Circuit training provides cardiorespiratory and strength benefits in persons with paraplegia

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ABSTRACT

JACOBS, P. L., M. S. NASH, and J. W. RUSINOWSKI, JR. Circuit training provides cardiorespiratory and strength benefits in persons with paraplegia. *Med. Sci. Sports Exerc.*, Vol. 33, No. 5, 2001, pp. 711–717. **Purpose:** This study tested the safety and the effects of circuit resistance training (CRT) on peak upper extremity cardiorespiratory endurance and muscle strength in chronic survivors of paraplegia due to spinal cord injury. **Methods:** Ten men with chronic neurologically complete paraplegia at the T_5–L_1 levels participated in the study. Subjects completed 12 wk of CRT, using a series of alternating isoinertial resistance exercises on a multi-station gym and high-speed, low-resistance arm ergometry. Peak arm ergometry tests, upper extremity isoinertial strength testing, and testing of upper extremity isokinetic strength were all performed before and after training. **Results:** None of the subjects suffered injury from exercise training. Significant increases were observed in peak oxygen consumption (29.7%, $P < 0.01$), time to fatigue ($P < 0.01$), and peak power output during arm testing ($P < 0.05$). Significant increases in isoinertial strength for the training maneuvers ranged from 11.9% to 30% ($Ps < 0.01$). Significant increases in isokinetic strength were experienced for shoulder joint internal rotation, extension, abduction, adduction, and horizontal adduction ($Ps < 0.05$). **Conclusion:** Chronic survivors of paraplegia safely improve their upper extremity cardiorespiratory endurance and muscle strength when undergoing a short-term circuit resistance training program. Gains in fitness and strength exceeded those usually reported after either arm endurance exercise conditioning or strength training in this subject population. **Key Words:** EXERCISE, ENDURANCE, MUSCULAR, SPINAL CORD INJURY

Within the past two decades, cardiopulmonary disease has emerged as the major cause of death and an important source of morbidity for persons aging with spinal cord injuries (SCI) (15,16,39). One possible cause for their disease susceptibility is sedentary lifestyle, which is strongly associated with, and considered an independent risk factor for, heart disease (6). Profound physical inactivity is common among persons with paraplegia, with reports placing survivors of paraplegia at the lowest end of the human fitness spectrum (14,38). These findings are supported by a report in which 25% of healthy young persons with paraplegia had an upper extremity peak oxygen consumption ($\dot{V}O_{2peak}$) only marginally sufficient to maintain independent living (30). Additionally, survivors of paraplegia have blood lipid profiles characterized by elevated total cholesterol and low-density lipoprotein cholesterol, and depressed high-density lipoprotein cholesterol, a lipid profile normally associated with, if not a direct result of, sedentary lifestyle (4,5,8).

Regular participation in physical conditioning improves the fitness of persons with SCI (10,13,35), although their choices of exercise mode are more restricted than those available to persons without disability. The training modes commonly used by persons with paraplegia—arm ergometry (AE) and wheelchair ergometry (WE)—often cause upper extremity injuries that compromise their ability to perform necessary daily activities (7,11,31,32). Such training may also hasten the early onset of pain and musculoskeletal decline of the shoulders and arms reported among young persons with SCI (12,37). These concerns challenge the suitability of arm and wheelchair ergometry as primary training modes to enhance fitness and health of individuals with paraplegia.

Although many studies have examined the effects of endurance training on fitness levels in persons with SCI, reports investigating safety and effectiveness of resistance training are limited. Despite the recommendation of the American College of Sports Medicine for adults to include resistance training sufficient to develop and maintain fat-free mass (2), very few studies have considered whether resistance exercises improve cardiorespiratory endurance and muscle strength necessary for performance of daily activities using the shoulders and arms (9,13,29). Previous studies have either met with limited success in increasing both strength and endurance (29), have not tested both components of fitness (9), and/or have strengthened only a limited number of upper extremity muscles (13).

