Effects of Respiratory Resistance Training With a Concurrent Flow Device on Wheelchair Athletes

Lyn G Litchke, MEd, Christopher J Russian, MEd, [...], and John L Walker, EdD

Abstract

Background/Objective:

To determine the effect of respiratory resistance training (RRT) with a concurrent flow respiratory (CFR) device on respiratory function and aerobic power in wheelchair athletes.

Methods:

Ten male wheelchair athletes (8 with spinal cord injuries, 1 with a neurological disorder, and 1 with postpolio syndrome), were matched by lesion level and/or track rating before random assignment to either a RRT group (n = 5) or a control group (CON, n = 5). The RRT group performed 1 set of breathing exercises using Expand-a-Lung, a CFR device, 2 to 3 times daily for 10 weeks. Pre/posttesting included measurement of maximum voluntary ventilation (MVV), maximum inspiratory pressure (MIP), and peak oxygen consumption ($\dot{V}_{O_2peak}$).

Results:

Repeated measures ANOVA revealed a significant group difference in change for MIP from pre- to posttest ($P < 0.05$). The RRT group improved by 33.0 cm H_2O, while the CON group improved by 0.6 cm H_2O. Although not significant, the MVV increased for the RRT group and decreased for the CON group. There was no significant group difference between $\dot{V}_{O_2peak}$ for pre/posttesting. Due to small sample sizes in both groups and violations of some parametric statistical assumptions, nonparametric tests were also conducted as a crosscheck of the findings. The results of the nonparametric tests concurred with the parametric results.

Conclusions:

These data demonstrate that 10 weeks of RRT training with a CFR device can effectively improve MIP in wheelchair athletes. Further research and a larger sample size are warranted to further characterize the impact of Expand-a-Lung on performance and other cardiorespiratory variables in wheelchair athletes.

Keywords: Spinal cord injuries, Pulmonary function tests, Respiratory function tests, Respiratory therapy, Wheelchair sports, Paralympics

Persons with spinal cord injury (SCI) have reduced respiratory function due to diminished abdominal and chest wall strength and endurance (1). For example, when tested in a seated position, persons with SCI at C5-C8 had 21% lower total lung capacity, 44% lower vital capacity, and 27% higher residual lung volume compared to able-bodied individuals (2). This reduction in respiratory function can significantly limit exercise capacity for persons with SCI (3). Though not as pronounced, athletes with SCI, commonly referred to as wheelchair athletes, also experience reduced exercise performance due to diminished respiratory function (3,4). Logically, since exercise performance of wheelchair athletes is diminished by compromised lung function (3,4), perhaps overall performance of wheelchair athletes can be enhanced by improving their respiratory function.

Research addressing effective means of improving respiratory function in wheelchair athletes is sparse. The vast majority of research involving methods of improving respiratory function has occurred in rehabilitation rather than athletic settings and/or has primarily involved untrained subjects with SCI (3,5–11). Though many modalities in these studies have been shown to be effective in improving respiratory function of persons with SCI, certain modalities have shown more promise than others. For example, while aerobic exercise (5), abdominal weight training (8), and hyperpnea training with electrical stimulation (9) have been shown to effectively improve lung function in individuals with SCI, additional studies suggest that the use of respiratory resistance training (RRT) flow devices may have an even greater impact on lung function (1,3,6,10,11).

RRT flow devices induce a training stimulus by decreasing the diameter and increasing the resistance to airflow, thereby forcing the respiratory muscles to work harder (2). Studies have indicated that over time, respiratory muscles become stronger and more efficient through RRT with either an inspiratory resistance loading (IRL) (1,3,6,8,10) or concurrent flow resistance (CFR) (11) device. Briefly, IRL devices cause an increased strain on the respiratory muscles by providing resistance during inhalation, whereas CFR devices provide resistance during both inhalation and exhalation (12). Most training studies involving the effects of RRT on persons with SCI have incorporated only IRL devices (1,3,6,8,10). In fact, only 1 study was found that investigated the effects of training with a CFR device on lung function in persons with SCI (11). In that study, individuals with tetraplegia trained with a respiratory nose mask that involved a fixed expiratory and a variable inspiratory resistance airflow valve. During the 6-week training period, subjects were instructed to increase the inspiratory resistance at a self-determined rate based on their inspiratory ability. The results showed

improvements in lung function, as determined by peak expiratory flow. No study, however, was identified that investigated whether RRT with a CFR device involving a variable expiratory and inspiratory resistance airflow valve enhances exercise performance (eg, aerobic power) and other aspects of lung function (eg, diaphragm strength) for trained or untrained persons with SCI.

