Prosthetics and Orthotics International, 1994, 18, 68-77

Gait in male trans-tibial amputees: a comparative study with healthy subjects in relation to walking speed

Y. HERMODSSON*, C. EKDAHL**, B. M. PERSSON* and G. ROXENDAL**

**Department of Orthopaedics, Helsingborg Hospital, Helsingborg, Sweden*
***Department of Physical Therapy, Lund University, Lund, Sweden*

Abstract
Walking speed, stance duration and ground reaction forces were studied with the use of a stable force platform (Kistler) in 24 male trans-tibial amputees and 12 healthy subjects matched for sex and age. The aim of the study was to compare the gait performance of two groups with unilateral trans-tibial amputations for either vascular disease or trauma and also to compare the results of the two groups with the results of a group of healthy subjects. Multiple linear regression analysis was used to compare the stance duration and the ground reaction forces in relation to walking speed. The vascular and traumatic amputees had significantly reduced walking speeds compared with the healthy subjects, 0.85±0.2 m/s and 0.99±0.2 m/s. respectively, as compared to 1.42±0.2 m/s. By comparing the vascular and traumatic amputees with the healthy subjects in relation to walking speed, it was shown that the gait performance of the vascular amputee differed from that of the traumatic amputee, a difference that was not caused by the reduced walking speed. The active forces during push off on both the healthy ($p = 0.02$) and the prosthetic leg ($p = 0.003$) in the trauma group were not found in the vascular group. This disparity could be an effect of the systemic disease. It may be argued that the results of this study contribute to the understanding of the reduced walking ability of the vascular amputee and should be borne in mind when planning rehabilitation.

All correspondence to be addressed to Y. Hermodsson, Department of Orthopaedics, Helsingborg Hospital, S-251 87 Helsingborg, Sweden.

Introduction

After an amputation of a leg, the muscular strength and the somatosensory information are reduced. The postural function is now also dependent on the stump, the prosthesis and how well the stump fits the socket (Murdoch, 1969; Sanders *et al.*, 1992; Zahedi *et al.*, 1987). The person must regain the capacity to stand and walk with an artificial leg in order to feel confident in the activities of daily living (Moncur, 1969; Winter and Sienko, 1988).

In healthy subjects normal walking speed decreases with age (Nigg and Skleryk, 1988; Öberg *et al.*, 1993) and in general women have been found to walk at a slower speed than men (Öberg *et al.*, 1993). Walking speed is reduced in leg amputees compared with healthy subjects (Levine, 1984; Robinson *et al.*, 1977; Saleh and Murdoch, 1985), and is significantly decreased at higher amputation levels (Skinner and Effeney, 1985; Waters *et al.*, 1976). Variations in walking speed as well as abnormalities affect the walking pattern (Andriacchi *et al.*, 1977). Compared to the side with the normal leg in trans-tibial amputees, stance duration, vertical ground reaction force (Suzuki, 1972) and the horizontal ground reaction forces in the fore and aft directions (Seliktar and Mizrahi, 1986) are decreased on the side with the prosthetic leg. This creates an asymmetric gait where the sound leg has to compensate for the prosthetic leg (Hurley *et al.*, 1990).

The aim of the present study was to compare the gait performance of two groups with unilateral trans-tibial amputations for either vascular disease or trauma in males and to compare the results of the two groups with the results of a group of healthy subjects matched for sex and age. Stance duration and the ground reaction forces of the vascular and traumatic amputees were compared with the healthy subjects in relation to walking speed. Another aim was to relate the person's own perception of postural function when moving in different situations to the mean walking speed of each group respectively.

Subjects and methods

Subjects

The criteria for inclusion in this study were: men with unilateral trans-tibial amputation for either vascular disease or trauma, no major sight problems (with glasses if needed), ability to talk and write in Swedish, and to be able to walk stretches of 8 metres, repeatedly, with a prosthesis without using a walking aid. A total of 24 male amputees fitted with a prosthesis at the orthopaedic workshop at Helsingborg Hospital, Sweden, were asked to participate in the study. All the selected amputees agreed to participate. Twelve male vascular amputees were matched for age with 12 male traumatic amputees.

Vascular amputee group: Twelve men with trans-tibial amputation for vascular disease were included in the study. One third of the men had diabetes. Concomitant diseases among the men were gastric ulcer in 1 and varicose ulcer of the other leg in another. In addition, 2 men had a big toe amputation on the healthy leg. Concerning pharmacological treatment, half of the men were on antihypertensive and/or analgesics; 1 was on antihypertensives, analgesics and sedatives; 1 was on antacids and 4 not on drugs at all. Three men considered their hearing to be bad, but this was not evident at the clinical investigation. To feel secure 5

Table 1. Characteristics of the groups studied (n = 12 in each group).

