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THE GAIT OF UNILATERAL TRANSFEMORAL AMPUTEES

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ABSTRACT. The aim of this study was to describe the gait of persons with a unilateral transfemoral amputation by means of a questionnaire, gait analysis and measurement of energy expenditure, and to find correlations among the variables studied. The study included 29 transfemoral amputees amputated for other reasons than a chronic vascular disease. The patients were assessed using the following methods: 1) A questionnaire rating the walking distance and walking difficulty in different circumstances. 2) Gait analysis measuring temporal variables and goniometry of hips and knees. 3) Measurement of energy expenditure during sitting and walking. Scores on the questionnaire showed a correlation with socket design, a negative correlation with age and energy expenditure, and a positive correlation with fast speed. The gait of transfemoral amputees was asymmetrical as far as temporal variables were concerned, and for most amputees also for the range of motion of hip and knee. The walking speed of the amputees was lower than that of non-amputees and showed a positive correlation with hip extension-flexion range of motion and a negative correlation with age and stride time. The energy expenditure of the amputees during ambulation was higher than that of non-amputees, and seemed to correlate with residual limb length and the hip abduction-adduction range of motion.

Key words: transfemoral amputee, questionnaire, gait analysis, energy expenditure.

Several studies on various aspects of the gait of transfemoral amputees have been undertaken (6, 7, 11, 15). Each study has increased our knowledge about prosthetic gait. The treatment of amputees, especially the prosthetic management, has changed considerably over time. Knowledge about the gait of the amputee is important for optimal treatment and for research purposes.

The aim of this study was to describe the gait of unilateral transfemoral amputees in a quantitative way.

MATERIAL AND METHODS

Subjects

The study included 29 unilateral transfemoral amputees living in the north of the Netherlands. All gave informed consent. The amputees had no other major diseases of the lower extremities. Some had back ache or problems with the non-prosthetic leg, but these did not cause disturbances of the gait. There were no skin problems of the stump.

The characteristics of the patients are summarized in Table I. The residual limb length mentioned was measured as the distance from the major trochanter to the distal end of the femur.

Seventeen patients had been amputated for traumatic reasons, 10 patients because of a malignant tumour, 1 patient because of a congenital vascular disease, and 1 patient because of acute arterial occlusion without signs of chronic vascular disease. All patients had an Otto Bock 4-bar linked knee with a mechanical swingphase control (3R20). All but two had a Multiflex foot. Two patients had an Otto Bock Lager foot. Seventeen patients had a quadrilateral socket, 12 patients a (modified) NML socket. Some patients had a pelvic suspension: 9 patients used a Silesian bandage, 3 patients an elastic sleeve (TES-belt®). About half of the patients were currently fitted, others had used their prosthesis for some years. Fit and alignment of the prosthesis were checked and found to be satisfactory. All were adjusted to their prosthesis.

Four patients walked with a stick, even for short distances.

Data collection

The patients were assessed by the following methods:

1. a questionnaire
2. gait analysis
3. measurement of energy expenditure during walking

1. Questionnaire: (see Table II.) The questionnaire consisted of two types of questions about walking with eight multiple choice questions about the maximum walking distance and the degree of difficulty presented by walking in different circumstances (grading 0–5). In addition, there were four questions about walking under different circumstances, using an 8-point rating scale : 0 meant impossible, 7 meant excellent. The scores per question were averaged for the eight

Table I. *Characteristics of the transfemoral amputees*

	Mean	(SD, range)
Age (years)	41	(13, 15–63)
Time from amputation (years)	19	(13, 2–48)
Residual limb length (cm)	22	(6, 12–35)
Weight (kg)	81	(13, 59–110)
Length (m)	1.79	(0.09, 1.56–1.99)
Male/female	24/5	

and four questions respectively. Thus, we obtained two scores on ambulation: score A (0–5) and score B (0–7).

2. *Gait analysis*: Gait analysis was performed on a 10 m conductive level floor area and on a treadmill. After getting used to the situation, the patients walked on the walkway at comfortable and fast speed and on the treadmill at a speed of 2 and 3 km/h. While on the walkway, patients were instructed first to walk at normal speed and then as fast as possible. While walking on the treadmill the patients could hold on to the bars so as not to fall. In order to standardize the procedure, each patient was told to hold on to the bars with the minimum amount of weight on the arms. The amputees first walked on the walkway without equipment, to measure walking speed. Subsequently, swing and stance phase recording the goniometry of the hip and knee were performed. For the time recordings, metallic strips over the length of the sole of the shoe were supplied in order to determine heelstrike and toe off. Infrared beams at the beginning and end of the walkway, placed 7 m apart, started and stopped the measurements automatically. Because the treadmill had no conductive surface, time recordings were only measured on the walkway. The ranges of motion of hip flexion-extension, hip abduction-adduction and knee flexion-extension of both sides were measured during walking on the walkway as well as walking on the treadmill.

