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Development of an exercise testing protocol for patients with a lower limb amputation: results of a pilot study

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Due to a decrease in physical activity, lower limb amputees experience a decline in physical fitness. This causes problems in walking with a prosthesis because energy expenditure in walking with a prosthesis is much higher than in walking with two sound legs. Exercise training may therefore increase the functional walking ability of these patients. To generate a safe and effective aerobic training program, exercise testing of amputees is recommended. The objectives of this study were to develop a maximal exercise testing protocol for lower limb amputees and to compare two different testing methods: combined arm–leg ergometry and arm ergometry. The protocols were tested in five amputee patients. Combined ergometry elicited a higher oxygen uptake and heart rate than arm ergometry. Electrocardiography during combined ergometry was easier to read. Combined ergometry was judged most comfortable by the amputees. The exercise testing protocol was useful in lower limb amputees to determine their maximal aerobic capacity and their main exercise limitation. Future exercise training programs may be based on this testing protocol. Combined arm–leg ergometry is appropriate for unilateral amputees without significant claudication of the remaining leg. Continuous arm ergometry is suitable for unilateral amputees with significant claudication of the remaining limb or bilateral amputees.

Infolge einer verminderten körperlichen Betätigung beobachten Patienten mit amputierten unteren Gliedmaßen eine Abnahme ihrer körperlichen Fitness. Probleme entstehen beim Gehen mit einer Prothese, da dabei wesentlich mehr Energie verbraucht wird als beim Gehen mit zwei gesunden Beinen. Solche Patienten profitieren daher möglicherweise von sportlichen Übungen, die ihre funktionale Gehfähigkeit steigern. Um ein sicheres und effektives aerobes Trainingsprogramm aufstellen zu können, empfehlen sich Fitnesstests für Beinamputierte. Im Rahmen dieser Studie werden ein Protokoll für eine maximale Körperbetätigung bei Beinamputierten entwickelt und zwei verschiedene Testmethoden miteinander verglichen: eine kombinierte Arm-Bein-Ergometrie und eine Arm-Ergometrie. Die Protokolle wurden an fünf Amputierten erprobt. Bei der kombinierten Ergometrie konnten ein höherer Sauerstoffverbrauch und eine höhere Herzfrequenz als bei der Arm-Ergometrie beobachtet werden. Die EKG-Werte konnten während der kombinierten Ergometrie leichter abgelesen werden. Die kombinierte Ergometrie wurde von den Amputierten als am angenehmsten empfunden. Das Körperbetätigungsprotokoll erwies sich bei Patienten mit amputierten unteren Gliedmaßen als besonders nützlich, da so ihre maximale aerobe Kapazität und ihre körperlichen Grenzen festgestellt werden konnten. Künftige Trainingsprogramme basieren möglicherweise auf diesem Prüfprotokoll. Eine kombinierte Arm–Bein-Ergometrie eignet sich für einseitig amputierte Patienten ohne signifikantes Hinken des verbliebenen Beins, eine kontinuierliche Arm-Ergometrie für einseitig amputierte Patienten mit signifikantem Hinken des verbliebenen Beins oder aber für beidseitig amputierte Patienten.

La aptitud física de los individuos amputados de miembros inferiores se deteriora como resultado de la reducción de la actividad física de los mismos. Esto les causa problemas a la hora de caminar con una prótesis, ya que el gasto de energía al caminar usando la misma es mucho mayor que al caminar utilizando ambas piernas. El entrenamiento físico podría, por tanto, incrementar la capacidad funcional de estos pacientes para caminar. Al generar un programa de entrenamiento aeróbico seguro y eficaz, es recomendable evaluar la respuesta de los amputados de miembros inferiores al ejercicio. Los objetivos de este estudio fueron desarrollar un protocolo de evaluación de la respuesta máxima al ejercicio físico para amputados de miembros inferiores, y comparar dos de dichos métodos de evaluación: la ergometría combinada brazo-pierna y la ergometría de brazo. Los protocolos se probaron en cinco pacientes amputados. La ergometría combinada suscitó un mayor consumo de oxigeno y un mayor aumento del ritmo cardíaco que la ergometría de brazo. Los electrocardiogramas realizados durante la ergometría combinada resultaron más fáciles de leer. Los pacientes amputados consideraron la ergometría combinada como más cómoda de realizar. El protocolo para evaluar la respuesta al ejercicio resultó útil en el caso de los amputados de miembros inferiores a fin de determinar la capacidad aeróbica máxima de los mismos y sus principales limitaciones al realizar ejercicios físicos. Los programas futuros de entrenamiento físico deben realizarse sobre la base de este protocolo de evaluación. La ergometría combinada brazo-pierna resulta apropiada para los amputados unilaterales que no presenten claudicación significativa del miembro restante. La ergometría continua de brazo resulta apropiada para los amputados unilaterales con claudicación marcada del miembro restante, o para los amputados bilaterales.

