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CARDIAC LOADS DURING PROSTHETIC TRAINING IN LEGAMPUTEES

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Abstract

Eighteen subjects, mean age 70, range 52 - 89 years, with a legamputation because of peripheral vascular disease were studied during prosthetic rehabilitation. The cardiac load as indicated by the heartrate was measured during normal prosthetic training activities. The cardiac condition was investigated monthly using graded exercise testing.

The rehabilitation program consisted of three stages of walking: one leg walking, walking with a preliminary prosthesis and walking with the definitive prosthesis. The cardiac load was measured weekly in each stage. Changes in the cardiac load were related to changes in walking speed and distance.

We observed that the highest cardiac loads in prosthetic training occured during walking exercises especially when a specific exercise was performed for the first time. One leg walking and walking with a preliminary prosthesis induced higher cardiac loads in the individual patient than walking with the definitive prosthesis. The cardiac condition of the patients didn't change as a result of the rehabilitation program, but the walking became more efficient resulting in an increased walking speed and distance with a decreased cardiac load.

Introduction

Eighty to ninety percent of the legamputations in the Netherlands are performed because of circulatory problems caused by atherosclerosis (13). Therefore the majority of legamputees admitted to a rehabilitation centre for prosthetic training suffer from vascular disease. This disease may also cause atherosclerosis of the corona arteries. Therefore and because of the advanced age and the sedentary way of life in these patients, they often have a poor cardiac condition (1,9). This increases the risk for cardiac accidents and therefore they should avoid exercises that provoke high cardiac loads.

To our knowledge no information is available concerning the cardiac loads provoked by prosthetic training programs. Only measurements of energy cost during ambulation in legamputees are found in literature. The results of these measurements show which cardiac loads can be expected during various kinds of ambulation because an increased energy consumption results in an increase of heartrate (2) and because the heartrate is a good index for myocardial oxygen consumption and therefore for cardiac load (4,11). The measurements show that prosthetic walking is less efficient in comparison with unimpaired walking (4,6,7). The energy consumption is related to walking speed, amputation level (above, through and below knee), type of prosthesis and walking aids. The measurements show that the lower efficiency during ambulation results in a decreased comfortable walking speed. At this speed however the energy consumption, expressed in volume oxygen uptake per time unit, is similar to that during unimpaired walking at comfortable walking speed.

These measurements concerned amputees who were experienced in prosthetic walking. Therefore the results are not suitable in patients who are admitted to a rehabilitation centre for prosthetic training soon after a legamputation. Compared with trained amputees it can by expected that their way of ambulation is less efficient. This will result in a lower walking speed or, when low walking speeds are not allowed during training exercises, in an increased energy consumption and cardiac load. In order to stay within safe levels of activity during training exercises, knowledge of a patients cardiac condition and of the cardiac loads induced by specific exercises is necessary. If also information is available about the changes in cardiac load and condition as a result of prosthetic training this knowledge can be used to optimize therapeutical intensity of exercises.

In this study the heartrate as a measure of cardiac load was measured during various exercises in different stages of the rehabilitation program. The changes in cardiac load were determined by repeating the measurements at regular time intervals. Besides this the cardiac condition was investigated using a specially designed graded exercise test. The observed cardiac loads were related to the cardiac condition of the individual patients.

Methods

- pilot study

The amputees were admitted to a rehabilitation centre for prosthetic training one to three months after the legamputation. They took part in various therapeutic activities like wound treatment, muscle strength exercises, sports and walking exercises. A pilot study was performed to determine which activities provoked the highest cardiac loads. All patients performed a graded exercise testing to obtain their cardiac condition. In this study the cardiac condition was defined as the peak heartrate that was obtained during graded exercise testing without cardiac problems (1). The peak increase of heartrate was defined as the difference between the heartrate at rest and the peak heartrate. In four patients the heartrate was recorded for 24 hours during their stay in the rehabilitation centre to get an impression of the highest cardiac loads during all days activities. We concluded from these recordings that the highest cardiac loads were provoked by the exercises during physical therapy.

In 19 patients the heartrate was recorded as a measure of cardiac load during various kinds of physical therapy at different stages in the rehabilitation program. The observed increases of heartrate were compared in the individual patients to the peak increases obtained during graded exercise testing. Only some walking exercises provoked increases of heartrate of more than 50 percent of the individual peak increases and we got the impression that the patients were only motivated to exert themselves during walking exercises. Therefore we decided to measure the cardiac loads at regular times only during walking exercises.