	Vascular			Trauma			Healthy		
Characteristics	M	SD	range	M	SD	range	M	SD	range
Age (years)	67	10.6	48-82	67	9.9	48-82	68	10.5	48-82
Height (cm)	173	7.3	161-187	175	3.9	168-180	176	6.7	165-191
Body mass (kg)	74	17.8	51-111	75	7.4	63-90	74	6.0	60-83
Years since the amputation	7	5.7	0-18	39	19.5	5-62	–	–	–
Age of the last prosthesis (years)	2	2.8	0.7	3	3.0	0.11	–	–	–
Stump length (cm)	15	3.1	11-21	15	7.4	8.34	–	–	–

Characteristics	Vascular (Number)	Trauma (Number)	Healthy (Number)
Sight (normal/slight impairment)	7/5	9/3	7/5
Hearing (normal/slight impairment/bad)	7/2/3	7/4/1	4/8/0
Smoking habits (smokers/ex-smokers/non-smokers)	5/4/3	2/7/3	1/4/7
Concomitant diseases (yes/no)	2/10	6/6	–
Medication (yes/no)	9/3	8/4	–
Walking aid outdoors (yes/no)	5/7	5/7	–
Side of amputation (right/left)	5/7	7/5	–
Stump pain (yes/no)	4/8	3/9	–
Phantom sensation (yes/no)	11/1	4/8	–
Phantom pain (yes/no)	10/2	6/6	–
Satisfaction with last prosthesis (yes/no)	8/4	6/6	–
Suspension (PTB/Supracondylar/PTB with a thigh corset/other	0/12/0/0	1/7/4/0	–
Liner (foam/leather/silicone/other)	11/0/1/0	10/1/1/0	–
Make (Boa/Bock/Swepro/TPJ/Flex-Foot/other)	3/6/1/1/1/0	1/11/0/0/0/0	–
Foot (SACH/Single-axis/Multi-axis/Energy storing/other)	6/3/2/1/0	4/4/4/0/0	–

men walked with a walking-stick outdoors. The characteristics of the vascular group are shown in Table 1.

Trauma amputee group: The vascular amputee group was matched for age with a group of 12 traumatic amputees. Regarding concomitant diseases among the men, 2 had asthma and 1 had both cardiac insufficiency and chronic bronchitis. Two men had had myocardial infarction and another had had a minor stroke more than one year previously but they were all back in their normal status again without any sequelae. Concerning pharmacological treatment, half of the men were on antihypertensives and/or analgesics; 1 was on antihypertensives, analgesics and sedatives; 1 was on anti-asthmatic inhalation medication and 4 were not on drugs at all. One man considered his hearing to be bad, but this was not evident at the clinical investigation. To feel secure 5 men walked with a walking-stick outdoors. The characteristics of the trauma group are shown in Table 1.

Healthy reference group: The vascular and traumatic amputee groups were matched for age with a group of 12 healthy men. The criteria for inclusion in this group were feeling healthy, taking no medicine and having experienced no problems with standing balance. All the subjects selected according to these criteria agreed to participate. The characteristics of the healthy group are shown in Table 1.

Methods

Force platform: The Vifor system was used for data collection of the gait performance. The main components of the Vifor system are a stable force platform (Kistler) measuring the forces between the foot and the surface, two video cameras and a video cassette recorder for recording the pattern of movement, a personal computer (IBM AT-3 compatible) for processing the force data, plotting ground reaction forces in video format and controlling the video cassette recorder, and a video mixer for superimposing information from the video cameras onto the computer images. In addition, the system includes two photocells for recording the walking speed and a video copier to furnish hard copies of selected video images (Lanshammar, 1991). In this study only the walking speed and the force platform data were