In light of the positive effects of RRT on lung function in persons with SCI, it is logical to question whether RRT with a CFR device can enhance exercise performance by improving the lung function of wheelchair athletes. The purpose of this study was to determine the effects of RRT with a CFR device on respiratory muscle function and exercise performance in wheelchair athletes. Due to studies on the effects of RRT using both IRL (1,3,6,8,10) and CFR devices (11) in persons with SCI, it was hypothesized that 10 weeks of RRT with a CFR device would increase lung function and aerobic power in wheelchair athletes.

METHODS

Selection of Subjects

Ten men, 21 to 49 years of age, were recruited from a community-based sports and recreation wheelchair program. All study participants used their wheelchairs independently to carry out activities of daily living. Furthermore, as criteria for participation in the study, only individuals who trained and competed in sports-specific activities such as tennis, basketball, swimming, rugby, track and field, hand-cycling, or road-racing were recruited. Their competitive track ranking ranged from T51 to T54. One person, with a T54 ranking, withdrew for work-related responsibilities associated with the Hurricane Katrina relief effort. Results from the 9 remaining participants were used in the final data analyses. Group mean and individual descriptive characteristics of all participants are reported in Tables 1 and 2, respectively.

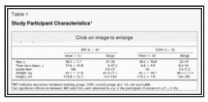

Table 1

Study Participant Characteristics*

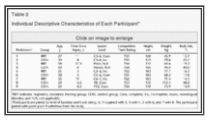

Table 2

Individual Descriptive Characteristics of Each Participant*

After a detailed description of testing procedures was provided, written consent was obtained from each participant. This investigation was submitted to and approved by the university's Institutional Review Board.

Materials

A calibrated wheelchair scale (Scale-Tronix 2002, White Plains, NY) was used to measure weight, and a Lufkin flexible steel tape measure (Cooper Industries, Houston, TX) was used to determine height. An EasyOne Spirometer (ndd Medical Technologies, Andover, MD) was used to measure maximal voluntary ventilation (MVV), while a manometer (Instrumentation Industries, Bethal Park, PA) was used to measure maximal inspiratory pressure (MIP), also referred to as Negative Inspiratory Force (NIF). Calibration was performed on the EasyOne Spirometer prior to each test using a 3-L calibration syringe. Manometer calibration was verified by zeroing the needle prior to each test. Maximal exercise tests were performed on wheelchair rollers (MCLAIN, Lansing, MI), with each participant's speed measured using a Comp 130 cycling computer (TOPEAK, Taiwan) calibrated according to the diameter of one of the wheelchair rollers. Also, during maximal exercise testing, heart rate (HR) was measured by a Polar Vantage XL telemetric HR monitor (Stamford, CT) and expired air was analyzed with a PARVO Medics metabolic analyzer (Salt Lake City, UT). Ventilation (V_E), oxygen consumption (VO_2), carbon dioxide production (VCO_2), and respiratory exchange ratio (RER) were determined from 60-second averages. Rating of perceived exertion (RPE) was recorded at the end of each minute according to the Borg 6- to 20-point scale (13). Before each exercise test, calibration was performed using a certified gas mixture (O_2 16% and CO_2 4%, Scott Medical Products, Plumsteadville, PA). Expand-a-Lung (Expand-a-Lung Inc, Miami, FL) was used by the RRT group. Briefly, this CFR device consisted of a flexible, long-bite silicone mouthpiece connected to a 2-way valve. Air flow through the 2-way valve was controlled by a single resistance-adjustment dial with 7 levels of resistance. These levels were marked in color by the test administrator to assist participants with accuracy in recording levels of resistance. For instance, level 1 was color-coded red, level 2 yellow, etc. By turning the dial 0.32 cm counterclockwise (ie, one level to the next), the participant was able to increase resistance to air flow. On the eighth turn, air flow was occluded.