Electrogoniometers (Penny & Giles) were used for range of motion measurements. The goniometers were positioned on long plastic strips which were fixed to the leg and to a bandage around the pelvis. A good test-retest reproducibility, with a standard deviation of $\approx 2^\circ$ between two measurements, was found in normal subjects.

3. *Measurement of energy expenditure during sitting and walking*: Oxygen uptake was measured using an Oxycon gas analyzer (Mijnhardt) during walking on a treadmill. During the test, the patients breathed air through a rubber mouthpiece, connected with the Oxycon gas analyzer, while the nose was kept closed using a spring clip. The Oxycon gas analyzer calculated the following mean variables: $V(O_2)$ L/min, $V(CO_2)$ L/min and respiratory coefficient. The amputees were first sitting for 6 min and then they walked for 6 min at the speed of 2 and 3 km/h, with 6 min of rest inbetween. The mean value for the last 2.5 min of each run was taken as the measured value at that speed. Depending on the respiratory quotient the energy consumption per liter O_2 (EE) was estimated (1) and the energy expenditure per second and per kilogram body weight (P) was calculated at each speed, using the following equation:

$$P(J/s.kg) = \{V(O_2)(L/min) \times EE(J/liter\ O_2)\}/\{60 \times BW(kg)\}$$

where $V(O_2)$ = oxygen uptake, EE = energy uptake per litre of O_2 and BW = body weight.

The amputees held on to the bars while walking on the treadmill.

The room was air-conditioned, with a temperature between 20° and 22°C and a relative humidity between 60 and 70%.

Statistical analysis

In order to gain insight into the possible relationships among the variables, we calculated Spearman rank correlations or performed Wilcoxon tests. As a next step, separate multiple regression analyses were carried out for each ambulation score, each speed and each energy expenditure as the dependent variables and with the following independent variables: age, sex, body height, socket design and gait parameters (except speed). Moreover, in studying the ambulation scores the speeds and energy expenditure were treated as independent variables.

Non-significant ($p > 0.05$) variables were removed from regression models; the adequacy of the analyses was examined by inspecting residuals from final models.

RESULTS

The data from the questionnaires, gait analysis and energy expenditure measurements are summarized in Table III.

The ambulation scores A and B were highly correlated (Spearman $r = 0.76$, $p < 0.001$), as were the fast and the comfortable speeds (Spearman $r = 0.83$, $p < 0.001$).

Although this data seems to indicate that the amputees walked rather symmetrically as far as hip and knee motions are concerned, one has to realize that the data represents the mean values. At comfortable speed, the hip abduction-adduction range of motion of the prosthetic side of the 25 amputees not walking with a stick was less than 80% of that of the sound side in 8 amputees and more than 120% of that of the sound side in 5 amputees. For the same speed the hip extension-flexion range of motion of the prosthetic side was less than 80% than that of the sound side in 9 amputees and more than 120% of that of the sound side in 3 amputees.

The knee extension-flexion range of motion of the prosthetic side was more clearly influenced by the walking speed than that of the sound knee. The mean difference in the knee motion between comfortable and fast speed was 8° for the knee joint and 2° for the sound knee. This difference was significant ($p < 0.01$, Wilcoxon signed rank test).

The knee extension-flexion range of motion was correlated with the walking speed. The Spearman rank correlation coefficient was 0.54 ($p < 0.01$) at comfortable speed and 0.47 ($p < 0.01$) at fast speed.