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En raison de la diminution de leur activité physique, les amputés des membres inférieurs souffrent d'un déclin de leur forme physique générale. Cette situation est problématique en cas de marche avec une prothèse, le niveau d'énergie requis pour marcher avec ce type d'accessoire étant beaucoup important que pour la marche avec deux jambes saines. Un programme d'exercices d'entraînement pourra donc améliorer la capacité fonctionnelle des patients à ce niveau. Afin de préparer un programme d'exercices d'aérobic sans danger et efficace, il est nécessaire de faire subir des tests aux amputés. L'objectif de cette étude est le développement d'un protocole de test optimal pour les exercices physiques à l'attention des amputés des membres inférieurs et la comparaison entre deux méthodes de test différentes : ergométrie bras-jambe combinée et ergométrie du bras seulement. Les protocoles ont été testés chez cinq patients. L'ergométrie combinée fait ressortir une consommation d'oxygène et un rythme cardiaque plus importants que l'ergométrie du bras seul. Les mesures électrocardiographiques effectuées durant l'ergométrie combinée sont plus faciles à lire. L'ergométrie combinée est considérée comme plus confortable par les amputés. Le protocole de test des exercices s'avère particulièrement utilie pour les amputés des membres inférieurs, en ceci qu'il leur permet de déterminer leur capacité aérobic maximale et leurs limites en termes d'exercices. Les programmes futurs de formation aux exercices pourraient reposer sur ce protocole de test. L'ergométrie bras-jambe combinée est adaptée aux amputés unilatéraux ne soufrant pas de claudication significative de la jambe valide. L'ergométrie continue du bras convient aux amputés unilatéraux souffrant de claudication significative dans la jambe restante ou les amputés bilatéraux. *International Journal of Rehabilitation Research* 28:237–244 © 2005 Lippincott Williams & Wilkins.

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Introduction

In the Netherlands around 2000 major lower limb amputations are performed each year. The incidence of lower limb amputations is around 18–20 per 100 000. Most of these patients (around 94%) have an amputation for peripheral vascular disease (PVD) (Rommers, 2000). Many patients who have an amputation for PVD have had severely limited physical activity for weeks to months prior to the amputation as a result of gangrene, osteomyelitis or vascular claudication (Davidoff *et al.*, 1992; Chin *et al.*, 2002a). In addition, having a lower limb amputation usually means a severe decline in physical fitness, caused by a reduced amount of physical activity (Saltin *et al.*, 1968).

In summary, lower limb amputees experience a decline in physical fitness due to limited physical activity prior to and after the amputation. This decline in physical fitness is a problem because walking with a prosthesis costs more energy than walking with two sound legs. The extra amount of energy that is needed depends on the level of amputation (Waters *et al.*, 1976). To be able to learn to walk with a prosthesis at a functional level of activity, it is very important that the amputee is able to meet the high energy expenditure demands (Chin *et al.*, 2002a). Chin *et al.* demonstrated that cardiorespiratory endurance in the physical fitness of amputees was clearly lower than that of able-bodied individuals (Chin *et al.*, 2002b). A poor physical condition may (1) influence the progress of rehabilitation, (2) increase the risk of coronary problems during the rehabilitation process and (3) influence the functional activity level (Van Alsté *et al.*, 1985).