Procedures

Study participants visited the laboratory on 2 occasions separated by a 10-week period. Prior to the first visit to the laboratory, the participants were rated by a Certified Wheelchair Track, Field, and Slalom Official and a 2005 US Paralympic Track and Field Coach (14). Participants were first paired by level of function and competitive track rating, and then each member of the pair was randomly assigned to either the RRT or control (CON) group (Table 2). Though both groups participated in pre- and posttesting, only the treatment group underwent RRT.

In preparation for the first laboratory visit, participants were provided pretest instructions based on the American College of Sports Medicine (ACSM) guidelines for exercise testing (15). During visit 1, participants signed an informed consent form and completed a health appraisal questionnaire, as well as measurement of (a) height and weight, (b) MVV, (c) MIP, and (d) peak oxygen consumption ($\dot{V}_{O_2peak}$).

Anthropometric procedures for body weight were performed according to Bulbulian et al (16). Briefly, body weight was determined by taking the difference between the weight of the person in his wheelchair and the weight of his wheelchair. Height was measured with the participant lying in a supine position (17).

To reduce error, anthropometric measurements were taken twice. For body weight and height, if the trials were not within 1% of each other, then another trial was performed (16). For each measurement, the average of the 2 trials that were within the previously stated parameters was used for descriptive statistics. Test-retest reliability for body weight and height were $r = 0.999$, $r = 0.966$, and $r = 0.996$, respectively.

Pulmonary function tests included a test of overall function of the respiratory system (MVV) and a test of respiratory muscular strength (MIP). To assess MVV, participants inspired and expired as hard and fast as possible for 12 to 15 seconds (18). To reduce error, the MVV was performed twice. If the 2 trials were not within 10% of each other, a third trial was performed. The best of the 2 trials that were within 10% of each other was used for data analysis. To assess MIP, participants forcibly inhaled through a mouthpiece attached to a closed pressure gauge (18). Participants were instructed to hold their inspiratory effort for 2 seconds when performing the MIP maneuver. The best of 3 MIP measurements was used for data analyses. Reliability analyses for MVV and MIP were $r = 0.979$ and $r = 0.986$, respectively.

Following lung function testing, participants rested for a minimum of 15 minutes to allow for recovery. The participant's $\dot{V}_{O_2peak}$ was then measured with a wheelchair mounted on rollers (WCR) using the general protocol described by Bhambhani et al (19). Based on an e-mail from Y. N. Bhambhani, the protocol was slightly modified (Y. N. Bhambhani, PhD, written communication, April 2005). Each participant's personal wheelchair was mounted on the wheelchair rollers, which were interfaced with a cycling computer. Once secured, the participant propelled his wheelchair at a self-selected comfortable velocity. Two minutes into the test, participants with paraplegia were instructed to increase their velocity by 2 $km \cdot h^{-1}$ and participants with tetraplegia by 1 $km \cdot h^{-1}$ every minute until volitional fatigue was achieved. The highest VO_2 was considered peak VO_2 and used in data analysis (4,19). Ten weeks following pretesting, participants returned to the laboratory for posttesting that included measurement of MVV, MIP, and $\dot{V}_{O_2peak}$.

Intervention

After pretesting was completed, all participants were instructed to continue their current training regimens and to keep a daily exercise log. Participants in the RRT group also received the CFR device and training protocol. Specifically, participants in the RRT group were instructed to: (a) inhale as slowly and deeply as possible through the mouthpiece of the CFR device, (b) hold their breath for 2 to 5 seconds, (c) exhale through the mouthpiece slowly until almost out of breath, and then, (d) forcefully blow out as much of the remaining residual air as possible. Participants were instructed to repeat this sequence up to 10 times, with 10- to 20-second rest periods between each sequence. Once they were able to perform the sequence 10 times (1 set) without experiencing respiratory muscle fatigue, lightheadedness, or dizziness, they were instructed to increase the resistance to airflow by 1 level. They were asked to perform 1 set of these RRT exercises in a well-ventilated area 3 different times per day (before breakfast, exercise, and bedtime) for 10 weeks. On the days the participants did not exercise, they were asked to only perform the RRT exercises twice. The participants were also instructed to record in their exercise journal the day, date, and level of resistance (as indicated by color).