Circuit resistance training (CRT) performed by persons without physical disability reportedly increases both cardiorespiratory endurance and muscle strength (2,20,27). This type of conditioning consists of resistance exercises performed in series, with one set executed per exercise. A

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prescribed number of circuits are then completed for each training session. The cardiorespiratory benefits of CRT have been related to resistance intensity, total training volume, and the duration and type of rest/recovery periods (20). The sole controlled study to examine the effects of CRT in subjects with paraplegia reported significant increases of cardiovascular endurance after 9 wk of training but did not investigate strength outcomes (9). Further, the hydraulic exercise equipment used for training restricted resistance exercises to two maneuvers employing concentric contractions alone and required repeated physical transfers of subjects from their wheelchair to the seat of the exercise station. This likely allowed prolonged rest between exercises, which should be minimized in the design of CRT programs. The present study utilized a commercially available weight training system that permits independent use by persons with paraplegia from their wheelchairs and allows resistance training using concentric and eccentric contractions of key muscles of the arms and shoulder complex. The purpose of this study was to examine the safety and effects of a CRT program using mixed resistance training and arm ergometry on measures of muscle strength and cardiorespiratory endurance in persons with paraplegia secondary to SCI.

METHODS

Approach to the problem. The CRT algorithm used for this study was modeled after a previously published training program found effective for increasing both muscular strength and cardiopulmonary endurance in adolescents with insulin-dependent diabetes mellitus (27). As cardiorespiratory endurance is generally poor in persons with paraplegia, and as limited evidence suggests that resistance training alone might significantly increase their upper limb endurance, a small percentage of the total exercise time was dedicated to arm ergometry. In contrast to all earlier studies examining training in persons with SCI, this arm exercise was conducted without applied resistance, which has been thought to contribute to upper extremity pain after SCI. Otherwise, the training goals were twofold. First, we sought to strengthen the upper trunk and shoulder complex, with emphasis on the deltoids, posterior shoulder muscles, scapular stabilizers, and upper back. These are areas of defined muscle weakness for persons with paraplegia (29,33,34). Second, we sought to stretch muscles whose tightness is known to limit range and decrease shoulder joint and shoulder girdle stability and balance (11,31,32). As such, the exercises were performed throughout the entire functional range using both concentric and eccentric actions that especially encouraged stretching of the chest (pectorals) and back (scapular stabilizers and shoulder girdle depressors). These muscles are seldom stretched during the course of daily activities by persons living with paraplegia.

Although target intensities for resistance and endurance training of healthy persons have long been known, far less is known of the resistance targets necessary to satisfy the specific needs of persons with disabilities. The percentage of peak muscular effort needed by persons with lower limb disability to: 1) locomote a wheelchair, 2) depress and transfer the body, and 3) elevate and support the body weight during pressure relief all formed the basis for the selected resistance intensities (28,33,34). Various reports have suggested guidelines for muscle strengths necessary to satisfy the performance of these three key activities, which have not been applied in other studies attempting to strengthen the upper extremities after SCI (9,13). Most shoulder girdle, chest, and arm muscles use less than 15% of their maximal strength to effect the various phases of weight relief. However, the sternal pectoralis major requires an average force output of 32% during the lift phase, and the latissimus dorsi 58% and 51% during the lift and hold phases, respectively. During wheelchair propulsion, the greatest force output (on a percentage basis) is supplied by sternal pectoralis major during the push phase (at a peak force averaging 58% of maximal with a median intensity of 35%) and by the supraspinatus during the push phase (at 67% of maximum and a median intensity of 27%) (28). For the recovery phase of wheelchair locomotion (which primarily uses the middle and posterior deltoids, supraspinatus, subscapularis, middle trapezius, and triceps), the percentage of maximum forces ranges from 30% for the subscapularis (first onset) to 55% and 67% for the middle trapezius and subscapularis (second onset), respectively. During body weight transfers, the serratus anterior requires 47% of maximal force in the leading arm and 54% in the trailing arm with the sternal pectoralis major, the latissimus dorsi, and the anterior deltoid requiring 81% and 49%, 40% and 25%, with 20% and 44% of maximal force in the leading and trailing arms, respectively. In most cases, the greatest forces exerted during these daily activities were placed on the muscles that move and stabilize the scapula, as well as the pectoralis major functioning as a prime mover of both shoulder flexion and horizontal adduction (33). The resistance intensities selected for training in the current study were modeled after, and satisfied, these needs.