The training program consisted in general of three stages of walking. First the patient learned to stand and walk on one leg. As the stump had healed sufficiently he learned to walk with a preliminary prosthesis like an airboot or Campprosthesis. When his own definitive prosthesis could be used he learned prosthetic walking. During walking exercises several kinds of aids like parallel bars, walking frame, two crutches and one stick were used.

- measurements

Every unilateral vascular legamputee (above, below or through knee) who was admitted to the rehabilitation centre in the period january - october 1983 took part in this study. First the patients performed a graded exercise test to measure their cardiac condition. For this test a specially designed rowing ergometer was used (1). The heartrate and bloodpressure were measured as a function of the in time increasing workload. The test was repeated monthly in order to check for changes in cardiovascular responses to graded exercise testing.

The cardiac load was recorded once a week in every amputee during his normal daily walking exercises. The legamputees, although encouraged by the physical therapists, could chose their own walking speeds and periods of rest. The type of walking exercise performed varied with the stage in the rehabilitation program from one leg walking to prosthetic walking using various walking aids. As stated before the heartrate was used as the index for cardiac load. This heartrate was obtained continuously from computer analysis of the telemetric recorded electrocardiogram (ECG). The ECG was recorded using the bipolar leads CC5 and CM5. Information was also obtained about the occurence of ST-segment abnormalities and the occurence of arrhythmia. These parameters can indicate an overload of the heart and can be used as an indirect measure of cardiac load. Exercise parameters such as type of exercise, distance walked, beginning and end of each exercise were entered in the computer by the keyboard during the recordings.

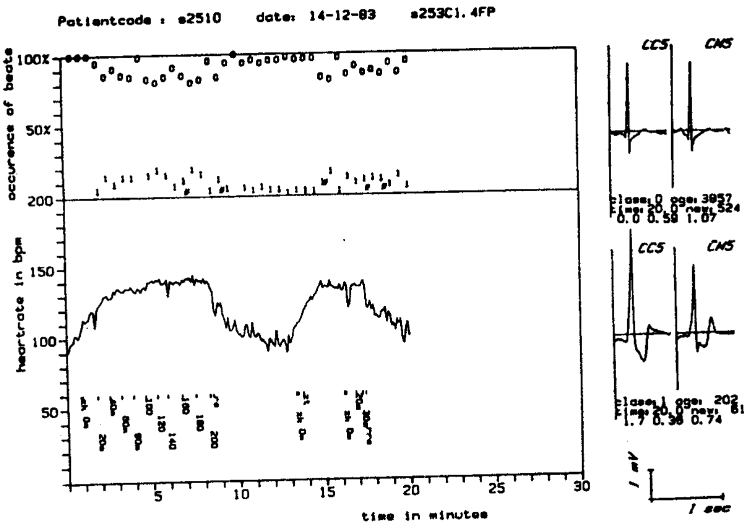

Figure 1: Measurement of cardiac load during prosthetic walking.

In figure 1 an example is shown of a measurement in a legamputee who suffered from arrhythmia. This resulted in the occurence of both normal and abnormal ECG beats. All ECG beats were classified in morphological classes by computer analysis. The ECG beat shapes (two leads: CC5, CM5) of the normal beats (class 0) and of the abnormal beats (class 1) were plotted in the right part of figure 1. Every 30 seconds during the measurement the percentages of occurence of normal and abnormal beats in the past half minute were plotted in the upper left part of the figure. The averaged heartrate was calculated every 6 seconds and plotted in beats per minute (bpm) in the lower left part. The exercise parameters were plotted in the lower left part at their place along the time axis. These parameters were plotted every 30 seconds during the exercises, so the cardiac loads were available immediately.

Results

A group of 18 vascular legamputees was followed during their entire rehabilitation program. To illustrate the results obtained some measurements in two patients will be described extensively.