Statistical Methods

Prior to statistical analyses, the dependent variables MVV, MIP, and $\dot{V}_{O_2peak}$ were examined for the RRT and CON group at pretest and posttest to examine the tenability of general linear model assumptions (ie, normality, linearity, homogeneity of variance/covariance, and outliers). We examined MVV, MIP, and $\dot{V}_{O_2peak}$ for normality by using skewness and kurtosis coefficients (z tests of greater or less than 1.96) and the Shapiro-Wilks test. The results of the data screening process revealed that the assumptions of normality and homogeneity of variance were violated for the $\dot{V}_{O_2peak}$ dependent variable at pretest and posttest time points for both the RRT and CON groups. Given this finding and also due to very small sample sizes in the RRT and CON groups (resulting in very low estimated statistical power to detect a true effect), the Mann-Whitney U test, a nonparametric test of median change by groups, was employed in addition to the parametric matched samples pretest-posttest (dependent) t test to determine whether statistically significant differences existed on MVV, MIP, and $\dot{V}_{O_2peak}$.

RESULTS

Group mean and individual aerobic fitness and pulmonary function results are reported in Tables 3 and 4, respectively. Repeated measures ANOVA revealed a significant group difference in change for MIP from pre- to posttest ($F_{1,7} = 6.39$, $P = .039$). The RRT group improved by 33.0 cmH_2O, while the CON group improved by only 0.6 cmH_2O. The results of the nonparametric analysis of MIP concurred with the parametric findings from pre- to posttest χ^2 (1, N = 9) = −2.09, $P = 0.032$, and a standardized effect size of $\phi = 0.54$ (medium). Although the parametric analysis did not yield a statistically significant result ($P = 0.066$), the MVV increased for the RRT group and decreased for the CON group. This finding was consistent with those of the nonparametric analysis of MVV from pre- to posttest χ^2 (1, N = 9) = −1.96, $P = 0.063$, although the observed standardized effect size of $\phi = 0.42$ indicated a medium-level practical effect. There was no statistically significant difference between $\dot{V}_{O_2peak}$ for pre- and posttesting using parametric or nonparametric analyses ($P = 0.652$ and $P = 0.413$, respectively). The observed effect sizes for both analyses were very small, indicating little or no practical effect.

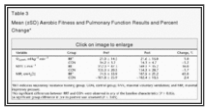

Table 3

Mean (±SD) Aerobic Fitness and Pulmonary Function Results and Percent Change*

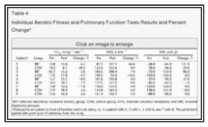

Table 4

Individual Aerobic Fitness and Pulmonary Function Tests Results and Percent Change*

From review of the exercise logs, the athletes were categorized into levels of physical activity based on number of hours of participation in sport activities (20). The CON group was comprised of 1 sedentary (no weekly participation), 1 active (3 to 6 hours/week), 2 moderately active (1 to 3 hours/week) and 1 very active (more than 6 hours/week) athletes. Similarly, the RRT group was comprised of 1 sedentary, 1 moderately active, and 2 very active athletes. Results of an independent *t* test indicated that the groups did not differ significantly according to physical activity status ($P = 0.714$). The 2 sedentary participants reported suffering minor injuries during the study that prevented them from playing rugby or basketball. All other subjects participated in endurance exercises, weight training, and a variety of sport activities (eg, basketball, tennis, and rugby). Because there appeared to be no disparity in level of physical activity between the groups, it is unlikely that the influence of exercise training impacted the findings.

From review of RRT participants' training logs, each participant used the device an average of 110 times. Based on the training protocol, the expected usage ranged from 140 times for those who were completely sedentary to 210 times for those who exercised on a daily basis. The reasons noted in logs for noncompliance included illness, minor surgery, and travel. Presumably, with better compliance, the findings may have revealed greater significance.

DISCUSSION

Previous research has demonstrated that RRT flow devices can enhance the lung function (1,3,6,8,10,11) and exercise performance (3) of individuals with SCI. Although the effects of RRT with IRL devices have been studied extensively (1,3,6–8,10), there is limited research examining the effects of RRT with CFR devices (11). This project was designed to assess the effects of regular RRT with a CFR device on both lung function and exercise performance for wheelchair athletes. The results of this study show that 10 weeks of regular RRT with a CFR device improved MIP but had no significant effect on MVV or $\dot{V}_{O_2peak}$ in wheelchair athletes.