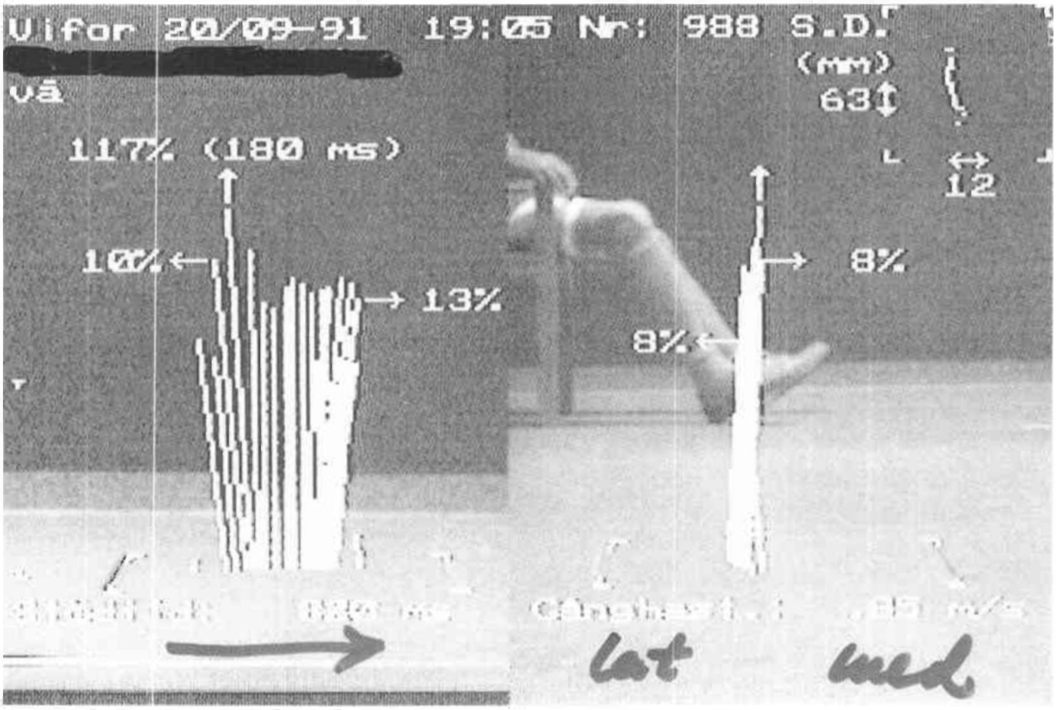

Fig 1. Parameters on the summary picture in the Vifor system for the gait performance of the sound leg of one of the male vascular trans-tibial amputees. Walking speed = 0.85 m/s; stance duration = 820 ms; max acc GRF (%BW) = 13; max ret GFR (%BW) = 10; med GRF (%BW) = 8; max lat GRF (%BW) = 8.

used for the gait analysis.

In the middle of the 8 m walkway, the force platform was incorporated into the floor and on a level with it. The force platform and the walkway were covered with the same material to prevent the subject from modifying the gait pattern in order to hit the platform properly. When the second photocell had been passed by the subject, a summary of the measurements was displayed on the screen. This summary contained a graphic illustration of the ground reaction forces during the step in the sagittal and frontal planes measured with 50 samples per second (Lanshammar, 1991).

Parameters shown on the summary picture in the Vifor system for the gait performance: walking speed = mean velocity (m/s) along the walkway; stance duration = total support time on the force platform (ms); max GRF (%BW) = the largest measured vertical ground reaction force in per cent of body weight; max acc GRF (%BW), max ret GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the fore and aft directions respectively in the walking direction; max med GRF (%BW), max lat GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the medial and lateral directions respectively perpendicular to the walking direction (Lanshammar, 1991).

Gait performance: As the ground reaction force (GRF) is measured in per cent of body weight (%BW) all subjects were weighed on the force platform. The subjects wore their ordinary walking shoes. Before recording with Vifor each subject walked repeatedly on the walkway. When walking the subject was instructed to look straight ahead and to walk at what they considered their normal walking speed when walking along a pavement without obstructions. In order to get the stance phase of each foot on the force platform, starting marks were placed at the beginning of the walkway. These were adjusted according to the gait performance of each subject. Three stance phases of each leg were recorded. One recording for each leg which was closest in time according to walking speed was chosen for the analysis, as changes in walking speed produce changes in the overall pattern of movement (Andriacchi *et al.*, 1977). The gait performance of the sound leg in 2 men is illustrated in Figures 1 and 2, 1 vascular