Table II. *Questionnaire, ambulation scores A and B*

0 means impossible, 7 means very well possible

	Score
Questions for score A	
* I am able to walk without rest	
O less than 50 m	(1)
O between 50 and 500 m	(2)
O between 500 and 2000 m	(3)
O between 2 and 5 km	(4)
O more than 5 km	(5)
* I have to be careful not to fall while walking outside	
O never	(5)
O only while walking a long distance, on uneven ground and such-like	(4)
O usually	(3)
O always	(2)
O I never walk outside	(1)
* If I walk with a healthy person of about my own age, I am able to keep his/her speed	
O without any difficulty	(5)
O with some difficulty	(4)
O with fairly great difficulty	(3)
O with very great difficulty	(2)
O impossible	(1)
* I am able to walk without rest	
O less than 5 minutes	(1)
O between 5 and 15 minutes	(2)
O between 15 and 30 minutes	(3)
O between 30 and 60 minutes	(4)
O longer than 60 minutes	(5)
* Fast walking	
O without any difficulty	(5)
O with some difficulty	(4)
O with fairly great difficulty	(3)
O with very great difficulty	(2)
O is impossible	(1)
* I use a stick or crutch or support myself on pieces of furniture or some other support while walking inside	
O never	(4)
O sometimes	(3)
O usually	(2)
O always	(1)
* I use a stick or crutch or other support or I walk supported by somebody else while walking outside	
O never	(5)
O sometimes	(4)
O usually	(3)
O always	(2)
O I never walk outside	(1)
* I have to be careful not to stub the foot of the prosthesis on uneven ground	
O never	(5)
O only while walking a long distance, on uneven ground and such like	(4)
O usually	(3)
O always	(2)
O I never walk outside	(1)

Questions for score B

* Walking is	0	1	2	3	4	5	6	7
* Fast walking is	0	1	2	3	4	5	6	7
* Sauntering is	0	1	2	3	4	5	6	7
* Walking on a fresh-cut grass is	0	1	2	3	4	5	6	7

Table III. *Mean and standard deviation of the variables studied in 29 transfemoral amputees*

abbreviations:
abd./add. : abduction-adduction range of motion in degrees
ext./fl. : extension-flexion range of motion in degrees
prosth.side : prosthetic side
J/s.kg : Joules per second per kilogram body weight

	n	Mean	St. dev.
Questionnaire			
ambulation score A	29	3.6	0.77
ambulation score B	29	5.0	1.14
Gait analysis			
comfortable speed (m/s)	29	1.04	0.17
fast speed (m/s)	29	1.27	0.22
swing phase prosth.side (ms)			
comfortable speed	29	634	73
fast speed	29	615	62
swing phase sound side (ms)			
comfortable speed	29	465	66
fast speed	29	428	49
stride time (ms)			
comfortable speed	29	1382	119
fast speed	29	1260	114
hip abd./add prosth.side			
comfortable speed	25	10.4	3.35
fast speed	25	10.9	4.20
2 km/h	29	9.0	3.27
3 km/h	27	10.5	4.03
hip abd./add sound side			
comfortable speed	25	11.7	3.51
fast speed	25	13.5	4.67
2 km/h	29	10.1	3.17
3 km/h	27	11.2	3.91
hip ext./fl.prosth.side			
comfortable speed	29	32.8	8.95
fast speed	29	36.3	10.00
2 km/h	29	30.2	9.34
3 km/h	27	33.2	9.70
hip ext./fl.sound side			
comfortable speed	29	36.3	6.69
fast speed	29	40.9	7.37
2 km/h	29	31.6	5.94
3 km/h	27	35.7	6.34
knee ext./fl.prosth.side			
comfortable speed	29	64.6	17.70
fast speed	29	72.5	19.09
2 km/h	29	51.7	16.57
3 km/h	27	63.0	16.69
knee ext./fl.sound side			
comfortable speed	29	65.8	9.25
fast speed	29	68.0	4.72
2 km/h	29	59.1	6.11
3 km/h	27	62.8	6.15
Energy expenditure in J/s. kg			
energy expenditure			
sitting	29	1.10	0.421
3 km/h	27	4.19	0.429
2 km/h	29	3.46	0.404

Table IV. *Results of multiple regression analysis*

*[1]: hip ext./fl. prost. + sound : hip extension-flexion range of motion of the prosthetic side and sound side summed, walking at comfortable speed
*[2]: hip ext./fl. prost. + sound : hip extension-flexion range of motion of the prosthetic side and sound side summed, walking at fast speed
*[3]: hip abd./add prost. + sound : hip abduction-adduction range of motion of the prosthetic side and sound side summed, walking at fast speed

Dependent variable	Variables in the equation	R-square	*p*-value	Pos./neg.relationship dependent-independent variables
ambulation score A	– socket type	0.63	0.00	score quad. > nml
	– age		0.00	–
	– fast speed		0.00	+
ambulation score B	– socket type	0.60	0.00	score quad. > nml
	– age		0.02	–
	– fast speed		0.00	+
	– energy expenditure 3 km/h (similar results were obtained when 3 km/h was replaced by 2 km/h)		0.01	–
comfortable speed	– hip ext./fl. prost.+sound v = comf.*[1]	0.69	0.00	+
	– body height		0.02	+
	– age		0.06	–
	– stride time v = comf.		0.00	–
fast speed	– hip ext./fl prost.+sound v = fast*[2]	0.78	0.01	+
	– body height		0.00	+
	– age		0.04	–
	– stride time v = fast		0.00	–
energy expenditure 3 km/h	– hip abd./add. prost.+sound v = fast*[3]	0.37	0.02	+
	– residual limb length		0.01	–
energy expenditure 2 km/h	– residual limb length	0.10	0.10	–

The knee motion was asymmetrical in many amputees: at comfortable speed, the knee extension-flexion range of motion of the prosthetic side was less than 80% of that of the sound side in 4 amputees and more than 120% of that of the sound side in 6 amputees.

