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Ergometer Modification for Combined Arm-Leg Use by Lower Extremity Amputees in Cardiovascular Testing and Training

Andrew G. Bostom, MS, PT
Department of Physical Education, Queens College, Flushing, NY 11367
Eugene Bates, COTA
Department of Prosthetics and Orthotics, Helen Hayes Hospital, West Haverstraw, NY 10993
Nicholas Mazzarella, MS, Ellen Block, MS, Joan Adler, MA
Goldwater Memorial Hospital, Roosevelt Island, NY 10044

ABSTRACT. Bostom AG, Bates E, Mazzarella N, Block E, Adler J: Ergometer modification for combined arm-leg use by lower extremity amputees in cardiovascular testing and training. Arch Phys Med Rehabil 68:244–247, 1987.

• A commercial arm-leg ergometer was adapted so that combined bilateral arm-single leg work could be performed by unilateral lower extremity amputees from their own wheelchairs. Three middle-aged to elderly unilateral amputees performed progressive discontinuous bilateral arm crank and combined bilateral arm-single leg cycle exercise tests on the same air-braked ergometer adapted for either form of ergometry. Select amputees may achieve greater peak oxygen uptakes ($\dot{V}O_2$), power outputs (PO), and heart rates (HR) during combined bilateral arm-single leg cycle testing versus bilateral arm crank testing. Following 14 weeks of combined arm-leg training on the modified ergometer, a 73-year-old above-knee amputee demonstrated peak $\dot{V}O_2$ and PO increases of 25% (+3.8mL·kg^{-1}·min^{-1}) and 33% (+25W) respectively. Combined arm-leg ergometry as described herein may activate the largest available muscle mass and elicit the greatest oxygen uptake during exercise testing. In addition this exercise modality may simultaneously condition the arms and leg, providing functional gains in both wheelchair propulsion and prosthetic ambulation.

KEY WORDS: Amputees; Exercise therapy; Physical fitness; Rehabilitation

Peripheral vascular disease (PVD) and trauma account for the overwhelming majority of lower extremity amputations.[1] Amputees with PVD have a high incidence of concurrent ischemic heart disease,[9] while traumatic amputees are at increased risk for the development of cardiovascular disease subsequent to the amputation.[6] Prevalent cardiovascular disease within the amputee population necessitates the use of cardiovascular exercise testing and individualized endurance training programs to facilitate optimal rehabilitation.

For much of the early stages of rehabilitation, and in a large number of cases for prolonged periods, many amputees will be essentially wheelchair-dependent.[1] Glaser and associates[3] have shown that wheelchair ergometry imposes a substantially greater cardiovascular strain than does bicycle ergometry at equivalent submaximal power outputs. Amputees in general demonstrate poor overall aerobic fitness,[7] and diminished upper body aerobic capacity in particular.[8] Wheelchair propulsion or upper body testing and training modalities such as wheelchair or arm crank ergometry may impose significant metabolic[12] and cardiovascular[17] strain on a population with poor upper body work capacity. In two recent studies, Toner and associates[15,16] demonstrated that the cardiovascular strain of submaximal arm crank ergometry could be diminished by distributing a percentage of the total power output to the lower extremities while performing combined arm-leg ergometry. Accordingly, a Schwinn Air Dyne ergometer was adapted so that bilateral arm-single leg work could be performed by unilateral amputees from their own wheelchairs. This report contains clinical evidence demonstrating the efficacy of combined arm-leg ergometry as a testing and training modality for the middle-aged to elderly amputee population.

