a somewhat larger (n = 18) group of patients, each of whom had received a particular type of replacement (12 distal, 3 proximal and 2 total femoral replacements) and who had had a distinctly longer postoperative period (mean : 12 years), was reported by Rompen *et al* (*19*).

Using very simple equipment and without recording an EMG or an analysis of the GRF data, they achieved very divergent results. Ten patients exhibited the so-called "stiff knee" *gait*, whereas a "flexed knee" *gait* was seen in six and an abnormal "flexion-extension" pattern in the hip of nine patients. The differences between the "flexed knee" gait and the "stiff knee" gait was not explained by the authors and their criteria of the so-called "stiff gait" pattern seemed to be different from those described by Benedetti *et al* (*1*). The course of the kinematic curves mentioned by Benedetti *et al* (*1*) and which they defined as a "stiff-knee" pattern, resembles the course in all the STP and SWP graphs reported by Rompen *et al* (*19*).

In our understanding the "flexed-knee-gait" mentioned by Rompen *et al* (*19*) is the same as the "stiff-gait pattern" reported by Benedetti *et al* in 1999 (*1*). The curves of their so-called "stiff knee gait" exhibited the same course when compared to their graph of a "flexed knee gait" but with a parallel shift towards extension ; we could not see any hyperextension in this particular graph. Owing to the similarity between the graphs, it is likely that there was a technical failure in the positioning of the goniometer producing the parallel shift.

Similar to our data and those from Benedetti *et al* (*2*), in the paper published by Rompen *et al* (*19*) the graphs showing the kinematic of the knee during STP did not exhibit any undulation usually visible in controls with an undisturbed gait.

However, we do not agree that there is any real hyperextension which is, in our understanding, an extension of the straight leg position.

When Ochs *et al* (*17*) compared patients who had a distal femoral replacement with those who had a proximal tibial replacement and who all had the same type of megaprosthesis, in the patients with the distal femoral resection, the authors found a "quadriceps-avoiding" pattern combined with a "stiff-knee" gait but no "flexed-knee" pattern (*17*). Unfortunately, they did not analyze the EMG.

We are unclear as to whether the so-called "flexed-knee" pattern is, in principle, the same as the "stiff-knee" pattern but was a result of the goniometers having been repeatedly stuck to the leg with tape, which would seem a very uncertain way of acquiring reliable data. On the other hand, it may have been a sampling error since some authors analysed patients in a group without differentiating those with a proximal femoral megaprosthesis and from those with a distal femoral megaprosthesis.

Also other authors analysed only those patients who had a distal femoral megaprosthesis but did not differentiate between patients with a medial and those with a lateral resection of the vastus muscles. In addition, the different trials had analysed the varying criteria but had not always recorded the EMG and GRF.

In addition, our data exhibited also a distinct disturbance of gait characteristics in the contra-lateral healthy legs and is in accordance with recently published data by Okita *et al* (*18*).

Our patients had received a rather individual rehabilitation programm depending on the individual extend of the tumor resection and necessary localisation of the incision. Nevertheless, it is known that gait deficits may improve with a special rehabilitation programme (*1,7*) including physical and also psychological factors into the rehabilitation protocol as shown in transfemoral amputees (*20*).

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