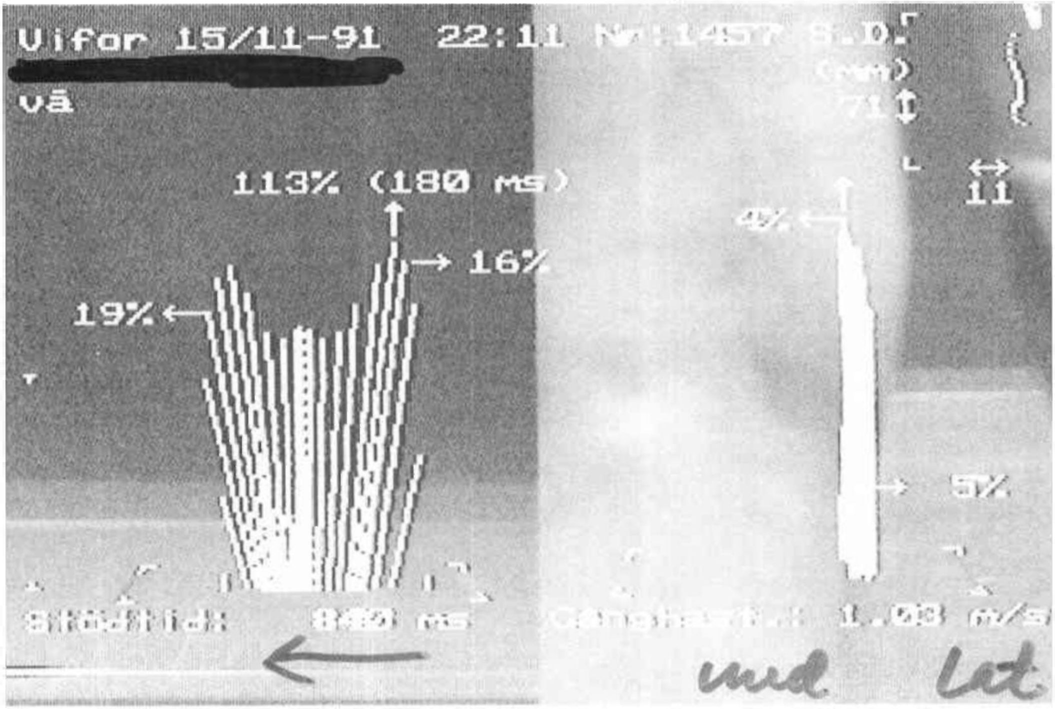

Fig. 2. Parameters on the summary picture in the Vifor system for the gait performance of the sound leg of one of the male trauma trans-tibial amputees. Walking speed = 1.03 m/s; stance duration = 840 ms; max acc GRF (%BW) = 19; max ret GFR (%BW) = 16; med GRF (%BW) = 4; max lat GRF (%BW) = 5.

amputee (Fig. 1) and 1 trauma amputee (Fig. 2).

Questionnaires: Before the tests of postural function, the subjects were asked to fill in a questionnaire about height, body mass, sight (normal/slight impairment), hearing (normal/slight impairment/bad), smoking habits (yes/ex-smokers/non-smokers), concomitant diseases (yes/no) and medication (yes/no).

For the leg-amputees additional questions were asked about years since the amputation, age of last prosthesis, stump length, walking aids outdoors (yes/no), side of amputation (right/left), stump pain (yes/no), phantom sensation (yes/no), phantom pain (yes/no) and satisfaction with the last prosthetic (yes/no). Together with the prosthetist suspension (PTB/Supracondylar/PTB with thigh corset/other), liner (foam/leather/silicone/other), make (Boa/Bock/Swepro/TPJ/Flex-Foot/other) and foot of the prosthesis (SACH/Single-axis/Multi-axis/Energy storing/other) were recorded. Abbreviations for prosthesis, make and foot: PTB = Patellar Tendon Bearing. PTS = Patellar Tendon Suspension. TPJ = Torsten Pettersson Jigg. SACH = Solid Ankle Cushion Heel.

In the other questionnaire all subjects were asked about their own perception of their postural function (good/fair/bad/cannot) when walking across the street, walking up the stairs, walking down the stairs, rising from a chair and sitting down on a chair. They were also asked how they would describe a perceived good postural function (There are times when the balance might not be as good as at other times. How do you perceive your balance when it is good? Please, write in your own words in the empty space below).

Statistics: Multiple linear regression was used in the analysis of the walking test battery where the walking speed was the dependent variable along with the interesting prognostic factors. All categorical data were analysed using the Chi-square test. All pairwise comparisons between the groups were analysed using the Student's t-test. To declare a test statistically significant, a level of 5% was used. The statistical software used in the analysis was SAS Version 6.08.

Results

There were no significant differences between the three groups concerning the characteristics in common (Table 1). A longer period of time since the amputation ($p = 0.0003$) among the amputees was the only characteristic showing significant difference between the vascular and traumatic groups, but this was not, however, found to affect walking speed.

Gait performance

Means and standard deviations for the vascular, traumatic and healthy groups during the gait performance are shown in Table 2. Compared to the healthy leg, the prosthetic leg had a reduced max acc GRF (%BW) and max

Table 2. Means and standard deviations for the groups studied (n = 12 in each group) during the gait performance according to the summary picture on the Vifor system.

	Vascular group				Trauma group				Healthy group			
	Healthy leg		Prosthetic leg		Healthy leg		Prosthetic leg		Right leg		Left leg	
Gait variables	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Walking speed (m/s)	0.85	0.2	0.85	0.2	0.99	0.2	0.99	0.2	1.42	0.2	1.42	0.2
Stance duration (s)	0.85	0.1	0.83	0.1	0.87	0.1	0.80	0.1	0.67	0.0	0.67	0.1
Max GRF (%BW)	113.1	8.8	106.3	8.7	114.9	9.3	107.3	10.6	123.3	9.8	122.8	10.3
Max acc GRF (%BW)	13.1	4.9	10.3	4.2	17.4	5.2	10.8	2.7	21.3	3.9	21.0	4.2
Max ret GRF (%BW)	12.2	4.1	9.3	3.6	17.0	4.3	11.2	5.2	20.0	6.3	20.8	5.0
Max med GRF (%BW)	6.9	2.1	6.8	2.0	6.4	1.2	6.6	2.1	6.5	2.1	5.6	2.0
Max lat GRF (%BW)	3.2	1.5	1.6	1.3	4.1	2.6	2.1	0.8	5.5	3.0	5.6	2.7

Abbreviations: max GRF (%BW) = the largest measured vertical ground reaction force in per cent of body weight; max acc GRF (%BW), max ret GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the fore and aft directions, respectively, in the walking direction; max med GRF (%BW), max lat GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the medial and lateral directions, respectively, perpendicular to the walking direction.