MATERIALS AND METHODS

The unique construction design of the Schwinn Air Dyne ergometer made it particularly suitable for studying the acute and chronic cardiovascular responses to combined arm-leg work in the amputee population. With arm levers and foot pedals interconnected to an air-resistant flywheel, arm work performed as a push-pull movement and leg work performed as pedal cranking could be conducted independently or in combination.[4,13] Minimal coordination was required to perform arm plus leg work as the arm and leg mechanisms are coupled. In the combined arm-leg work apparatus of Toner and associates,[15,16] for example, the arm and leg ergometers were not coupled and therefore a coordinated effort was required to maintain equal crank rates on the separate arm and leg ergometers.[15] Combined bilateral arm-single leg testing was performed with the patients seated in their own wheelchairs at a distance behind the ergometer that permitted single-leg cycling without excessive hip-knee flexion or knee hyperextension. The ergometer was bolted to a specially constructed wooden platform (fig) that also supported the patient in the wheelchair. Wheelchairs were secured with bevelled wooden chocks with stippled rubber undersurfaces to prevent sliding. Specially constructed footplates with kydex heel supports and Velcro straps facilitated single-leg cycling, while straight canes (interconnected via an elbow piece and a fitted aluminum clamp to the vertical component of the ergometer's arm mechanism) enabled subjects to perform simultaneous push-pull arm work from their own wheelchairs. The height and length of the cane attachment were adjustable for a patient's seated height and arm length. The workload indicator was mounted on a malleable metal support and repositioned at the front of the platform (down and to the patient's right or left) to avoid contact with the clamps (see inset, fig).

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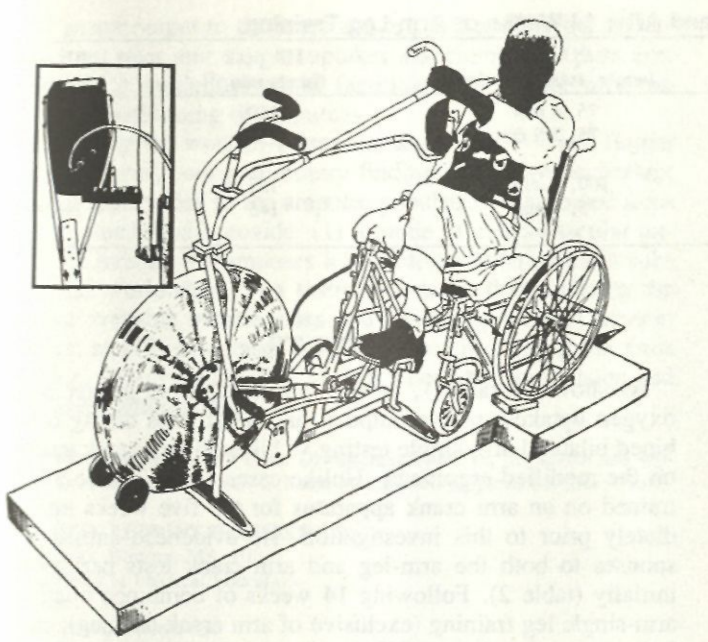

The Schwinn Air Dyne ergometer modified for combined bilateral arm-single leg work from a wheelchair. Inset shows mounting of workload indicator.

Arm crank tests were performed on the Schwinn Air Dyne adapted for bilateral arm crank ergometry by replacing the foot pedals with foam-coated hand grips. The arm crank ergometer was then mounted on a table and secured so that the hand grips were at a comfortable height and distance (approximately shoulder level) for subjects to perform bilateral arm work from their own wheelchair.[2] Prior to testing, a newly purchased and unused Schwinn Air Dyne ergometer was calibrated according to the manufacturer's specifications.[13] It should be noted that Telford and associates,[14] utilizing dynamometer testing, found that air-braked ergometers were at least as accurately calibrated as their mechanically braked counterparts, such as the standard Monark bicycle ergometer.

Construction of the primary modifications. The clamps were constructed from a block of aluminum rod 2in in diameter by 2in thick. One inch and ¾in diameter openings were made in the block with a drill. The entire block was then cut with a band saw to create a bivalve configuration. The two halves were joined together by hexheaded steel screws.

The footplates were constructed from the following materials: a 4×11in piece of plywood, two pieces of pine block (4in wide by the pedal thickness high), a kydex heel loop (7in long by 2in wide), and two 4×2in Velcro hooks attached to the undersurface of the plywood. The two pieces of pine,

attached to the plywood with wood screws, secured the footplate to the sides and upper surface of the ergometer pedal. An additional piece of plywood was cut to secure the remaining free surface of the pedal. This plywood support was fastened to the pine supports with T-nuts and thumb screws to make it removable.

The elbow pieces were constructed from a 20-in length of ¾in aluminum tubing. Using a tube bender a 90° elbow bend was made 10in from one end. A hole was drilled in the opposite end to accommodate the spring clip from the adjustable straight cane.