The majority of studies on the effects of regular training with an IRL device reveal that MIP increases for untrained persons with SCI (1,3,6,10). For instance, in an 8-week study investigating the effects of RRT with an IRL device, MIP significantly increased by 24% (1). The present study is the first to investigate the effects of RRT with a CFR device on MIP in athletes with SCI. The results from this study demonstrate that 10 weeks of training with the CFR device results, on average, in a 61% improvement in MIP. A slightly longer RRT period (10 vs 8 wk) and/or the use of a CFR device (instead of an IRL device) may explain the dramatic differences between the present study and the study by Rutchik et al (1).

The MIP test is often used to assess the contraction strength of the respiratory muscles, primarily the diaphragm, during inspiration (18). With high level SCI injury, such as C3–C7, diaphragm function is impaired (18). A weakened diaphragm can result in lower lung volumes, thereby limiting functional independent activities, including exercise (1,3). Although not substantiated by this study, it is likely that by increasing diaphragm strength through RRT, functional independence and exercise performance will improve (1). This study has, however, determined that regular RRT with a CFR device improves respiratory muscular strength.

Improvements in respiratory muscle strength may be due, in part, to improvements in neuromuscular efficiency. For example, the phrenic nerve is the major neural pathway for electrical impulses to the diaphragm. Increases in phrenic motoneuron activation have been observed during and after inspiratory resistance training (21,22). Activation of phrenic motoneurons and recruitment of phrenic nerve axons may have contributed to the increases in respiratory muscle strength observed in this study.

Although change in absolute values in MVV from pre- to posttest was greater in the RRT group than the CON group (+15% vs −2%, respectively), the difference was not significant. In contrast, a previous study showed that IRL training resulted in significant within-treatment improvements in MVV (8).

MVV is a test that provides an estimate of the respiratory reserves available to meet the demands of exercise (18). A normal MVV indicates that during exercise, one's respiratory muscles should be able to provide the necessary ventilation to meet the needs of the body. If the MVV is low, one may not be able to increase ventilation to a point sufficient to engage in intense exercise. After participants in this study trained with the CFR device, improvements in MVV occurred, though they were not significant. A lack of significant findings in this study may be the result of a small sample size and/or a short training period. Future studies should include larger sample sizes and longer training periods to determine if RRT results in significant increases in MVV, and whether such an improvement will have a positive impact on exercise performance of wheelchair athletes.

Studies investigating the effects of RRT using an IRL device on $\dot{V}_{O_2peak}$ in individuals with SCI are sparse. In a study by Uijl et al (3), $\dot{V}_{O_2peak}$ in untrained individuals, with an average $\dot{V}_{O_2peak}$ of 0.9 L·min^{-1}, significantly improved by approximately 11% following 6 weeks of training with an IRL device. In contrast, in the present study, $\dot{V}_{O_2peak}$ did not significantly improve in trained wheelchair athletes (average $\dot{V}_{O_2peak}$ = 1.3 L·min^{-1}) following 10 weeks of RRT training with a CFR device. Comparing these 2 studies is difficult due to the differences in trained vs untrained participants. However, a review of several studies involving trained, able-bodied individuals revealed that inspiratory muscle training did not significantly improve $\dot{V}_{O_2peak}$ (23–25). The high fitness level of the trained athletes at the onset of the studies may explain the lack of an effect. Training adaptations resulting from an overload stimulus are reduced the more fit an individual is at the onset of a study (12). In this study, all participants were wheelchair athletes. In fact, one participant in the treatment group was a highly trained, Paralympic marathon and track athlete who participated in altitude training regularly.

Other than initial fitness level, testing procedures implemented may explain the differences in findings between this study and the one conducted by Uijl et al (3). For example, when evaluating wheelchair athletes, wheelchair propulsion (WCR) is preferred over arm-crank exercise (ACE) due to the fact that WCR is specific to the mode of ambulation during a wheelchair competitive race or sport (4). In the study by Uijl et al (3), ACE was used to evaluate $\dot{V}_{O_2peak}$ in untrained SCI individuals. In the current study, however, WCR was used with trained SCI individuals. Furthermore, in the study by Uijl et al (3), specially designed mitts were used when necessary to secure the participants to the handles during the ACE test. In the present study, participants did not use any special gripping assistance to enhance push stroke during the test.