When training programs for lower limb amputees only cover walking training with a prosthesis, maximal aerobic capacity does not improve to the level of able-bodied persons (Chin *et al.*, 2002b). Therefore, training in prosthetic walking should accompany some kind of endurance exercise training with the aim of improving fitness of amputees.

Research has shown that amputees with PVD have a high incidence of ischemic heart disease, while traumatic amputees are at increased risk for development of cardiovascular disease subsequent to the amputation (Bostom *et al.*, 1987). This means these patients need appropriate exercise testing before engaging in exercise training programs (Finestone *et al.*, 1991) or before increasing the intensity of their program of physical activity (Fletcher *et al.*, 1988).

Amputees have altered blood pressure and heart rate responses to exercise (Kurdibaylo, 1994). In addition, many PVD amputees take medication for coronary artery disease. This means that maximal oxygen uptake ($\dot{V}O_{2max}$) cannot be reliably estimated from submaximal oxygen uptake and heart rate data. Maximal oxygen uptake has to be measured directly during a symptom-limited graded exercise test.

Table 1 Characteristics of patients

	1	2	3[a]	4	5
Sex	Man	Man	Man	Man	Woman
Age (years)	29	44	58	23	15
Height (m)	1.88	1.83	1.86	1.82	1.55
Weight (kg)	80.0	80.0	98.0	61.2	56.8
Level of amputation	Transtibial	Hemipelvectomy	Transtibial	Transtibial	Transfemoral
Cause of amputation	Trauma	Sarcoma	Diabetes	Neurofibromatosis	Osteosarcoma
Number of months after amputation	15	9	5	3	13

Weight was measured without prosthesis.
[a]This patient dropped out after performing combined arm–leg ergometry.

To make comparisons between a combined arm–leg ergometer and an arm ergometer possible, both ergometers should be tested with the same protocol. As yet, a safe and effective exercise test for determining the aerobic capacity of lower limb amputees has not been developed. Therefore, the main purpose of this pilot study is to develop a protocol for graded exercise testing that can be used safely for lower limb amputees. Based on the results of a literature study, exercise testing using a combined arm–leg ergometer will be compared to an exercise test on an arm ergometer.

Patients

Inclusion criteria for participation in the study were unilateral lower limb amputation at the following levels: hemipelvectomy, hip disarticulation, transfemoral amputation, knee disarticulation or transtibial amputation. Patients followed their rehabilitation program at a center for rehabilitation. Exercise training was part of their normal rehabilitation program. Exclusion criteria were evidence or serious suspicion of coronary artery disease, stress- or exercise-related pain in the chest, bilateral lower limb amputation and upper limb amputation. Five patients who fitted these criteria were included in the study. Their characteristics are summarized in Table 1.

Methods

Two different ergometers were used for aerobic exercise testing: the Angio arm ergometer (Lode, Groningen, The Netherlands) (Fig. 1) and the Cruiser combined arm–leg ergometer (Enraf-Nonius, Delft, The Netherlands) (Fig. 2). The Angio can be adjusted to patient height. It is driven by synchronous arm cranking. On the Cruiser the amputee uses the arms as well as the leg. It is equipped with a comfortable seat, which gives a lot of support and stability. When using the Cruiser, the leg and arms are used alternately to overcome the resistance provided by the ergometer.

Patients were first tested on the combined arm–leg ergometer and then on the arm ergometer with at least a 1-week time interval. One patient dropped out after performing combined arm–leg ergometry due to evidence of cardiac ischemia.

Fig. 1

Arm Ergometer.

Before testing, patient age, height, weight and sex were noted. With these parameters maximal predicted heart rate (HR_{max}) (beats/min), oxygen uptake (ml/min) and minute ventilation (l/min) were calculated. The predicted values were calculated as follows (Cooper and Storer, 2001).

Maximal predicted heart rate

$$HR_{max} = 220 - \text{age (age is in years)}.$$

Fig. 2

Combined arm–leg ergometer.