Table 3. Multiple linear regression analysis for the stance duration and the ground reaction forces in the gait performance using walking speed as a dependent variable for the matched men in the vascular and trauma groups compared to the healthy group (n = 12 in each group).

	Trauma & vascular/healthy groups				Vascular/healthy groups				Trauma/healthy groups			
	Healthy leg		Prosthetic leg		Healthy leg		Prosthetic leg		Healthy leg		Prosthetic leg	
Gait variables	Difference[a)]	p	Difference[a)]	p	Difference[a)]	p	Difference[a)]	p	Difference[a)]	p	Difference[a)]	p
Stance duration (s)	0.01	0.66	-0.02	0.44	0.00	0.99	0.00	0.95	0.04	0.17	-0.01	0.60
Max GRF (%BW)	5.39	0.14	-6.62	0.18	4.39	0.09	-1.50	0.64	5.27	0.21	-4.77	0.40
Mac acc GRF (%BW)	3.80	0.01	-3.97	0.007	1.40	0.11	0.24	0.74	3.86	0.02	-5.30	0.003
Max ret GRF (%BW)	3.36	0.10	-2.78	0.14	1.11	0.47	-1.32	0.29	4.56	0.06	-1.91	0.38
Max med GRF (%BW)	-0.16	0.87	0.55	0.61	0.31	0.70	0.60	0.44	-0.20	0.85	1.64	0.20
Max lat GRF (%BW)	0.25	0.84	-3.36	0.001	-0.11	0.90	-1.98	0.03	0.50	0.76	-2.72	0.03

[a)] Difference in seconds for the stance duration and in %BW for the ground reaction forces (GRF).
Abbreviations: max GRF (%BW) = the largest vertical ground reaction force in per cent of body weight; max acc GRF (%BW), max ret GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the fore and aft directions, respectively, in the walking direction; max med GRF (%BW), max lat GRF (%BW) = the largest measured horizontal ground reaction forces in per cent of body weight in the medial and lateral directions, respectively, perpendicular to the walking direction.

lat GRF (%BW) in the vascular group (p = 0.01 and p = 0.03, respectively) and a reduced max acc GRF (%BW), max ret GRF (%BW) and max lat GRF (%BW) in the trauma group (p-values = 0.0003, 0.001 and 0.03, respectively). The remaining gait variables in this comparison between the healthy and prosthetic leg did not reach statistical significance in the vascular or traumatic groups.

Stance duration and ground reaction forces in relation to walking speed

The vascular and trauma groups, calculated together or separately, had significantly reduced walking speeds compared with the healthy group (p = 0.0001 in all three cases). Multiple linear regression analysis was used to compare the stance duration and the ground reaction forces of the vascular and traumatic amputees with the healthy subjects in relation to walking speed (Table 3). The vascular and traumatic amputees as one group, differed significantly in their max acc GRF (%BW) on both the healthy (p = 0.01) and prosthetic leg (p = 0.007) and the max lat GRF (%BW) (p = 0.001) on the prosthetic leg only, compared to the healthy group. When comparing the vascular group separately with the healthy group only max lat GRF (%BW) differed significantly (p = 0.03) on the prosthetic leg. The trauma group differed significantly (p = 0.02) in their max acc GRF (%BW) on the healthy leg while the max ret GRF (%BW) on this leg showed a tendency towards a significant difference (p = 0.06). The max acc and max lat GRF (%BW) on the prosthetic leg differed significantly (p = 0.003 and p = 0.03, respectively) in the trauma group compared to the healthy group.

Perceived postural function

Perceived postural function is reported in Table 4. No significant differences were found between the three groups in the self-report of perceived postural function when walking across the street and sitting down on a chair. Self report of perceived postural function when

Table 4. Perceived postural function when moving (good/fair/bad/cannot). Frequencies in the vascular, trauma and healthy groups.

Activity	Vascular (n = 12)	Trauma (n = 12)	Healthy (n = 12)
Walk across the street	8/4/0/0	8/3/1/0	11/1/0/0
Walk up the stairs	5/7/0/0	6/5/1/0	11/1/0/0
Walk down the stairs	6/6/0/0	5/5/2/0	12/0/0/0
Rise from a chair	9/3/0/0	7/5/0/0	12/0/0/0
Sit down on a chair	10/2/0/0	8/4/0/0	12/0/0/0

walking up and down the stairs and getting up from a chair were found to differ significantly between the three groups (p-values = 0.058, 0.01 and 0.05, respectively). The healthy group thought their balance to be significantly (p = 0.01) better than the trauma group and close to significantly (p = 0.06) better than the vascular group when getting up from a chair. In addition the healthy group considered their balance to be significantly better than the amputee groups when walking down the stairs (p = 0.01 in both cases). When walking up the stairs, however, only the vascular group reported a significantly (p = 0.01) decreased perceived postural function compared to the healthy group. Non of the three situations mentioned above was found to differ significantly between the vascular and trauma groups.