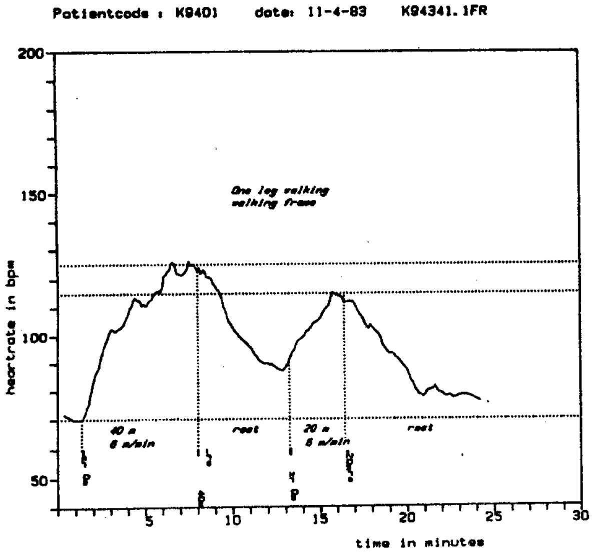

Figure 2: Heartrate during one leg walking with a walking frame.

The first patient is an 84 year old man with a through knee amputation of the right leg. The rest-ECG showed evidence of an old anterior infarct. The patient used neither digoxine nor a beta-blocking agent during the rehabilitation. One leg walking after 12 weeks of training is compared to prosthetic walking after 3 weeks of prosthetic training. He used a walking frame during one leg walking and two crutches during prosthetic walking. In figure 2 the heartrate response during one leg walking is plotted. The mean walking speed was 6 m/min. The amputee walked first 40 m and after 5 minutes rest another 20 m. After walking 40 m the heartrate had increased from 70 bpm to 125 bpm. Figure 3 shows the heartrate response during prosthetic walking. The mean walking speed was 8 m/min and after walking 100 m the heartrate had increased from 80 bpm to 98 bpm.

The heartrate response shown in figure 3 can be divided into three stages. In the first two minutes of exercise the heartrate increased (stage 1) to 120 bpm and then it didn't change much (stage 2, steady state) until it again increased (stage 3). During one leg walking (figure 2) only stage 1 occured (non steady state response). The heartrate depended more on the distance walked during one leg walking than during prosthetic walking. The highest heartrates and cardiac loads were achieved during one leg walking. The use of a prosthesis when walking helped to decrease the cardiac load and increased the walking speed and the distance walked.

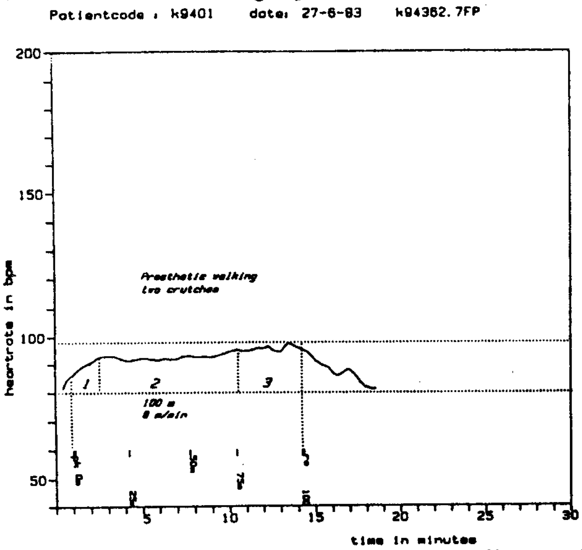

Figure 3: Heartrate during prosthetic walking with two crutches.

The second patient, a 57 year old man with a through knee amputation of the right leg, had no cardial problems in his history and used neither digoxine nor a beta-blokking agent. He first trained one leg walking. Due to wound healing problems the prosthetic training started 26 weeks after the amputation. One leg walking was compared to three stages of prosthetic walking: 1) walking with the help of parallel bars, 2) using two crutches 3) using one crutch. During one leg walking the walking speed was 23 m/min and the distance 80 m. The heartrate increased from 105 to 128 bpm (figure 4). During prosthetic walking the heartrate increased to 115 bpm (figure 5, parallel bars), to 120 (figure 5, two crutches) and to 136 (figure 6, one crutch). The walking speed increased from 14 m/min (parallel bars) to 28 m/min (one crutch). The distance walked increased