VO_{2max} tested with the combined arm–leg ergometer men:

$$VO_{2\,max} = (0.0716\times height - 0.0518)\times(44.22 - 0.394\times age) + (0.0058\times weight)$$

women:

$$VO_{2\,max} = (0.0626\times height - 0.0455)\times(37.03 - 0.3971\times age) + (0.0058\times weight)$$

(VO_{2max} is in l/min, height is in m, age is in years and weight is in kg).

VO_{2max} tested with the arm ergometer

$$VO_{2\,max}(\text{arm ergometer}) = 0.7\times VO_{2\,max}\times(\text{combined ergometer})\,.$$

Maximal predicted ventilation (VE_{max})

$$VE_{max} = FEV_1\times 37.5$$

$\times$(FEV_1 is in *l* and represents
$\times$Forced Expired Volume in 1 second).

During testing, the following parameters were measured: maximum power output (W), heart rate (beats/min), oxygen consumption (VO_2 in ml/min), carbon dioxide output (VCO_2 in ml/min) and maximum ventilation (VE in l/min). The parameters VO_2, VCO_2 and VE were recorded using an Oxycon Delta (Jaeger, Bunnik, The Netherlands). Heart rate was measured using a Polar chest band (Polar, Vantaa, Finland) or by recording the electrocardiogram (ECG) with a Marquette (MAX-1 electronics, Milwaukee, USA).

The following parameters were calculated.

Breathing equivalents (EqO_2 and $EqCO_2$), defined as VE/VO_2 and VE/VCO_2.

Respiratory exchange ratio (RER), defined as the amount of exhaled carbon dioxide divided by the amount of inhaled oxygen. A RER of 1 during exercise was defined as the anaerobic threshold (AT). At power outputs above AT, carbon dioxide output by the lungs increases more rapidly than oxygen uptake because carbon dioxide generated by the bicarbonate buffering of lactic acid is added to the metabolic carbon dioxide production (Wasserman *et al.*, 1999). This makes RER increase to values above 1.

Breathing reserve (BR) (%), defined as the difference between the maximum voluntary ventilation and the maximum exercise capacity. Hence, this represents the body's residual capacity for further increasing ventilation at maximum exercise (Wasserman *et al.*, 1999). Normally during maximum exercise a BR of 50–20% is reached. If sufficiently severe, mechanical abnormalities such as obstructive or restrictive lung disease, respiratory muscle weakness or reduced chest wall compliance could result in true ventilatory limitation at maximum exercise (a BR of 0% is reached; Cooper and Storer, 2001).

Oxygen pulse, defined as the oxygen uptake divided by the heart rate (VO_2/HR). Oxygen pulse is reduced in physical deconditioning and all forms of cardiovascular limitation or disease (Cooper and Storer, 2001).

Relative oxygen uptake (VO_2/kg) in ml/min/kg.

Testing protocol

Both exercise tests started with 5 min of quietly sitting on the ergometer with the Polar chest band or ECG and Oxycon facemask on to get baseline measurements. After these 5 min, a warming-up was performed at a power output of 20 W for 3 min. After the warming-up, power output was increased by 5 W every minute, until any of the stopping criteria occurred (see below). Directly after the exercise test was terminated, a cooling-down of 5 min was performed.

Termination of exercise testing was indicated by either (1) the ergospirometer data, (2) the ECG or (3) the patient.

(1) Testing was stopped if either a RER of 1.15 was reached or VO_{2max} was achieved. This was the case if further increments in the workload did not cause a further rise in oxygen uptake.
(2) The test was terminated with the following abnormalities on the ECG recordings (American College of Sports Medicine, 1980):
   (a) ST-T segment horizontal of 'divergent' displacement of 0.2 mV above or below the resting isoelectric line for at least 0.8 s duration after the junction ('J') point;