CONCLUSION

The results of this study indicate that RRT with a CFR device improves aspects of lung function in wheelchair athletes. Specifically, the improvements in MIP in wheelchair athletes found in this study clearly support RRT with a CFR device. Furthermore, although not significant, the trend towards improvements in MVV also indicates that with either a longer study and/or a larger sample size, further benefits of this device may become evident. Although lung function improved as a result of RRT, level of aerobic fitness did not. Future studies need to involve actual tests of exercise performance in addition to tests of aerobic fitness.

Interestingly, some participants in the RRT group reported substantial changes such as a stronger sneeze and cough. Two participants in the RRT group reported that it was easier to take deeper breaths. The Paralympic athlete stated, “My lungs feel stronger and I am more comfortable.” Further research with a larger sample size, longer training period, and field- and lab-based tests of exercise performance is warranted to further explore the impact of RRT with CFR devices on exercise performance, other cardiopulmonary variables, and quality of life in wheelchair athletes.

Acknowledgments

We acknowledge the contributions and assistance of Expand-a-Lung, Chase Bearden, Carolyn Clay, Michael Hobbs, and Keith Kaiser.

Footnotes

Respiratory resistance training equipment provided by Expand-a-Lung (Miami, FL).

Article information

J Spinal Cord Med. 2008; 31(1): 65–71.
PMCID: PMC2435026
PMID: 18533414

Lyn G Litchke, MEd,[1] Christopher J Russian, MEd,[2] Lisa K Lloyd, PhD,[1] Eric A Schmidt, PhD,[3] Larry Price, PhD,[3] and John L Walker, EdD[1]

[1]The Human Performance Laboratory, Department of Health, Physical Education, and Recreation, Texas State University-San Marcos, San Marcos, Texas
[2]Department of Respiratory Care, Texas State University-San Marcos, San Marcos, Texas
[3]Department of Educational Administration and Psychological Services, Texas State University-San Marcos, San Marcos, Texas
Please address correspondence to Lyn Litchke, MEd, Department of Health, Physical Education, and Recreation, Texas State University-San Marcos, San Marcos, TX 78666; phone: 512.245.2951; fax: 512.245.8678 (e-mail: LL24@txstate.edu).

Received 2006 Sep 7; Accepted 2007 Jun 7.