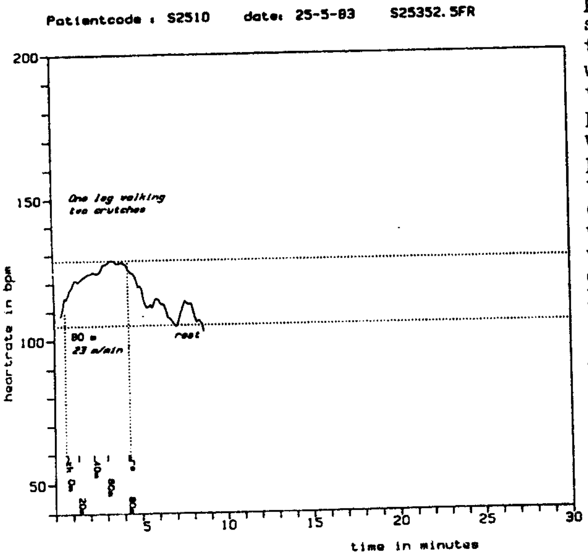

Figure 4: Heartrate during one leg walking with two crutches.

from 36 m to 150 m. Only prosthetic walking with the help of parallel bars resulted in a steady state response of the heartrate.

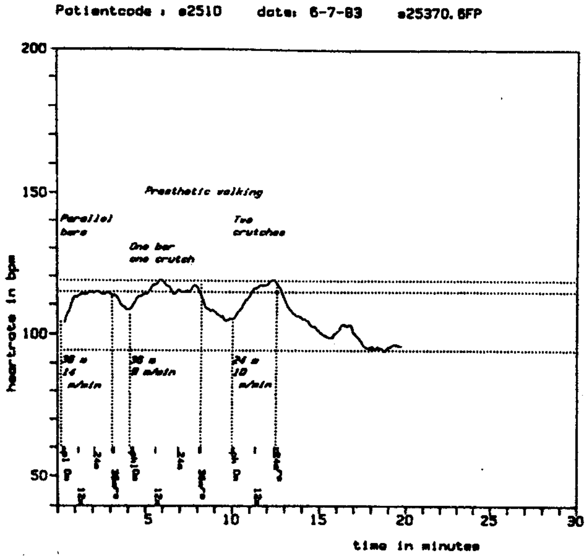

Figure 5: Heartrate during prosthetic walking.

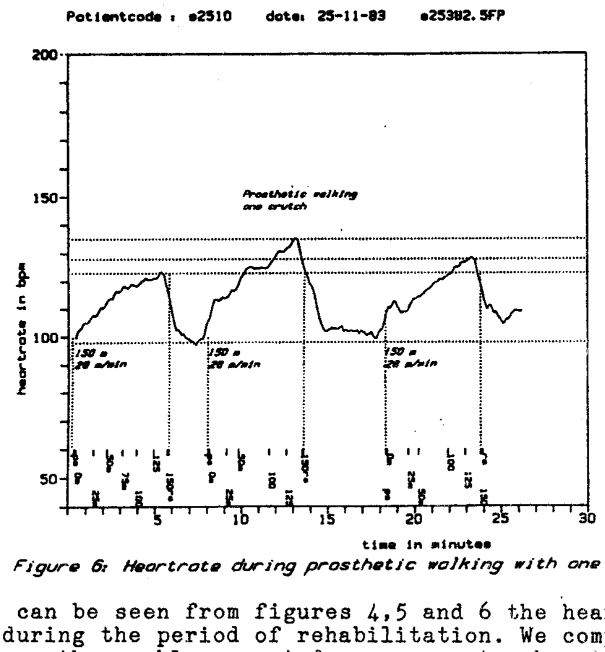

Figure 6: Heartrate during prosthetic walking with one crutch.

As can be seen from figures 4,5 and 6 the heartrate response changed during the period of rehabilitation. We compared similar events from the weekly repeated measurements: heartrate at rest, peak heartrate and the heartrates after walking 25, 50 and 100 metre. The measured heartrates were plotted against time of rehabilitation in figure 7. Week 0 indicates the date of the amputation. The different stages in walking as indicated in the middle part of figure 7 were: until week 26 one leg walking, then