Table 2 **Results of the exercise test on the combined arm-leg ergometer**

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
W_{max} (W)	115	105	65	95	90
$\dot{V}O_{2max}$ (predicted) (ml/min)	2244 (3180)	2267 (2594)	1804 (2307)	2117 (3114)	1357 (1931)
$\dot{V}O_2$/kg (ml/min/kg)	28.05	28.34	18.41	34.59	23.89
HR_{max} (predicted) (beats/min)	158 (181)	148 (176)	168 (162)	188 (197)	195 (205)
AT (HR)					
VE/$\dot{V}O_2$	123	105	Indeterminate	126	165
RER	123	105	128	131	165
AT (%$\dot{V}O_{2max}$)	74.7	66.0	69.7	44.3	61.4
$\dot{V}O_2$/HR (ml/min^2)	14.58	15.38	12.26	10.98	6.96
BF_{max} (min^{-1})	40	24	28	41	34
VE_{max} (predicted) (l/min)	82.7 (178.1)	69.9 (153.8)	56.3 (143.6)	78.6 (172.9)	35.9 (93.8)
RER_{max}	1.08	1.06	1.04	1.18	1.11
Reason for termination	Pain in leg	Pain in leg	General fatigue	Unable to sustain pace (50 rpm)	Pain under foot

W_{max}, maximal Watt; $\dot{V}O_{2max}$, maximal oxygen uptake; $\dot{V}O_2$, oxygen consumption; HR_{max}, maximal heart rate; AT, anaerobic threshold; HR, heart rate; VE, ventilation; RER, respiratory exchange ratio; BF_{max}, maximal beat frequency; VE_{max}, maximal ventilation; RER_{max}, maximal respiratory exchange ratio.

(b) ventricular arrhythmia (three or more successive ectopic ventricular complexes) or tachycardia;
(c) continuous bigeminal or trigeminal ectopic ventricular complexes or frequent unifocal or multifocal ectopic ventricular complexes amounting to greater than 30% (trigeminy) of the total beats/min;
(d) atrial–ventricular or ventricular conduction disturbances;
(e) second-degree atrial–ventricular block, Mobitz type I or type II (Wenckebach);
(f) Third-degree (complete) atrial–ventricular block or sudden left bundle branch block.

(3) Finally, testing was terminated if the patient showed any of the following signs: inability to maintain a revolution speed of 50 rotations/min, tiredness, pain in the arms or leg, a painful feeling in the chest, a feeling of dizziness or feeling faint, severe dyspnea, severe stab-like pains in the side, paleness, cyanosis, a cold and clammy feeling of the skin or a sudden strong decline of performance without direct cause. Testing was also terminated in the case of a defect in the measurement system. After testing a cooling-down was performed and the reason for termination of the exercise test was noted. After performing both exercise tests, patients were asked about their preference.

In one combined arm–leg exercise test and one arm exercise test the ECG was recorded. During the other tests, heart rate was monitored using a Polar chest band. Data were analysed manually and individually. Due to the exploratory nature of the study and the low number of participants more rigorous measures of analysis were not used.

Results

See Table 2 for the results of the exercise test on the combined arm–leg ergometer. Patients 3, 4 and 5 reached a heart rate of at least 10 beats/min from their age-predicted maximal heart rate. In patients 4 and 5 this indicates normal cardiac limitation for this type of exercise without cardiac disease. The ECG for patient 3 showed ST-T segment depression, indicating cardiac ischemia. This patient subsequently dropped out of the study. Patients 1 and 2 showed muscular limitation because they did not reach their maximal predicted heart rate or predicted maximal ventilation, while their maximum RER was higher than 1.05, indicating maximal effort.

See Table 3 for the results of the exercise test on the combined arm ergometer. All patients showed muscular limitation for arm exercise, because they did not reach their age-predicted maximal heart rate or predicted maximal ventilation, which rules out cardiac or pulmonary limitation. RER was higher than 1.05 in all cases, ruling out poor effort as the exercise limitation.

See Table 4 for a comparison of results for combined arm–leg ergometry and arm ergometry.

When comparisons were made between predicted $\dot{V}O_{2max}$ values and attained $\dot{V}O_{2max}$ values on the combined arm–leg ergometer, it is striking that our relatively fit amputees consistently attained a lower than predicted maximal oxygen uptake, ranging from 68 to 87% of the predicted value.