Table IV summarizes the results of the multiple regression analysis.

DISCUSSION

This study attempted to quantify the gait of 29 unilateral transfemoral amputees by means of a questionnaire, gait analysis and measurement of energy expenditure. Scores A and B in the questionnaire were strongly correlated. The subjective rating showed a negative correlation with age and energy expenditure and a positive correlation with fast speed. In contrast to what we had expected from clinical practice, the amputees with a quadrilateral socket rated their walking ability higher than those with a (modified) NML socket. Perhaps, there is a confounding factor which influences both the prosthetic management and the subjective rating, but this could not be shown from the data.

The comfortable and fast speeds of the amputees were lower than those of normal subjects, which are known from the literature (11). This speed reduction is in agreement with the findings of James & Oberg (7) and Murray et al. (11), although the population in these studies was not entirely comparable to ours.

The swing phase time of the prosthetic side was longer than that of the sound side in all patients, differing by an average of 36% at comfortable speed. The altered function of the hip musculature (6), knee and ankle function or the inertial parameters of the prosthesis are the most likely causes of the asymmetry (5).

In the regression analysis, using speed as the dependent variable, entering the hip extension-flexion ranges of motion of the prosthetic and sound sides separately into the equation yielded a poorer fit than a summation of the prosthetic and sound sides. It is likely that hip extension-flexion range of motion as well as body height correlated with the step length. Step length was not measured in this study. The positive correlation found in this study between speed and hip motion at the sagittal plane, body height and stride time is in agreement with earlier findings in amputees (5,7) and non-amputees (12).

The age of the amputees showed a negative correlation with the walking speed. This is in agreement with the findings of earlier studies in non-amputees, comparing young and elderly subjects (4), but the decline of walking speed of persons below the age of 60 is not evident (13).

Energy expenditure was about 40% higher in the amputees studied than in normal subjects, whose average values were taken from the literature (14).

Energy expenditure at 3 km/h showed a significant correlation with the hip abduction-adduction range of motion at the fast speed ($p = 0.02$), but not with the hip abduction-adduction range of motion at 3 km/h ($p = 0.17$) or at comfortable speed ($p = 0.08$). At 3 km/h the amputee walked on a treadmill holding on to the bars. Walking on the treadmill may influence muscle activity in such a way that a relationship between the hip abduction-adduction values measured on the treadmill and energy expenditure could not be shown. The correlation between the hip abduction-adduction range of motion at fast speed energy expenditure at 3 km/h, may be an indication that the energy expenditure during walking is influenced by the hip motion in the frontal plane in transfemoral amputees.

The energy expenditure at 3 km/h was related to the residual limb length. A similar relationship between energy expenditure during ambulation and residual limb length has also been shown in transtibial amputees (3, 8).

Like Gailey et al. (2), we were unable to show a relationship between socket design (quadrilateral versus NML) and energy expenditure at slow speed. These authors found a higher energy expenditure in amputees with a quadrilateral socket than in amputees with a NML-socket at a speed comparable with the comfortable speed of non-amputees. The characteristics of our population, however, prevented us from studying the energy expenditure at this speed.

Contrary to findings in non-amputees by Waters et al. (14) we failed to find a significant difference between male and female amputees. The most likely cause of this is the relatively small number of female amputees.

The correlation between the knee extension-flexion range of motion and the walking speed is in agreement with what was expected on theoretical grounds and from the findings by Hale (5).

No relationship could be found either between hip abduction-adduction range of motion and residual limb length or socket design. Our impression from clinical practice is that excessive lateral lurging towards the prosthetic side is more often seen in amputees with a short stump than in amputees with a long stump. Perhaps the lurging is partly due to excessive trunk motion. Future studies will have to consider measurement of trunk motion at the lumbar level.

Although, on theoretical grounds, the hip abduction-adduction range of motion in amputees fitted with a NML socket should be less than that in amputees fitted with a quadrilateral socket (9), we found no such difference.

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