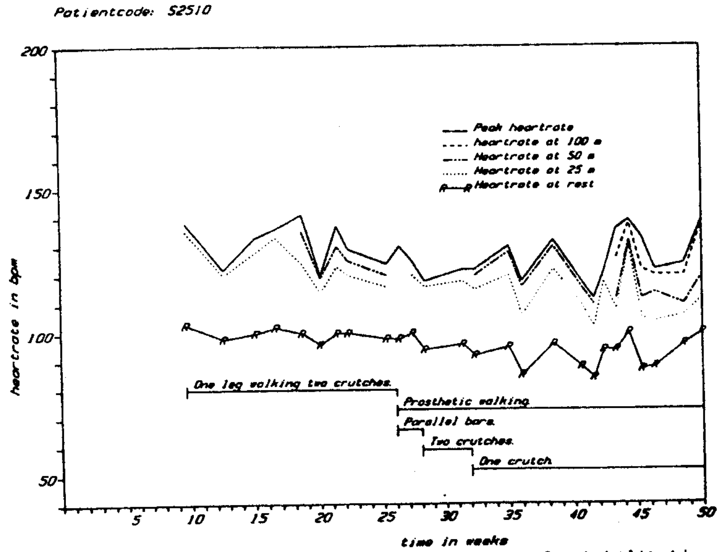

Figure 7: Measured heartrates during the period of rehabilitation.

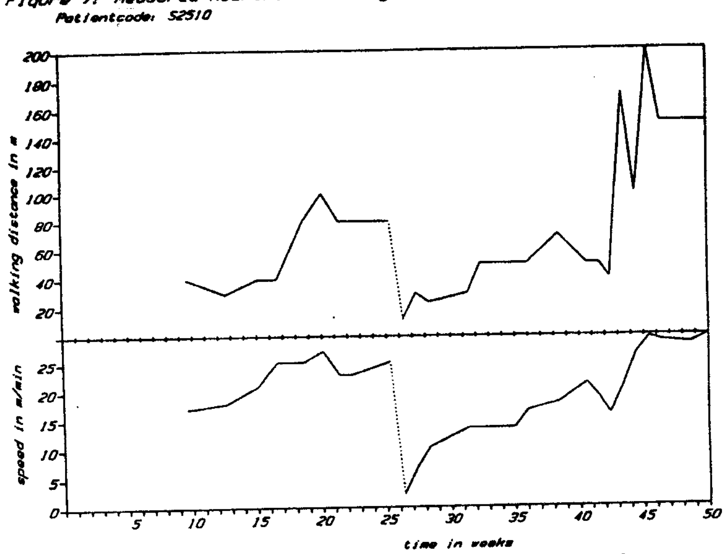

Figure 8: Walking distance and speed during the period of rehabilitation.

prosthetic walking, first using parallel bars, second using two crutches and third using one crutch. The heartrates at rest and at a distance of 25 m decreased whereas the peak heartrates also decreased during the first months of rehabilitation and increased later on as the walking distance increased. The walking speed and distance are plotted in figure 8. At the start of prosthetic walking (week 26) the speed decreased to 2 m/min and the walking distance to 20 m. After 24 weeks of prosthetic training the walking speed was 32 m/min and the walking distance more than 150 m.

Monthly the legamputee performed a graded exercise test. In figure 9 the heartrates at three stages in the test are plotted: heartrate at rest, the peak heartrate and the heartrate at a workload of 60 watt. The heartrate at rest first decreased but returned to the starting level in the end. The peak heartrate increased whereas at a workload of 60 watt it didn't change much. The peak workload is also plotted in figure 9. It increased as the peak heartrate increased. The patient said he was tired at peak workload during all tests and made no further complaints.

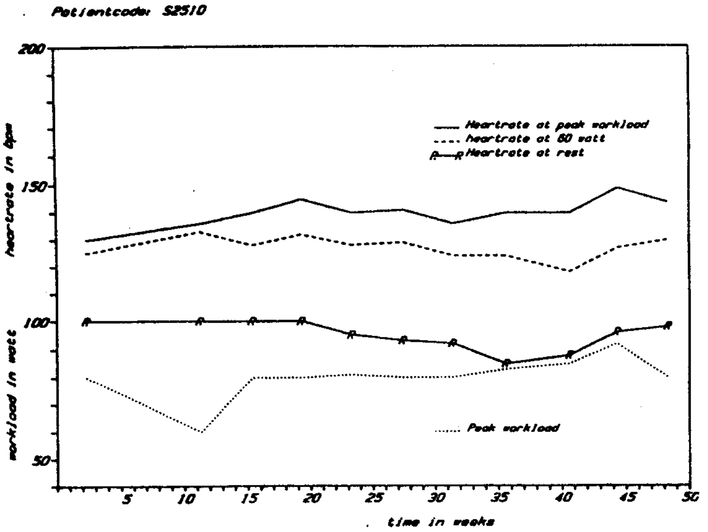

Figure 9: Results of exercise testings in one patient.