Subjects. Subjects for this investigation were 10 healthy men between 28 and 44 yr old with chronic neurologically stable spinal cord injuries at the T_5–L_1 levels. The T_5 level was designated as the upper limit since persons with lesions at or below this level experience both competent and relatively homogeneous cardiovascular sympathetic drive (23). All subjects had neurologically complete spinal cord lesions as defined by the American Spinal Injury Association Standards for Neurological Classification (17). Subjects included those in good health, operationally defined as asymptomatic for acute treatable illness, and without histories of shoulder joint dysfunction (defined as chronic pain that limited range or subluxation at rest or during activity). The absence of cardiac dysrhythmia or ischemia at rest and during exercise stress was assessed by a peak effort graded exercise test (GXT) with 12-lead electrocardiography. Subjects provided written informed consent in accordance with guidelines established by the Institutional Medical Sciences Subcommittee for the Protection of Human Subjects. Descriptive characteristics of the study subjects are shown in Table 1.

TABLE 1. Descriptive characteristics of 10 subjects with thoracic level paraplegia.

Variables	Range	Mean ± SD
Age (yr)	28.4–44.5	39.4 ± 6.0
Level of injury	T_5–T_{12}	—
Duration of injury (yr)	0.7–16.8	7.3 ± 6.0
Body mass (kg)	59.1–97.6	74.0 ± 12.7
Height (cm)	154.9–180.3	172.9 ± 7.8

Cardiorespiratory exercise testing. A previously described peak, multi-stage, discontinuous GXT, using a calibrated, hydraulically braked arm ergometer (UBE, Cybex, Ronkonkoma, NY), was performed before and after CRT (24). The ergometer seat was adjusted to match the heights of the ergometer crank axis and the subject's shoulder joint, while allowing a slight bend of the elbow when the crank handle was at the farthest point from the subject. Testing was performed at 60 revolutions per minute. Metabolic and cardiac responses to exercise were continuously monitored via open-circuit spirometry (SensorMedics Horizon System, Loma Linda, CA) and 12-lead electrocardiography (Fikuda-Denshii, Tokyo, Japan). An initial 3-min work interval was performed with a power output of 400 kpm, with subsequent increases of power output equaling 100 kpm per every 3-min interval thereafter. Physiologic and electrocardiographic exercise termination points were consistent with the Guidelines for Exercise Testing and Training of the American College of Sports Medicine (3). Peak work was operationally defined as volitional exhaustion, inability to maintain power output, or the point at which increasing workload failed to provoke further increase of $\dot{V}O_2$.

Isoinertial strength testing. Isoinertial maximum strength was assessed before training and repeated after 4, 8, and 12 wk of CRT. The isoinertial testing was performed on an Equalizer 7000 Multi-Station Exercise System (Helm; Bozeman, MT), the same resistance equipment used for subject training. Before the initial strength testing session, subjects were allowed several warm-up repetitions at each station. The weight stack for each maneuver was then set at the minimum resistance and progressively increased in standard increments for all maneuvers. Subjects were instructed to complete 10 repetitions of each maneuver in good form and control, with incremental resistance increases until they were unable to complete more than eight such repetitions. Maximal isoinertial strength was calculated using the Mayhew regression equation (26):

$$1\text{RM} = \text{Wt}/(0.533 + 0.419e^{-0.055*\text{reps}}),$$

where 1RM was the calculated one repetition maximum, Wt was the resistance used in the last set where more than three repetitions but less than eight repetitions were completed, and reps was the number of repetitions completed in the last set. Values calculated using this procedure correlate very highly ($r = 0.96$) with the measured one repetition maximum (26). Subsequent testing sessions (weeks 4, 8, and 12) utilized a series of incremental sets based on the previous testing session. During those test sessions, subjects completed three sets per exercise station using 60%, 75%, and 90% of the 1RMs calculated during the previous test session, with the Wt and reps values of the third set used to calculate the adjusted 1RMs for the next month of training.