All the healthy subjects thought they had no problem with balance. To have good balance when using a prosthesis could be expressed as, "Then it feels as if I have two legs," or, "It's like having a real leg, only a little more stiff." One of the men in the trauma group thought that, "It can never be exactly the same as when you have two legs. The balance is in my healthy leg and the prosthetic leg I only use as a support," and one of the men in the vascular group wrote, "The days when the prosthesis fits well the balance is quite good. Then I enjoy life." Activities difficult to perform were walking up and downhill, walking fast, walking when the ground was slippery, sloping or bumpy and walking in the wind.

Perceived postural function compared to the mean walking speed.

Those who thought their postural function was "good" when walking across the street, walking up and down the street, sitting down and getting up from a chair were separated from those who felt that their postural function was "fair/bad/cannot" in one or more than one of the five situations. Of the 6 men who walked faster than 0.85 m/s in the vascular group, only 1 though his postural function was good. Among the 6 men who walked more slowly, half thought their postural function was good. In the trauma group 8 walked faster than 0.99 m/s and half of them thought their postural function was good. Four walked more slowly and 1 of them thought his postural function was good. In the healthy group 6 walked faster than 1.42 m/s and 5 of them thought their postural function was good, and among the 6 men who walked more slowly 5 said their postural function was good.

Discussion

The results of this study show that the gait performance of the male vascular amputee differs from that of the male traumatic amputee. Due to the availability of too few female amputees, a corresponding comparison between female vascular trans-tibial amputees and female traumatic trans-tibial amputees could not be carried out. The small number of female traumatic amputees is explained by the high frequency of accidents among men in contrast to women (Hansson, 1964). Female vascular amputees having a higher failure rate than males in using the prosthesis (McKenzie, 1953) explains the small number of female vascular amputees, but the reason for this remains unclear and merits further study. Amputees having significantly reduced walking speed compared to healthy subjects, as reported earlier in the literature (Levine, 1984; Robinson *et al.*, 1977; Saleh and Murdoch, 1985), is confirmed in this study. In the pairwise comparison, significantly reduced horizontal ground reaction forces were found in the fore direction in the vascular group and in the fore and aft directions in the trauma group on the prosthetic leg, compared to the healthy leg. This asymmetry is partly in agreement with earlier studies (Hurley *et al.*, 1990; Seliktar and Mizrahi, 1986; Suzuki, 1972).

Subjects with diseased joints in the lower limbs have been found to have a decreased walking speed as compared to normal walking speed. According to Andriacchi *et al.* (1977) one should distinguish which variations from normal walking patterns are due to differences in walking speed and which are due to gait abnormalities. As the aim of this study was to investigate whether the gait of vascular trans-tibial amputees differed from that of traumatic trans-tibial amputees, and whether any differences could contribute to the understanding of the reduced walking ability of the vascular amputee in daily life, self-selected walking speed was chosen as a clinically relevant walking speed for the gait analysis. No attempt was made to study the effect of walking speed on the gait variables. Stance duration was found by Andriacchi *et al.* to be inversely proportional to walking speed and the ground reaction forces to vary linearly with walking speed. Thus, the subjects in this study were asked to walk at their normal speed and the gait variables of the amputees were analysed in relation to the normal walking speed of the healthy subjects.

Two patients, one in each group and both on sedatives, walked more slowly than the mean walking speed of the amputee groups. As the two men were older (73 and 79 years) than the mean age of the groups, we are inclined to say that medication has not been proven to influence the walking speed. This is in agreement with Brocklehurst *et al.* (1982) who found no relationship to falls or sway in a group of healthy elderly people on sedatives compared with controls without sedatives. The authors agree, however, with Brocklehurst *et al.* that high dosage of sedatives could make a difference. Two men in the vascular group had a big toe amputation, but despite this they did not need any walking aids outdoors, and they both walked faster than the mean walking speed of the vascular group.

The mean normal walking speed of 1.42 m/s of the healthy men is comparable to the 1.45 m/s in men walking at unrestrained speed measured by Water *et al.* (1976). The lower walking speed of 1.32-1.41 m/s reported by Nigg and Skleryk (1988) could be due to the subjects being older, 60-82 years, and of both sexes. In order to analyse pathological gait data, attempts have been made to establish normal reference data. The reference tables of Öberg *et al.* (1993) show normal mean walking speed of healthy men 10-79 years to be 1.18-1.34 m/s, which is slower than the result of the present study. When comparing their tables to those of other authors, Öberg *et al.* found the results to be partly contradictory. Apart from being dependent on age and sex, they suggest that walking speed could be dependent on the length of the walkway and if the measurements have been performed under outdoor or indoor conditions. Accordingly, they recommend gait data only to be analysed with reference data made in the same test situation under the same test conditions.

