Original Article

Lipid profiles are influenced by arm cranking exercise and training in individuals with spinal cord injury

MS El-Sayed^{*,1} and A Younesian¹

¹Faculty of Science, School of Sport and Exercise Science, Liverpool John Moores University, Liverpool, UK

Study design: A prospective, two-group comparative intervention study.

Objective: To determine the acute and training effects of arm cranking exercise on blood lipid profiles in wheel chair bound individuals with spinal cord injury (SCI) and normal able-bodied subjects.

Setting: Faculty of Science, School of Sport and Exercise Science, Liverpool John Moores University, England.

Methods: Total cholesterol, triglyceride and high-density lipoprotein cholesterol (HDL-C) at rest and in response to arm cranking exercise before and after 12 weeks of training were compared between individuals with SCI ($N = 5$) and able-bodied subjects ($N = 7$). Following the determination of peak oxygen consumption (VO_{2peak}), all subjects performed a submaximal arm cranking exercise at an intensity corresponding to 60–65% VO_{2peak} for 30 min. Venous blood samples were obtained before and after submaximal exercise and measured for total cholesterol, triglycerides and HDL-C concentrations. These lipid parameters were remeasured in all subjects at rest and in response to the same submaximal arm cranking exercise after 12 weeks of individually supervised arm cranking training programme.

Results: Before training, the resting mean value of triglyceride in individuals with SCI was significantly ($P < 0.05$) higher than that found in able-bodied persons. Acute arm cranking exercise did not change total cholesterol or triglyceride concentrations in either the SCI or the able-bodied groups. However, HDL-C increased significantly following exercise in the able-bodied subjects. Following training, the resting mean value of total cholesterol in the group with SCI was significantly ($P < 0.05$) higher compared with able-bodied individuals. Furthermore, the resting and post submaximal arm cranking exercise mean values of total cholesterol in the able-bodied group, but not in the group with SCI, were significantly lower than those observed before training. While the resting mean value of HDL-C before training in the group with SCI was lower than that found in the able-bodied, this difference did not reach the designated level of significance ($P > 0.05$). Submaximal arm cranking exercise was followed by a significant increase in HDL-C only in the able-bodied individuals. Compared to pretraining, the resting and post arm cranking exercise levels of HDL-C in the group with SCI increased significantly ($P < 0.05$) after training.

Conclusion: It is concluded that acute arm cranking exercise and training in individuals with SCI is associated with favourable effects on HDL-C, whereas total cholesterol and triglycerides were not altered. The mechanism responsible for the increase in HDL-C with training in individuals with SCI is not known, but it is likely to be related to increased activity of cholesterol transport enzymes lipoprotein lipase and acyltransferase.

Spinal Cord (2005) 43, 299–305. doi:10.1038/sj.sc.3101698; Published online 7 December 2004

Keywords: lipids; spinal cord injury; arm cranking exercise; exercise training

*Correspondence: MS El-Sayed, Faculty of Science, School of Sport and Exercise Science, Liverpool John Moores University, Liverpool L3 2ET, UK

Introduction

Those with lower limb paralysis due to spinal cord injury (SCI) naturally employ their arms for wheelchair locomotion and other activities of daily living, as well as for exercise training and sports activities.¹ The comparatively small muscle mass under voluntary control,

impaired cardiovascular reflex responses and the inactivity of the skeletal muscle pump of the legs all lead to a diminished arm muscles ability to exercise. Furthermore, the limitations of the skeletal muscle system results in early onset of fatigue and exhaustion. This dampens an active lifestyle and daily life activities become more physically demanding due to the low level of muscular strength and cardiovascular fitness. Sedentary lifestyles worsen this condition leading to a debilitating chain of physical and cardiovascular complications that can be difficult to prevent. Indeed, spinal cord injured individuals endure a multitude of cardiovascular complications including coronary heart disease.²