Isokinetic strength testing. Isokinetic testing was conducted on a Kin-Com Dynamometer (Chattanooga Inc, Hixson, TN). The following movements were tested on the dominant limb before and after CRT: 1) seated elbow flexion and extension, 2) seated shoulder external and internal rotation, 3) seated shoulder flexion and extension, 4) seated shoulder abduction and adduction, and 5) supine shoulder horizontal adduction and abduction.

Subjects were allowed 3 min of exercise on an arm ergometer before isokinetic testing. Subjects were then positioned and stabilized according to manufacturer recommendations, with modification for the elbow testing performed while seated in their wheelchairs. Gravity correction was employed with the dynamometer level arm close to the horizontal position (18). The following steps were taken to ensure replication of testing parameters from pretest to posttest (35):

1) System parameters were recorded to assure replication of subject position on the posttest:

A. Dynamometer height, tilt, rotation, mechanical range of motion stops, and level arm length

B. Seat rotation, back angle, bottom depth, and angle.

2) Subjects were stabilized with an adjustable strap around their torso and either the wheelchair or the Kin-Com seat.

3) Testing was conducted at $60°\cdot s^{-1}$ using the concentric/eccentric mode with 60 s allowed between each muscle contraction. This speed of contraction has been used to test isometric strength of persons with paraplegia (25).

4) Time between maneuvers was kept constant at 5 min, which allowed sufficient time for setting up the next maneuver.

5) Subjects received mild, but not excessive, verbal encouragement throughout testing.

Warm-up movements were performed before each testing movement with three to five repetitions of submaximal effort allowed per action. Subjects executed three repetitions of both the concentric and eccentric actions for each isokinetic test maneuver, after which the peak and average torques were recorded. Force/angle relationships were displayed in real-time on the system computer screen and printed after each maneuver. Peak and average torques(N·m) used for data analysis were the best three efforts. In all cases eccentric testing followed concentric, and the order of testing for the posttest was identical to the pretest.

Resistance training program. Subjects underwent 12 wk of exercise training performed three times weekly on nonconsecutive days. Each session lasted approximately 40–45 min and employed resistance training (weight lifting) and endurance activities (arm cranking) with interposed periods of incomplete recovery (i.e., heart rate not falling to baseline). Subjects required approximately 1 wk of CRT to attain proficiency in the station changes and contraction rates, and were guided by the investigators until this proficiency was achieved.

The following full range bilateral resistance maneuvers were performed on an Equalizer 7000 multi-station exercise system (Helm):

1. Military press: shoulder abduction with scapular elevation and upward rotation starting from the fully adducted and depressed position.
2. Horizontal rows: shoulder horizontal abduction with scapular adduction starting from a position of maximum forward reach.
3. Pec dec: shoulder horizontal adduction while in external rotation to the midline, from the maximum tolerated horizontal abduction in external rotation.
4. Preacher curls: elbow flexion supported on an inclined pad from the fully extended position.
5. Wide grip latissimus pull-down: shoulder adduction with scapular downward rotation and depression starting from the maximal upward reaching position.
6. Seated dips (or "Rickshaw"): shoulder flexion, scapular depression and elbow extension while maintaining arms as near the body as possible, from the fullest allowed point of shoulder joint extension, scapular elevation and elbow flexion.