When comparisons were made between predicted and attained $\dot{V}O_{2max}$ during arm ergometry, the amputees reached 72–115% of their predicted $\dot{V}O_{2max}$, which was assumed to be 70% of that reached on the combined arm–leg ergometer (Cooper and Storer, 2001).

Out of the four patients who performed both exercise tests, three stated their preference for the combined arm–leg ergometry in comparison to the arm ergometry. One patient had no preference at all.

Table 3 Results of the exercise test on the arm ergometer

	Patient 1	Patient 2	Patient 3[a]	Patient 4	Patient 5
W_{max} (W)	115	125		80	70
$\dot{V}O_{2max}$ (predicted) (ml/min)	2047 (2226)	2089 (1816)		1589 (2180)	1183 (1352)
$\dot{V}O_2$/kg (ml/min/kg)	25.59	26.11		25.96	20.83
HR_{max} (predicted) (beats/min)	138 (181)	153 (176)		147 (197)	177 (205)
AT (HR)					
VE/$\dot{V}O_2$	115	122		132	168
RER	115	106		132	151
AT (%$\dot{V}O_{2max}$)	62.2	81.7		77.2	83.8
$\dot{V}O_2$/HR (ml/min^2)	13.42	15.81		10.73	7.73
BF_{max} (min^{-1})	41	28		32	35
VE_{max} (predicted) (l/min)	79.4 (177)	68.2 (153.8)		55.7 (172.9)	36.5 (93.8)
RER_{max}	1.08	1.07		1.12	1.11
Reason for termination	Pain in hands	Cramping of hands		Shortness of breath	Pain in arms and hands

W_{max}, maximal Watt; $\dot{V}O_{2max}$, maximal oxygen uptake; $\dot{V}O_2$, oxygen consumption; HR_{max}, maximal heart rate; AT, anaerobic threshold; HR, heart rate; VE, ventilation; RER, respiratory exchange ratio; BF_{max}, maximal beat frequency; VE_{max}, maximal ventilation; RER_{max}, maximal respiratory exchange ratio.
[a]Test not performed.

Table 4 Comparison of combined arm–leg ergometry and arm ergometry

	Combined arm–leg ergometry	Arm ergometry
$\dot{V}O_{2max}$	+	−
HR_{max}	+ +	±
Electrocardiogram	±	− −
Maximum power output	+	±
Determining AT	+	+
Ergometer access	±	+ +
Exercise time	−	−
Patient preference	+ +	+
Stump support	− −	+

These scores were based on the opinions of the researchers (+ +, excellent; +, good; ±, neither good nor bad; −, bad; − −very bad). $\dot{V}O_{2max}$, maximal oxygen uptake; HR_{max}, maximal heart rate; AT, anaerobic threshold.

The ECGs for both the combined arm–leg ergometry and the arm ergometry protocol showed a lot of interference due to muscle activity. However, the combined arm–leg ergometer ECG was easier to interpret than the arm ergometer ECG. The ECG during arm ergometry showed a lot of disturbances on the baseline, making reliable interpretation of the P and RS complexes impossible.

Discussion

We have proven that arm ergometry and combined arm–leg ergometry in amputees are feasible. Future research will have to provide data on reliability and validity.

Combined arm–leg ergometry elicited higher maximal oxygen uptake in all patients. Heart rate and maximal ventilation were higher in three out of four patients who performed both tests. This is as expected, because more muscles are used during combined arm–leg ergometry. Therefore, combined ergometry places the largest load on the cardiovascular and pulmonary systems and thus seems better suited to exercise testing.

Only five patients were included in this study. This is not a large study sample and it makes statements about reliability and validity of the protocol impossible. Furthermore, all patients were relatively healthy and were about to finish or had already finished their rehabilitation program. This group of patients is not very comparable to the average, elderly PVD amputee.

Predicted $\dot{V}O_{2max}$ values were based on equations for non-amputees exercising on a cycle or treadmill ergometer, because there were no prediction equations available for the amputee group. Reference values need to be developed for the lower limb amputee population to make comparison between amputees possible.