The measurements as described previously were performed in all vascular legamputees admitted for prosthetic training. Up till now 18 legamputees were followed during their entire training program. The results of the measurements are summarized in table 1. First information is given about the status of the individual patients (amputation level, age, sex, cardiac history, diabetes mellitus and medication). Second the results of the graded exercise tests are shown (number of tests, heartrate at rest (HRrest), heartrate at peak workload (HRmax) and peak workload (Pmax)). If the patient performed four or more tests averaged results are shown of the first two tests (I), of all tests (II) and of the last two tests (III). Third the results of measurements during walking exercises are shown. The walking exercises are divided into three stages (one leg walking, walking with a preliminary prosthesis and prosthetic walking). The walking aids used are indicated by chararters (F= walking frame, C= two crutches, S= one crutch or walking stick). Then the number of weeks of training and the number

Table 1: Results of measurements in 18 legamputees.

		B05	H09	V04	E31	H12	M28	K04	B95	L18	S04	N11	E15	S25	O14	K20	O13	B14	P11
patient amputationlevel		AL	AR	AL	AL	AR	AL	TR	TR	TL	TR	TR	TR	TR	BR	BL	BL	BR	BL
age (year)		78	73	78	52	71	53	89	88	65	79	72	67	57	69	63	70	69	72
sex		M	F	F	F	F	M	M	M	M	M	M	M	M	M	M	F	F	M
cardiac hystory		X	X	X	X	-	-	X	X	X	X	X	X	-	X	X	X	X	-
diabetes mellitus		X	X	-	X	X	X	X	X	-	X	-	X	-	X	-	X	X	X
medication		D	-	D	B	-	-	-	D	D	D	BD	D	-	D	-	D	-	-
exercisetest																			
number of tests		8	7	8	5	1	3	7	3	2	4	3	3	12	2	5	1	2	5
HR rest (bpm)	I	91	75	98	97			79			110			100		75			74
	II	93	71	92	93	77	98	72	92	135	116	79	94	95	79	77	72	72	84
	III	95	64	94	90			67			122			97		77			57
HR max (bpm)	I	128	117	129	127			112			150			133		120			118
	II	123	121	128	126	85	174	114	108	180	158	100	141	140	135	120	150	98	114
	III	116	123	140	124			110			181			142		114			111
P max (watt)	I	43	62	35	45			57			59			70		80			71
	II	42	61	40	48	40	92	56	41	58	82	48	62	81	65	90	40	39	73
	III	40	62	42	50			57			65			85		81			78
one leg walking																			
aid		F		F				F		C	P			C	F	C		F	F
number of weeks		40		11				13		2	9			16	3	7		6	21
number of meas.		7		7				8		2	4			10	3	4		3	7
speed (m/min)	I	3		6				5			6			17		32		5	8
	II	5		5				8		20	9			22	13	27		8	12
	III	4		6				6			11			25		23		6	9
distance (m)	I	6		20				20			18			40		45		10	20
	II	23		23				22		49	14			73	27	73		12	36
	III	22		28				40			9			80		100		13	40
heartrate (bpm)	I	132		130				111			144			140		123		108	100
	II	124		129				111		173	140			130	122	116		113	96
	III	122		134				120			136			124		110		118	80
% HR (%)	I	130		105				82			70			106		108		133	72
	II	103		102				92		84	60			79	77	91		152	64
	III	96		117				114			50			64		77		163	32
preliminary prosthesis																			
aid			C	F	C	F	C		F	C	P	P	C		F		F		
number of weeks			5	8	4	5	3		3	2	13	2	8		3		2		
number of meas.			5	5	3	3	3		3	2	10	2	4		3		1		
speed (m/min)	I		3	6							6		8						
	II		3	5	7	3	20		3	18	5	10	9		11		4		
	III		4	6							6		10						
distance (m)	I		5	37							34		25						
	II		8	37	28	12	83		9	50	32	12	43		27		6		
	III		10	45							15		60						
heartrate (bpm)	I		115	125							140		117						
	II		118	130	123	83	135		107	168	135	80	115		112		130		
	III		120	135							136		113						
% HR (%)	I		88	82							60		34						
	II		94	105	91	75	48		107	73	48	5	31		58		75		
	III		98	119							50		28						
prosthetic walking																			
aid		F	C	F	S	F	C	C	F	C	C	F	C	S	S	S	F	S	C
number of weeks		6	28	12	5	3	3	3	11	9	7	8	8	17	9	14	11	8	3
number of meas.		5	14	9	4	3	2	2	6	4	6	6	6	13	3	4	8	4	3
speed (m/min)	I	4	5	5	8				5	14	4	4	8	14	28	18	4	15	
	II	3	8	5	8	3	19	8	6	18	5	5	15	22	32	28	8	24	18
	III	4	8	6	10				7	18	7	8	17	30	43	40	7	30	
distance (m)	I	14	28	28	82				11	80	31	23	40	50	80	50	3	40	
	II	27	38	32	69	18	60	75	25	85	37	19	61	98	116	95	15	98	117
	III	42	20	40	80				35	100	40	20	60	150	200	140	20	135	
heartrate (bpm)	I	125	130	114	110				97	167	132	80	118	121	105	93	125	111	
	II	123	118	122	110	85	117	97	97	165	130	85	112	128	107	97	130	108	78
	III	121	112	136	110				101	150	150	88	113	132	110	102	130	108	
% HR (%)	I	107	118	61	52				34	71	40	5	36	58	48	37	68	144	
	II	100	94	83	52	100	25	60	34	87	35	28	37	69	50	47	75	133	88
	III	93	82	120	52				64	33	85	43	28	82	55	58	75	124	