Each training session was preceded by a 2-min warm-up period using a Saratoga Cycle arm ergometer (Fort Collins, CO). Subjects then performed one set of 10 repetitions with resistive maneuver 1 followed immediately by 10 repetitions of resistive maneuver 2. A full repetition was defined as a 6-s movement pattern, with approximately 3-s concentric and 3-s eccentric contraction phases. Subjects then changed stations without interruption or rest and propelled an arm ergometer for 2 min at maximal rate using minimal resistance. Maneuvers 3 and 4 were then performed as above, followed by two more minutes of arm propulsion. Subjects then completed maneuvers 5 and 6 and two more minutes of arm propulsion. This procedure comprised one "circuit," with each training session consisting of three such cycles performed without interruption. The periods between exercise stations were limited to the time required for the subjects to wheel to the next exercise station, an incomplete recovery interval between exercise bouts generally less than 15 s.

Resistive loads for training during weeks 1 and 2 were 50% of the 1RM values calculated during initial isoinertial testing. Resistive loads were increased to 55% and 60% of the 1RMs for training weeks 3 and 4, respectively. The 1RM for each maneuver was recomputed during the last training session of week 4, and the training intensities of weeks 5 through 8 were 50%, 50%, 55%, and 60% of the adjusted 1RMs. Similarly, during the last training session of week 8, 1RMs were recomputed for each maneuver, and the resistive loads applied during the final four training weeks adjusted to 50%, 50%, 55%, and 60% of these values.

Data analysis. Data are expressed as group means ± SD. All outcome measures were examined across time using a one-way ANOVA for repeated measures. The sources of significant differences among the multiple time points for isoinertial strength testing were discerned with *post hoc* analyses using Fisher's least significant difference (LSD) method. In all cases a P-value less than 0.05 was used as the criterion for statistical significance.

TABLE 2. Effects of CRT on peak metabolic responses to arm ergometry testing in chronic survivors of paraplegia (mean ± SD, $N = 10$).

	Pretraining	Posttraining	%Δ	P
$\dot{V}O_2$ peak ($L \cdot min^{-1}$)	1.45 ± 0.22	1.88 ± 0.31	+29.7	<0.01
Time to fatigue (s)	624 ± 195	816 ± 223	+30.8	<0.01
Power output peak ($kp \cdot m \cdot min^{-1}$)	655 ± 101	761 ± 106	+16.1	<0.05

RESULTS

Subjects and resistance training program. All subjects completed the 12 wk of exercise training without mishap or medical complications. Two subjects reported moderately intense muscle soreness after isokinetic testing that did not interfere with the scheduled training sessions.

Cardiorespiratory exercise testing. Peak metabolic responses to arm ergometry testing are displayed in Table 2. Subjects experienced a significant increase in $\dot{V}O_{2peak}$ from 18.7 ± 4.2 to 23.8 ± 6.0 $mL \cdot kg^{-1} \cdot min^{-1}$ after CRT ($P < 0.01$). The 29.7% enhancement of $\dot{V}O_{2peak}$ was reflected in a 30.8% increase in the time to fatigue on the arm ergometry test ($P < 0.01$) and a 16.1% gain in peak power output ($P < 0.05$).

Isoinertial strength testing. Isoinertial strength measured before CRT and after the 4th, 8th, and 12th week of the training program are displayed in Table 3. Significant increases in strength were observed over the 12-wk period for all isoinertial maneuvers used in training. The strength gains for the six maneuvers ranged from 11.9% to 30% (P ranges from < 0.01 to < 0.0001), with an average 21.1% gain. The values for most isoinertial strength measures also increased significantly on a monthly basis (Table 3).

Isokinetic strength testing. Concentric and eccentric isokinetic testing of 10 different upper extremity movements, before and after 12 wk of CRT, are presented in Table 4. No significant training effects were demonstrated for isokinetic elbow flexion or extension. The average and peak concentric values of shoulder internal rotation increased after CRT, with concurrent gains evidenced during eccentric movements (Ps < 0.05). Similar enhancement of concentric and eccentric strength were demonstrated during shoulder adduction and horizontal shoulder adduction (Ps < 0.05). Significant increases in concentric isokinetic strength were noted in the movements of shoulder extension, shoulder abduction, and horizontal shoulder abduction (Ps < 0.05).