$\dot{V}O_{2max}$ during arm ergometry was assumed to be 70% of predicted $\dot{V}O_{2max}$ for cycling ergometry (Cooper and Storer, 2001) but this might also be an inaccurate assumption. Interpretation of pulmonary limitations of exercise testing may be improved by a pulmonary function test especially in patients who smoke or have known pulmonary disease.

In this study, software and ergometer, blood pressure recordings and ECG or Polar heart band recordings were not integrated into one system, with several consequences for the measurements. The software could not measure work rate because the ergometer and software were not coupled, which made estimation of power output and energy consumption less accurate. After testing on the arm ergometer, it was not possible to decrease resistance immediately for cooling down. The arm ergometer first had to be turned off completely and then started up again to choose the resistance for cooling down. This procedure took about 20 s. If the arm ergometer had been coupled to the Oxycon software, the resistance would have been decreased automatically as soon as the cooling-down phase had been selected.

Installation of blood pressure recordings in the Oxycon software would make it possible to follow the blood pressure response of patients during testing, adding to protocol safety. It would also make determining cardiac limitation of exercise easier and more accurate.

Advantages of integrating ECG or heart rate measurements into the Oxycon measurements are the possibility of calculations with heart rate directly from the Oxycon results and the possibility of showing ECG abnormalities directly on the computer screen. It might be helpful to use ECG recordings with fewer leads. For some of the younger traumatic patients, recording of an ECG might not even be necessary.

Another point of discussion is that in this study, a protocol with increments of 5 W was used. However, most patients required more than 15 min to reach their symptom-limited maximum exercise capacity, whereas the ideal duration of an exercise test is 12–15 min (Powers and Howley, 2001). This means that increments of 10 W or more are indicated in patients who are deemed relatively fit. Protocol increments may also be adjusted to the heart rate after warming up, as in the Young Men's Christian Association protocol for the cycle ergometer (Young Men's Christian Association, 2000).

Most patients stated that they experienced the combined arm–leg ergometer as the most comfortable instrument to use for exercise testing. However, during observations in the fitness room it seemed that especially elderly people had some trouble finding the right rhythm. The arm ergometer on the other hand has proven to be easy to use, in this study as well as by other researchers (Fletcher *et al.*, 1988; Hutzler *et al.*, 1998). In addition, getting seated on the combined arm–leg ergometer requires quite a bit of maneuvering. Another problem for the elderly PVD amputee is that exercise testing may be terminated because of claudication in the remaining leg instead of the attainment of maximal heart rate, ventilation or oxygen uptake. This should be studied in future. Therefore, it might be advisable to use the arm ergometer for exercise testing of elderly amputees. However, the use of the arm ergometer for exercise testing in elderly amputees might not be safe. It is still not clear whether arm ergometry results in higher blood pressures and more cardiac stress. According to some researchers, cardiac stress is greater in arm ergometry exercise testing (Bostom *et al.*, 1987). On the other hand, in the study of Finestone, the main reason for terminating arm exercise testing was arm fatigue rather than pulmonary or cardiac problems (Finestone *et al.*, 1991). In this study, blood pressure was not recorded during exercise testing, because equipment did not make this possible. To be certain of blood pressure responses in amputees during arm exercise, further studies need to be performed.

Conclusion

Compared to arm ergometry, combined arm–leg ergometry elicited higher maximal oxygen uptake in all patients. The limiting factor during arm ergometry was in all cases muscular instead of cardiac or pulmonary. Therefore, combined ergometry places the largest load on the cardiovascular and pulmonary systems and thus seems better suited to testing maximal exercise capacity.

Based on the results and theory, recommendations for the use of different protocols in lower limb amputees are as follows.

(1) Combined arm–leg ergometer for patients with a unilateral amputation without significant claudication of the remaining leg or patients who require adequate ECG monitoring during exercise testing.
(2) Arm ergometry for patients with bilateral amputation or patients with significant claudication in the remaining limb. For patients who need ECG monitoring but cannot use the combined arm–leg ergometer, an intermittent protocol might be suitable.

In the future it might be possible to choose only one measurement protocol for the whole amputee group. However, the different problems that arose when using any of these protocols have to be solved first.

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