Amputation level: A = above knee, T = Through knee, B = below knee, R = right leg, L = left leg.
Sex: M = male, F = female.
Cardiac history: X = cardiac problems in history (myocardiac infarct, atrial fibrillation, bundle branch block, mitralis insufficiency, cardio myopathy, pericarditis), - = no cardiac problems.
Diabetes mellitus: X = diabetes mellitus, - = no diabetes mellitus.
Medication: D = digoxine, B = beta blocking agent.
Exercise test: I = averaged results of first two tests, II = averaged results of all tests, III = averaged results of last two tests.
Walking exercises: Aid: P = parallel bars, F = walking frame, C = two crutches, S = one crutch.
I = averaged results of measurements in first two weeks.
II = averaged results of all measurements.
III = averaged results of measurements in last two weeks.

of measurements are given. If the period of training during a certain stage was longer than 6 weeks the averaged results (walking speed, distance walked and peak heartrate) are shown of the measurements during the first two weeks (I), of all measurements (II) and of the measurements during the last two weeks (III). The peak heartrate obtained during the walking exercise (HRmeas) was related to the peak heartrate during the graded exercise test (HRmax). Therefore also a relative measure of the peak heartrate (%HR) is shown. This measure was defined as: %HR = (HRmeas - HRrest)/(HRmax - HRrest) x 100%. The averaged values of %HR during walking exercises were: 90 % (one leg walking, 10 patients), 68 % (walking with a preliminary prosthesis, 12 patients) and 61 % (prosthetic walking, 18 patients). The value was significantly different from 100 % (p = 0.05) during prosthetic walking and walking with a preliminary prosthesis.

Table 2: Comparison of averaged results.

Exercises testing (9 patients):	HRrest [bpm]	HRmax [bpm]	Pmax [watt]
first two tests	89	126	58
last two tests	85	127	62

Walking exercises:	speed [m/min]	distance [m]	heartrate [bpm]	%HR [%]
one leg walking (8 patients):				
first two weeks	10	22	124	102
last two weeks	11	42↑	118	89
preliminary prosthesis (4 pat):				
first two weeks	6	23	124	69
last two weeks	7	33	126	74
prosthesis (14 patients):				
first two weeks	10	39	116	63
last two weeks	17↑	76↑	119	71
one leg walking (10 patients):	13	35	125	90
prosthetic walking	16	78↑	115#	67#
preliminary prosthesis	8	29	120	68
prosthesis (12 patients)	11	48↑	115#	56