DISCUSSION

Circuit resistance training is a form of exercise programming in which a series of exercise stations are sequentially performed— one set per station—for a prescribed number of circuits. The cardiorespiratory benefits of CRT have been reported in several studies to exceed conventional resistance training protocols (1,40), with these benefits associated with training factors including exercise duration, the work/rest

TABLE 3. Isoinertial one repetition (1RM) maximal strength (lbs) in paraplegics after circuit resistance training (mean ± SD, $N = 10$).

Maneuver	Pretraining	Week 4	Week 8	Week 12	%Δ
Military press	127.0 ± 32.1	135.7 ± 36.9*	145.5 ± 37.6*	151.6 ± 38.2*	+19.4
Horizontal row	194.2 ± 37.2	206.5 ± 38.3*	227.2 ± 44.0*	234.6 ± 44.0*	+20.8
Pec deck	133.8 ± 34.2	134.1 ± 29.9	153.1 ± 32.7*	162 ± 34.3*	+21.1
Preacher curls	45.4 ± 8.0	47.6 ± 8.4*	49.8 ± 10.3*	50.8 ± 9.2	+11.9
Latissimus pull down	143.4 ± 23.2	155.4 ± 21.7*	169.8 ± 22.4*	176.6 ± 26.4*	+23.2
Dips (Rickshaw)	129.3 ± 32.8	151.8 ± 25.9*	160.5 ± 28.1*	168.3 ± 29.6*	+30.2

* Denotes a statistically significant increase ($P < 0.05$) in strength from the previous time point.

ratio, and the training intensity (20). Six to eight stations of such exercise are employed with rest periods between stations limited to 10–15 s. Superior cardiorespiratory adaptations have been reported when endurance activities such as cycling or treadmill running were used as either separate exercise stations or modes of active recovery periods as opposed to true rest periods. In the current study, these guidelines were employed to design a protocol making use of six resistance maneuvers on a multi-station isoinertial exercise machine adapted for wheelchair users. Pairs of isoinertial maneuvers alternated with low-resistance, high-rate AE sufficient to maintain heart rate elevated above baseline. Periodic checks during exercise performance showed average heart rate values ranging from 120 to 160 bpm throughout the circuit.

This study finds that 12 weeks of CRT significantly increases both cardiorespiratory endurance and muscular strength in persons with chronic paraplegia. The average increase in $\dot{V}O_{2peak}$ sustained by the subjects (29.7%) was greater than enhancements of aerobic capacity previously reported after many extended programs of endurance AE or WE exercise conditions (19). As individuals undergoing this training had varying degrees of residual trunk control, it is possible that increased $\dot{V}O_{2peak}$ resulted, in part, from improved trunk stability acquired during training. Such trunk stability would be beneficial for those requiring improved body stabilization during wheelchair locomotion and other daily activities. Although isoinertial strength increased significantly in all training movements by 12–30%, increases in isokinetic strength were concentrated in those movements similar to those implemented in the training program. These results suggest that greater attention needs to be paid to the training of muscles used in shoulder external rotation, whose weakness and imbalance has been associated with shoulder instability and activity-limiting pain in persons with paraplegia (22,31,32,36).

TABLE 4. Peak and average concentric and eccentric torque (Nn) before (pre) and after (post) circuit resistance training (mean ± SD, $N = 10$).