In the study mentioned previously, Waters *et al.* (1976) found that a group of vascular trans-tibial amputees with a mean age of 63 years, sex not accounted for, walked with a velocity of 0.75 m/s at unrestrained speed, which is slower than the men in this study who had a mean age of 67 years and walked with a velocity of 0.85 m/s. As walking speed decreases with age, the group of traumatic trans-tibial amputees with a mean age of 29 years in Waters *et al.* series are not comparable to the traumatic amputees in this study. Lemaire *et al.,* (1993) studied eight elderly traumatic male trans-tibial amputees who had an average walking speed of 1.20 m/s when walking at a natural cadence, which is faster than the men in the trauma group in the present study who walked with a velocity of 0.99 m/s.

As a general rule, those variables which do not change when adjusted for normal walking speed, indicate an abnormality (Andriacchi *et al.*, 1977). Stance duration and the max GRF (%BW) showed no change on the healthy or the prosthetic leg for the two amputee groups together or for the vascular and traumatic groups separately, compared with the healthy group. This might indicate that amputees of different etiology have the same reduced weight bearing ability during the stance duration on the supporting leg in the walking direction, on both the healthy and the prosthetic leg compared to healthy subjects.

The horizontal ground reaction forces show how much force the subject uses in the fore direction during push off and in the aft direction during heel strike and reflects how active the leg is (Seliktar and Mizrahi, 1986). The two amputee groups compared together showed an active push off on the healthy and the prosthetic leg. The trauma group was equally active in the push off on both legs in contrast to the vascular group, who turned out to lack this powerful push off on both legs. Besides, the trauma group showed a tendency towards an active heel strike, which might have been significant if the trauma group had been larger.

The ground reaction forces in the medial and lateral directions reflect the alternating motion sideways when moving the body over the supporting leg and taking a step forward. The medial ground reaction force showed no change in the amputee groups when analysed in relation to the walking speed of the healthy group. The lateral ground reaction force, however, changed on the prosthetic leg in both amputee groups. Andriacchi *et al.* (1977) came to the same conclusion when assessing patients with knee disabilities. They did not consider themselves to have sufficient data to explain why the medial force was the same in the knee patients as in the normal subjects. But they thought the finding was worth considering as the mediolateral forces cause bending moments in the knee which could cause loosening of prosthetic components. Like Andriacchi *et al.* the authors do not have sufficient data to explain the reason why the medial force does not change, but presume that these bending moments might occur between the stump and the prosthesis.

The amputee groups thought their postural function to be just as good as the healthy group when walking across the street. This is somewhat surprising as the traffic signals in Sweden are set according to a walking speed of 1.4 m/s (Dahlstedt, 1977). When rising from a chair the amputee groups considered their balance to be reduced. This is an agreement with Yoshida *et al.* (1983) who found hemiparetics to need more time to stand up and regain postural control than healthy elderly persons when rising from a chair. But the amputees did not perceive their balance to be reduced when sitting down on a chair as measured in the hemiparetics in the study by Yoshida *et al.* Walking up and down the stairs caused some difficulty in the amputee groups. To the authors' knowledge, studies on postural function when walking on stairs has not been reported in the literature.

The subject's own perception of his postural function when moving in the different situations did not correspond well to the mean walking speed of the different groups, which explains the somewhat contradictory findings mentioned above. This is in agreement with Ekdahl *et al.* (1989) who found low correlations between experienced and tested standing balance in patients with rheumatoid arthritis and osteoarthrosis. The fact that the healthy group showed more confidence in their postural function, independent of walking speed, confirms that they were selected according to the inclusion criteria. As they walked faster than the vascular and traumatic group, it could also indicate that when a person, as a normal walking speed, choses to walk at a speed approaching 1.4 m/s they also have a better postural function. This is similar to the results of Mathias *et al.* (1986) who found that in a group of elderly patients with some degree of balance disturbance, all subjects with a walking speed faster than 1 m/s had a sway path in standing balance below 20 mm/s. This they thought confirmed the dependence of rapid walking on good balance.

When trying to describe perceived good postural function, all groups had difficulties in putting words to this phenomenon regardless of what degree of postural function they had. In general, good balance is something that is natural, taken for granted or never given any special thought. When not good, as in the amputee groups, balance is classified in what activities one cannot do. As noted by others (Murdoch 1969; Sanders *et al.*, 1992; Zahedi *et al.*, 1987), the importance of a well-fitting prosthesis to good balance cannot be overlooked and it contributes to a greater satisfaction with life.