Test protocols. The arm crank and combined arm-leg exercise tests were performed with intermittent protocols to limit the effects of local muscular fatigue and facilitate the recording of diagnostic quality ECGs without compromising the achievement of maximal responses.[10,18,19] Four-minute work stages were followed by 12-minute rest periods. After an initial workload of 25W the workloads were increased by 25W each exercise stage to maximum. Predetermined endpoints for testing during both tests included moderate to severe angina pectoris or dyspnea, complex ventricular dysrhythmias, or more than 3mm of ST depression on monitoring ECG. The actual tests were terminated when subjects failed to maintain the desired power output despite what appeared to the investigators to be a maximal volitional effort. These endpoints corresponded to 106% and 109% of age-predicted maximal heart rate in case 3, 87% and 92% in case 2, and 74% and 80% in case 1 for the arm crank and combined arm-leg tests, respectively. It should be noted that case 1 had a 15-year history of diabetes mellitus (only recently under good control) and evidence of neuropathy when evaluating his heart rate response. (See Hilsted[5] for a discussion of these factors.) The respiratory quotients were well above unity for all subjects at their respective endpoints indicating true maximal volitional efforts.[2,4,10]

A 12-lead ECG was obtained at rest, following Valsalva maneuver, after hyperventilation, and immediately after termination of each exercise stage, as well as several times during the postexercise recovery period. The ECG rhythm was continuously monitored throughout the rest, exercise, and recovery periods via a lead V_5 placement. To obtain blood pressure during the exercise tests, the subject continued arm work with the left arm while one investigator recorded the blood pressure in the momentarily still right arm.[19] During this brief period, another investigator assisted the subject in maintaining the desired power output. These indirect brachial blood pressures were obtained at two minutes into each exercise stage using a mercury column sphygmomanometer. Blood pressure was also measured immediately after exercise and at several intervals during the postexercise recovery period.

One subject (case 3) participated in a 14-week training program of combined bilateral arm-single leg work on the mod-

Table 1: Peak Values for Arm-Leg and Arm Crank Tests

Case		Peak $\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	PO peak (watts, total duration)	HR peak (beats·min^{-1})	BP peak (mmHg)
1	Arm-leg test	14.0	100, 2 min	140	150/80
	Arm test	10.3	75, 2 min	130	130/80
2	Arm-leg test	14.3	50, 4 min	132	180/90
	Arm test	10.8	40, 3 min	125	200/100

Table 2: Peak Values for Tests, Before and After 14 Weeks of Arm-Leg Training

Case		Peak Vo_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	PO peak (watts, total duration)	HR peak ($beats \cdot min^{-1}$)	BP peak (mmHg)
3*	Arm-leg test (initial)	15.3	75, 4 min	160	194/96
	Arm test (initial)	14.9	75, 2.5 min	155	210/110
	Arm-leg test (after training)	19.1	100, 4 min	155	210/90
	Arm test (after training)	14.0	75, 4 min	145	194/90

*Case 3 had five weeks of arm crank training immediately prior to initial tests.

ified ergometer. No specific arm crank training took place during the 14 weeks of the study. Case 3 engaged in three training sessions per week. The training corresponded to 75%–85% of the maximal heart rate achieved on the initial arm-leg test, ie, 120 to 132 $beats \cdot min^{-1}$. The initial exercise program was as follows: three minutes of warm-up at 25W, seven minutes stimulus phase at 45W, and five minutes recovery, ie, 2.5 minutes active (at or near warmup power output) and 2.5 minutes passive.

During weeks 11-14, the exercise program consisted of the following: five minutes warmup at 35-40W, 25-30 minutes stimulus at 50-65W, and ten minutes recovery, approximately ⅓ active and ⅔ passive. For the first three sessions, case 3 was continuously monitored for rhythm disturbances by hard-wire ECG using a modified V_5 lead placement. Rhythm monitoring thereafter was performed at three-week intervals during the course of the investigation as the intensity and duration of the training program increased. Case 3 did not evidence any dysrhythmias during the investigation. Heart rate response was determined by palpation of the right radial pulse (except on those occasions when rhythm monitoring was conducted) while another investigator assisted case 3 in the performance of the arm work component of the arm-leg ergometry. Heart rates and blood pressures as previously described were recorded at rest, during warmup, several times during the stimulus phase, and following both active and passive recovery during each exercise session.