	Peak		Average	
	Pre	Post	Pre	Post
Concentric maneuver				
Elbow flex	47.0 ± 12.9	49.7 ± 13.6	40.7 ± 11.7	41.2 ± 12.1
Elbow ext	41.2 ± 9.4	43.8 ± 7.0	35.8 ± 8.0	38.7 ± 5.9
Sh int rot	39.7 ± 9.9	48.3 ± 11.5*	34.2 ± 9.0	41.9 ± 10.5*
Sh ext rot	30.9 ± 8.6	32.3 ± 6.0	21.9 ± 7.1	24.4 ± 7.0
Sh flexion	34.1 ± 12.7	39.5 ± 10.5	26.0 ± 10.6	28.2 ± 9.7
Sh exten	47.4 ± 12.8	55.2 ± 11.6*	37.2 ± 9.2	42.1 ± 8.5*
Sh abduct	23.5 ± 8.5	28.9 ± 9.2*	18.4 ± 7.7	23.1 ± 6.6*
Sh adduct	41.4 ± 12.1	49.3 ± 7.8*	35.3 ± 11.4	42.8 ± 5.8*
Sh hor add	39.9 ± 12.0	51.8 ± 16.1*	30.1 ± 8.0	39.3 ± 13.0*
Sh hor abd	39.7 ± 10.1	46.8 ± 12.7*	33.5 ± 9.2	36.2 ± 7.0
Eccentric				
Elbow flex	76.4 ± 30.9	72.7 ± 16.5	59.3 ± 19.4	57.7 ± 14.5
Elbow exten	65.1 ± 14.1	64.5 ± 9.1	49.6 ± 8.9	49.8 ± 6.4
Sh int rot	50.9 ± 9.6	58.0 ± 13.7*	43.0 ± 8.1	49.4 ± 12.3*
Sh ext rot	40.9 ± 9.3	39.5 ± 6.6	31.5 ± 8.0	31.4 ± 5.9
Sh flex	50.3 ± 14.7	50.0 ± 13.6	34.4 ± 11.9	33.5 ± 12.3
Sh exten	54.8 ± 16.2	63.8 ± 13.6	44.8 ± 11.2	52.4 ± 9.1
Sh abduct	30.9 ± 11.0	36.1 ± 8.8	25.3 ± 10.8	29.0 ± 7.3
Sh adduct	46.7 ± 12.5	56.2 ± 9.8*	40.9 ± 11.6	48.7 ± 8.5*
Sh hor add	53.0 ± 14.7	65.5 ± 23.2*	41.4 ± 10.8	52.1 ± 17.3*
Sh hor abd	53.0 ± 16.9	66.6 ± 27.2	43.2 ± 12.1	51.8 ± 13.8

* Denotes a statistically significant increase ($P < 0.05$) in strength from the previous measurement point.

The current investigation is the first to use isoinertial CRT as a conditioning program for persons with SCI. Despite the need for strengthening of persons aging with SCI, and the ACSM recommendation for inclusion of resistance training in adult exercise conditioning programs (2), only three studies have examined upper extremity strength training for persons with paraplegia. Nilsson and colleagues (29) were the first to describe a program consisting of interval AE followed by progressive resistance exercise. Subjects in their trial underwent 7 wk of three times weekly arm exercise defined as three 4-min bouts of arm exercise on a Monark ergometer, each bout followed by triceps muscle training in the sitting and supine positions. Their results showed increased peak $\dot{V}O_2$ (10.6%) and muscular strength (18.8%), both of which are significantly less than results reported in the current study. Their subjects also expressed greater confidence and enhanced senses of well-being. These responses were somewhat predictable, as many subjects in the study had low-level or incomplete spinal cord lesions and benefited from strengthening through improved crutch walking skills when using orthotic devices. Cooney and Walker (9) trained subjects by using hydraulic resistance equipment and multiple sets at two exercise stations, with controlled rest periods of 40–100 s between sets. Improvements in cardiorespiratory capacity of 28.1% and power output of 36.7% as assessed by arm ergometry testing were observed after the 9-wk training program, although no strength-related outcomes were reported. Unlike other programs of CRT in which station changes were made rapidly, several wheelchair transfers were required to perform the exercises, as the equipment used was not adapted for wheelchair use. Davis and Shephard (13) measured strength in subjects with undescribed lower-limb disabilities undergoing 16 wk of arm exercise conducted three times weekly on a Monark ergometer at 70% or 40% of measured $\dot{V}O_{2peak}$ oxygen uptake for either 40 or 20 min per session. Muscle strength for the study was operationally defined as the peak moment, peak power, average power, and total work of shoulder and elbow flexion/extension and shoulder joint abduction/adduction at isokinetic velocities ranging from 60 to $300° \cdot s^{-1}$. Results of training favored increased power in subjects trained at higher intensities and longer durations of exercise, and was best expressed during testing at higher isokinetic testing speeds. Unfortunately, the largest strength differences after training were observed for shoulder flexion and elbow extension in subjects training at high work intensities, which are not the weakest muscle groups nor those most in need of strengthening to perform ADLs for persons with SCI. Further, training at low work intensities actually lowered peak and average power of these muscles.