To conclude, by comparing the vascular and traumatic amputees with the healthy subjects in relation to walking speed, the authors have shown that the gait performance of the vascular amputee differs from that of the traumatic amputee, a difference that is not caused by the reduced walking speed. The active forces during push off on both the healthy and the prosthetic leg in the trauma group were not found in the vascular group. This disparity could be an effect of the systemic disease. It may be argued that the results of this study contribute to the understanding of the reduced walking ability of the vascular amputee and should be borne in mind when planning rehabilitation.

Acknowledgements

This study was supported from the Helsingborg Hospital, the LIC Orthopaedic workshop in Helsingborg, the Carl Jönsson Foundation II, the Foundation for Support to the Disabled in Scania, the Arvid Ohlsson Foundation and the Zoega Foundation, Sweden.

REFERENCES

Andriachi TP, Ogle JA, Galante JO (1977). Walking speed as a basis for normal and abnormal gait measurements. *J Biomech* **10,** 261-268.

Brocklehurst JC, Robertson D, James-Groom P (1982). Clinical correlates of sway in old age: sensory modalities. *Age Ageing* **11,** 1-10.

EKDAHL C ANDERSSON SI, SVENSSON B (1989) Muscle function of the lower extremities in rheumatoid arthritis and osteoarthrosis: a descriptive study of patients in a primary health care district *J Clin Epidemiol* **42,** 947-954

DAHLSTEDT S (1977). Slow pedestrians: walking speeds and walking habits of old-aged people. –Stockholm: The Swedish Council for Building Research, 1978.

HANSSON J (1964) The leg amputee: a clinical follow-up study. *Acta Orthop Scand* **35 (suppl 69),** 1-104.

HURLEY GRB, MCKENNEY R, ROBINSON M, ZADRAVEC M, PIERRYNOWSKI MR (1990). The role of the contralateral limb in below-knee amputee gait. *Prosthet Orthot Int* **14,** 33-42

LANSHAMMAR H (1991). Vifor: a system for load analysis during walking – Uppsala: Uppsala University Department of Technology, UPTEC 92011R.

LEMAIRE ED, FISHER FR, ROBERTSON DGE (1993). Gait patterns of elderly men with trans-tibial amputations. *Prosthet Orthot Int* **17,** 27-37

LEVINE AM (1984). The elderly amputee. *Am Fam Physician* **29,** 177-182.

MATHIAS S, NAYAK USL, ISAAC B (1986). Balance in elderly patients: the "get up and go" test *Arch Phys Med Rehabil* **67,** 387-389

MCKENZIE DS (1953). The elderly amputee. *Br Med J* **i,** 153-156.

MONCUR SD (1969). The practical aspect of balance relating to amputees. *Physiotherapy* **55,** 409-410

MURDOCH G (1969). Balance in the amputee. *Physiotherapy* **55,** 405-408.

NIGG BM, SKLERYK BN (1988). Gait characteristics of the elderly Clin Biomech 3, 79-87.

ROBINSON JL, SMIDT GL, ARORA JS (1977) Accelographic, temporal, and distance gait: factors in below-knee amputees. *Phys Ther* **57**, 898-904.

SALEH M, MURDOCH G (1985). In defence of gait analysis: observation and measurement in gait assessment *J Bone Joint Surg* **67B,** 237-241

SANDERS JE, DALY CH, BURGESS EM (1992). Interface shear stresses during ambulation with a below-knee prosthetic limb. *J Rehabil Res Dev* **29,** 1-8.

SELIKTAR R, MIZRAHI J (1986). Some gait characteristics of below-knee amputees and their reflection on the ground reaction forces. *Eng Med* **15,** 27-34.

SKINNER HB, EFFENEY DJ (1985). Gait analysis in amputees *Am J Phys Med* **64,** 82-89.

SUZUKI K (1972) Force plate study on the artificial limb gait. *J Jap Orthop Assoc* **46,** 503-516.

WATERS RL, PERRY J, ANTONELLI D, HISLOP H (1976) Energy cost of walking of amputees: the influence of level of amputation. *J Bone Joint Surg* **58A,** 42-46

WINTER DA, SIENKO SE (1988). Biomechanics of below-knee amputee gait. *J Biomech* **21,** 361-367.

YOSHIDA K, IWAKURA H, INOUE F (1983). Motion analysis in the movements of standing up from and sitting down on a chair: a comparison of normal and hemiparetic subjects and the differences of sex and age among the normals. *Scand J Rehabil Med* **15,** 133-140.

ZAHEDI MS, SPENCE WD, SOLOMONIDIS SE, PAUL JP (1987) Repeatability of kinetic and kinematic measurements in gait studies of the lower limb amputee. *Prosthet Orthot Int* **11,** 55-64.

ÖBERG T, KARSZNIA A, ÖBERG K (1993). Basic gait parameters: reference data for normal subjects, 10-79 years of age *J Rehabil Res Dev* **30,** 210-223.