Subjects. Three subjects participated in this preliminary trial. Case 1 was a 45-year-old man with a 15-year history of diabetes mellitus, not well controlled on oral hypoglycemic agents, who was placed on insulin 2/85 to improve control. He had a left below-knee amputation 1/85 secondary to an infected ulcer. The patient had a long history of alcohol abuse, and he was a one pack per day smoker for an undetermined number of years. He had evidence of peripheral neuropathy. The post-amputation hospital course was uneventful.

Case 2 was a 76-year-old woman who had a left below-knee amputation 4/85 secondary to a nonhealing ulcer refractory to intravenous antibiotics and left lower extremity sympathectomy. She had a history of hypertension and was treated with atenolol, 50mg per day. Her hospital course following amputation was uneventful. Case 3 was a 73-year-old man who had a right above-knee amputation 9/84 secondary to gangrene resulting from peripheral vascular disease. The patient also underwent successful debridement of a left ankle ulcer concurrent with the amputation. The rest of this patient's medical history was unremarkable and his postamputation hospital course was uneventful.

RESULTS

As shown in table 1, cases 1 and 2 achieved greater peak oxygen uptakes, power outputs, and heart rates during combined bilateral arm-single testing vs bilateral arm crank testing on the modified ergometer. Unlike cases 1 and 2, case 3 had trained on an arm crank apparatus for the five weeks immediately prior to this investigation. He evidenced similar responses to both the arm-leg and arm crank tests performed initially (table 2). Following 14 weeks of combined bilateral arm-single leg training (exclusive of arm crank training), case 3 demonstrated clearly differing responses to those two forms of work when retested. While the peak responses to arm cranking (Vo_2 peak, power output, heart rate, and blood pressure) remained similar to the pretraining values, combined arm-leg peak Vo_2 and peak power output increased by 20% ($+3.8 mL \cdot kg^{-1} \cdot min^{-1}$) and 33% (+25W) respectively (table 2).

DISCUSSION

Based on our preliminary trial, it appears reasonable to test and train a larger amputee population utilizing the modified arm-leg ergometer. The two subjects who had no previous arm crank training achieved greater peak oxygen uptakes and power outputs during arm-leg vs arm crank testing. The one subject who trained for 14 weeks on the arm-leg ergometer evidenced clear gains in both peak power output and peak oxygen uptake during the performance of arm-leg work.

Previous investigators have examined the cardiovascular responses to separate and combined arm and leg work on an air-braked ergometer.[4,11] Subjects achieved greater maximal power outputs and oxygen uptake values during combined arm plus leg work versus leg work or arm work alone.[4,11] At submaximal power outputs, arm work, performed independently as a push-pull movement, elicited significantly higher heart rate and Vo_2 responses compared to both independent leg cycling and combined arm push-pull, leg cycling work.[4] Future noninvasive studies that evaluate cardiac output (eg, CO_2 re-breathing) may further elucidate the differences between arm ergometry and combined single leg-bilateral arm ergometry in amputees. Nagle and colleagues[11] devised a strain gauge and optical sensing system for the Schwinn Air Dyne ergometer that displayed the separate power output contribution of the arms and legs for both investigator and subject. Use of a similar system with the modified ergometer described here could evaluate the cardiovascular responses to different specific distributions of total power output to the arms and leg. Ultimately guidelines might be established for *specific* distributions of

total power output to the arms and leg that mollify the excessive heart rates and oxygen uptakes associated with pure arm work. Such guidelines could facilitate safer, more efficient aerobic conditioning of amputees.

In light of the work of Toner and associates[15,16] and Hagan and associates,[4] our preliminary findings may have important clinical applications to the amputee population. Combined arm-leg ergometry may provide: (1) a mode of cardiovascular endurance training that imposes less cardiovascular strain at submaximal workloads, (2) a testing modality that activates the largest available muscle mass and elicits the greatest oxygen uptake, and (3) simultaneous aerobic conditioning of the arms and leg, improving function in both wheelchair propulsion and prosthetic ambulation.

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ADDRESS REPRINT REQUEST TO:
Andrew G. Bostom, MS, PT
Department of Physical Education
Queens College
65-30 Kissena Boulevard
Flushing, NY 11367

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