Although many studies examining exercise conditioning for persons with paraplegia have used continuous resistive AE and WE as training modes, recent concern for the long-term function of the upper extremities as persons age with disability calls into question whether this is appropriate (21). Many persons living with paraplegia require a wheelchair to perform daily tasks including locomotion, weight shifts, and body transfers, all of which place significant stress on upper body muscles and joints. The accumulated effects of these tasks hasten shoulder dysfunction as wheelchair users age with their disability (11,12,21,32), which may eventually compromise both their health and independence. Although sedentary lifestyles and hyperlipidemia often reported among paraplegia survivors confirm a need for increased physical activity, in many cases endurance exercise activities using the neurologically intact muscles of the upper body have only worsened shoulder, elbow, and wrist pain (7,11).

Although established guidelines concerning target intensities for endurance training are widely available, far less is known of the resistance targets necessary to satisfy the specific needs of persons with disabilities. The selection of resistive exercises and their intensities for the circuit used in this study were based in part upon previous reports that have described the most physically taxing activities of daily living. The activities of wheelchair propulsion, body weight shifts, and depression transfers are the tasks that require the greatest degree of muscular effort and during which chronic survivors of paraplegia experience the most weakness and pain. As all of these activities are essential in the daily routines of these persons, an understanding of the movements and musculature involved in their performance, and the intensities of muscular contraction, ought to serve as the best guides when designing an exercise training program for enhancement of physical capacity while preventing or minimizing upper extremity pain. Such exercises should also attend to diseases of the cardiopulmonary system and decline of musculoskeletal function, which currently represent major sources of morbidity for persons aging with paraplegia (15,39). These health problems are fostered by physical deconditioning and upper extremity muscle weakness that accompany the onset of paraplegia, and occur much sooner in life for those with SCI than those without (7,11,32).

Among the benefits of well-designed exercise conditioning programs are enhancements in function and life-satisfaction. Although this study did not specifically test these outcomes, several lifestyle alterations resulting from CRT were shared by subjects at their informal exit interviews. Several reported dramatic improvements in their ability to perform regular daily tasks that rely primarily on upper extremity strength and endurance. The number of daily tasks performed by one subject was formerly limited by the number of transfers required to enter and exit his van without using a mechanical lift. After training he was able to enter and exit his van as often as he wished, thereby increasing his freedom to fulfill daily responsibilities. Two subjects described lifestyles before participation in CRT that were restricted due to shoulder discomfort. After training, these individuals were able to dramatically increase their daily activities, and no longer described their lives as limited by discomfort. Although these reports are anecdotal and without research control, they illustrate the functional merit, in addition to the health benefits, of exercise conditioning in persons with disabilities.

CONCLUSION

Persons with paraplegia safely increased their endurance and muscular strength after 3 months of CRT. Endurance gains reported in this study match or surpass those reported after either AE or WE training. Strengthening of the movements necessary to perform activities of daily living was achieved after training, although greater training emphasis is required to strengthen shoulder external rotators and scapular adductors. Equipment that allows wider use of this type training program is required to meet the needs of persons aging with paraplegia, as well as other disabilities.

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