REFERENCES

1. Rutchik A, Weissman AR, Almenoff PL, Spungen AM, Bauman WA, Grimm DR. Resistive inspiratory muscle training in subjects with chronic cervical spinal cord injury. *Arch Phys Med Rehabil.* 1998;79:293–297. [PubMed] [Google Scholar]
2. Bodin P, Kreuter M, Bake B, Olsen MF. Breathing patterns during breathing exercises in persons with tetraplegia. *Spinal Cord.* 2003;41:290–295. [PubMed] [Google Scholar]
3. Uijl SG, Houtman S, Folgering HT, Hopman MTE. Training of respiratory muscles in individuals with tetraplegia. *Spinal Cord.* 1999;37:575–579. [PubMed] [Google Scholar]
4. Bhambhani YN. Physiology of wheelchair racing in athletes with spinal cord injury. *Sports Med.* 2002;32:23–51. [PubMed] [Google Scholar]
5. Crane L, Klerk K, Ruhl A, Warner P, Ruhl C, Roach KE. The effect of exercise training on pulmonary function in persons with quadriplegia. *Paraplegia.* 1994;32:435–441. [PubMed] [Google Scholar]
6. Liaw MY, Lin MC, Cheng PT, Wong MKA, Tang FT. Resistive inspiratory muscle training: its effectiveness in patients with acute complete cervical cord injury. *Arch Phys Med Rehabil.* 2000;81:752–756. [PubMed] [Google Scholar]
7. Loveridge B, Badour M, Dubo H. Ventilatory muscle endurance training in quadriplegia: effects on breathing pattern. *Paraplegia.* 1989;27:329–339. [PubMed] [Google Scholar]
8. Derrickson J, Ciesla N, Simpson N, Imle CP. A comparison of two breathing exercise programs for patients with quadriplegia. *Phys Ther.* 1992;72:763–767. [PubMed] [Google Scholar]
9. Zupan A, Savrin R, Erjavec T, et al. Effects of respiratory muscle training and electrical stimulation of abdominal muscles on respiratory capabilities in tetraplegic patients. *Spinal Cord.* 1997;35:540–545. [PubMed] [Google Scholar]
10. Gross D, Ladd HW, Riley EJ, Macklem PT, Grossino A. The effect of training on strength and endurance of the diaphragm in tetraplegia. *Am J Med.* 1980;61:27–35. [PubMed] [Google Scholar]
11. Beiring-Sorensen F, Knudsen JL, Schmidt A, Bundgaard A, Christensen I. Effects of respiratory training with a mouth-nose-mask in tetraplegia. *Paraplegia.* 1991;29:113–119. [PubMed] [Google Scholar]
12. Amonette WE, Dupler TL. The effects of respiratory muscle training on VO_2max, the ventilatory threshold and pulmonary function. *JEP Online.* 2002;5:29–35. [Google Scholar]
13. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982;14:377–381. [PubMed] [Google Scholar]
14. United States Paralympic Complete Classification. IPC Athletic Classification Handbook. Available at: http://www.paralympic.org/release/Summer_Sports/Athletics/About_the_sport/Rules/IPC_Athletics_Classification_Handbook_2006.pdf. Accessed June 15, 2006.
15. American College of Sport Medicine. Physical fitness testing and interpretation. In: Franklin BA, editor. *Guidelines for Exercise Testing and Prescription.* 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2000. pp. 57–90. [Google Scholar]
16. Bulbulian R, Johnson RE, Gurber JJ, Darabos B. Body composition in paraplegic male athletes. *Med Sci Sports Exerc.* 1987;19:195–201. [PubMed] [Google Scholar]
17. Buchholz AC, Burgaresti JM. A review of body mass index and waist circumference as markers of obesity and coronary heart disease risk in persons with chronic spinal cord injury. *Spinal Cord.* 2005;43:513–518. [PubMed] [Google Scholar]
18. Ruppel G. Spirometry and pulmonary mechanics. In: Shanahan JF, editor. *Manual of Pulmonary Function Testing.* 6th ed. St Louis, MO: Mosby; 1994. pp. 43–81. [Google Scholar]

19. Bhambhani YN, Burnham RS, Wheeler GD, Eriksson P, Holland LJ, Steadward RD. Ventilatory threshold during wheelchair exercise in untrained and endurance-trained subjects with quadriplegia. *Adapt Phys Act Q.* 1995;12:333–343. [Google Scholar]
20. Janssen TW, Dallmeijer AJ, Veeger DJ, van der Woude LH. Normative values and determinants of physical capacity in individuals with spinal cord injury. *J Rehabil Res Dev.* 2002;39:29–39. [PubMed] [Google Scholar]
21. Iscoe S. Phrenic motoneuron discharge during sustained inspiratory resistive loading. *J Appl Physiol.* 1996;81:2260–2266. [PubMed] [Google Scholar]
22. Road JD, Cairns AM. Phrenic motoneuron firing rates before, during, and after prolonged inspiratory resistive loading. *J Appl Physiol.* 1997;83:776–783. [PubMed] [Google Scholar]
23. Williams JS, Wongsathikun J, Boon SM, Acevedo EO. Inspiratory muscle training fails to improve endurance capacity in athletes. *Med Sci Sports Exerc.* 2002;34:1194–1198. [PubMed] [Google Scholar]
24. Fairbarn MS, Coutts KC, Pardy RL, McKenzie DC. Improved respiratory muscle endurance of highly trained cyclists and the effects on maximal exercise performance. *Int J Sports Med.* 1991;12:66–70. [PubMed] [Google Scholar]
25. Inbar O, Weiner P, Azgad Y, Rotstein A, Weinstein Y. Specific inspiratory muscle training in well-trained endurance athletes. *Med Sci Sports Exerc.* 2000;32:1233–1237. [PubMed] [Google Scholar]