↑ = increase significantly different from 0 (p = 0.05)
= decrease significantly different from 0 (p = 0.05)

The averaged results of the measurements in different stages of the rehabilitation program are shown in table 2. Nine patients performed the graded exercise test for four times or more. The averaged results of the first two tests and the last two tests were compared and the differences were not significantly different from 0. In eight patients one leg walking in the first two weeks was compared to one leg walking in the last two weeks of training. In four patients the results during walking with a preliminary prothesis were compared. The results during prosthetic walking were compared in twelve patients. As can be seen from table 2 the speed and distance increased and the heartrate and %HR decreased during the period of training. The differences significantly different from 0 are indicated in table 2. Ten patients were trained in both one leg walking and prosthetic walking. One leg walking resulted in a lower mean walking speed and distance and in a higher mean heartrate and %HR. The differences in distance, heartrate and %HR were significantly different from 0. The speeds, distances and heartrates were not corrected for differences in walking aids. Twelve patients were trained in both walking with a preliminary prosthesis and with a prosthesis. Walking with a preliminary prosthesis resulted in a lower mean walking speed and distance and in higher heartrates and %HR. Only the differences in walking distance and heartrate were significantly different from 0.

Conclusion

We investigated the cardiac load as indicated by heartrate during normal prosthetic training of legamputees. The measurements during the training program were not standardized in walking speed and walking distance because the patients always chose their own walking speed and stopped when they felt tired or when they felt pain in the stump or in the other leg. With weekly repetition of the measurements the changes in cardiac load, walking speed and distance as a result of training were recorded. It can be concluded from table 1 and 2 that in almost every patient one leg walking or the use of a preliminary prosthesis resulted in a higher cardiac load and lower walking speed compared to prosthetic walking. During the period of training the walking speed increased and the heartrate and cardiac load decreased. These changes in cardiac load and comfortable walking speed can be explained by changes in the man-prosthesis system (12):

1) The cardio-vasculair condition can improve by performing exercises at regular times. This results in a lower heartrate and cardiac load at the same workload.
2) The legamputees improve their technique of walking with a prosthesis during the period of training. This results in a more efficient manner of prosthetic walking.
3) Prosthetic walking will be more efficient if the prosthesis is adjusted to the individual legamputee.

Measurements in a larger group of legamputees showed that they have a poor cardiac condition at the start of their prosthetic training program (1). In motivated patients a special training program can be used to improve their cardiac condition (3,8,10). In general however the patients are only motivated to exert themselves during walking exercises as we concluded from our pilot study. As can be concluded from figure 9 and table 2 the relation between heartrate and workload hardly changed during the period of rehabilitation. So the changes in heartrate and walking speed during walking exercises are not due to changes in the cardio-vascular condition.

As one leg walking resulted in higher cardiac loads and lower walking speeds than prosthetic walking it can be concluded that the efficiency of walking is an important factor (table 2). The highest cardiac loads were achieved when the leg amputee walked on one leg for the first time. It can be concluded from table 1 that the improved efficiency of walking due to training resulted in a more pronounced change in walking speed and distance than in heartrate.

The relative measure of heartrate (%HR) shown in table 1 indicates that the heartrates achieved during graded exercise testing are usually higher then those achieved during walking exercises. If no cardiac problems occured during graded exercise testing they are not likely to occur during prosthetic training. Therefore the graded exercise test provides a good screening of exercise induced changes in the electrocardiogram.

We concluded from the preliminary results of measurements in 18 legamputees:

1) The highest cardiac loads in prosthetic training occured during walking exercises especially as a specific exercise was performed for the first time.
2) One leg walking induced higher cardiac loads than prosthetic walking.
3) The prosthetic training resulted in an increase of speed and distance and in a decrease of cardiac load during walking.
4) The cardiac condition of the legamputees didn't change despite the prosthetic training exercises

Only the peak heartrates are shown in table 1. As the heartrate is recorded continuously during the measurements not only the peak heartrates are obtained but also the heartrate responses. As illustrated in figures 2 and 3 the heartrate response can reach a steady state or not. As a steady state response can be expected from a physiological point of view (2) and as the walking distance is limited by non steady state responses these responses need further investigations.

In future investigations the results of the exercise tests and measurements during walking exercises will be related to the obtained rehabilitation results in the individual patients.

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