Although regular exercise has been shown to protect against cardiovascular diseases, the mechanism(s) through which it exerts this effect is not fully understood. The aetiological role of exercise in the primary and secondary prevention of cardiovascular diseases is linked with favourable alterations in blood lipid profiles. In recent years, morbidity and mortality associated with sedentary life and hyperlipidaemia have prompted many researchers to recommend daily regular activities for persons with SCI.³ It is also well recognised that dyslipidaemias may contribute to increased cardiovascular morbidity in individuals with SCI.⁴ Results in the literature suggest a link between sedentary lifestyle and the incidence of cardiovascular diseases in paraplegic and tetraplegic individuals⁵ who also exhibit abnormal lipid profiles and clinical complications from atherosclerosis.⁶

Consequently, interest has been heightened regarding the possible effects of exercise and training on blood lipid profiles, not only in normal healthy subjects but also in individuals with SCI. This is because the exact effects of vigorous arm exercise and conditioning on blood lipid profiles in individuals with SCI is not clearly defined. In addition, studying the influence of exercise on blood lipid profiles in individuals with SCI may have clinical as well as scientific significance because sedentary lifestyle can be a primary feature leading to significant degenerative cardiovascular disorders and these are the most frequent cause of death in this population.⁶ Therefore, the present study was designed to examine the effects of arm cranking acute exercise and 12 weeks of physical training of moderate intensity on blood lipid profiles in individuals with SCI in comparison with normal able-bodied subjects.

Materials and methods

Subjects

A total of 12 subjects (seven normal and five spinal cord injured) volunteered to participate in this study. One of the subjects with SCI exhibited some form of musculoskeletal and cardiovascular problems; this did not contraindicate his participation in exercise testing or the completion of the training programme. The data generated from this subject were included in the statistical analyses. None of the subjects had previously engaged in an organised training programme. Verbal

and written consent were obtained from each subject prior to testing and training, and the Human Ethics Committee of the University approved the study testing procedures and experimental protocol. Subjects completed a health history questionnaire prior to the commencement of the study. Before the main experiments, all subjects took part in two sessions of habituation in order to familiarise themselves with the exercise protocol and laboratory environment. The mean ($\pm$ SD) age of the subjects was 32 ± 1.6 years for able-bodied subjects and 31 ± 2.9 years for spinal cord injured individuals.

Measurement of peak oxygen consumption

All subjects performed a continuous progressive workload arm cranking exercise test on arm cranking ergometer (Monark, Sweden) until volitional fatigue for the determination of peak oxygen consumption (VO_{2peak}). All subjects performed the VO_{2peak} test trial twice, 1 week before and 1 week after the completion of the conditioning programme. Subjects reported to the laboratory for testing, fasted for 12 h and had had no alcohol for the preceding 24 h. All tests and blood sampling commenced at the same time of day. Following a 5-min warm-up period at an exercise intensity of 30 W, the work rate was increased every 2 min by 30 W until exhaustion. During the test, a cranking frequency of 60–65 was maintained by using a metronome. Minute ventilation, oxygen uptake and carbon dioxide production were continuously analysed and recorded by an open-circuit system (Metamax; Cortex; Germany). Calibration of the system was carried out according to the manufacturer's instructions. Heart rate was measured at rest and continuously during exercise by short-range radio telemetry (Polar, P.E.3000, Kempele, Finland). The physiological data obtained from the VO_{2peak} test were utilised, using regression analysis, for the calculation of the exercise intensity corresponding to 60–65% VO_{2peak} . The indication for termination of exercise was subjective maximal exercise as suggested by the participants' own symptom of fatigue or breathlessness. Other indications for stopping the exercise test were the occurrence and progression of any symptoms to the point of unwillingness of the subject to continue or the continuation of the test becoming detrimental to the subjects' welfare. The attainment of VO_{2peak} was judged when the following criteria were met: (1) a plateau in VO_2 with increasing workload, (2) inability of the subject to maintain the designated pedalling frequency and (3) a respiratory exchange ratio of 1.1 or above. If a subject did not complete a satisfactory maximal test, the testing procedures were repeated after 7 days.

Submaximal arm cranking exercise test protocol before conditioning

Approximately 1 week after the measurement of VO_{2peak} , each subject performed a submaximal exercise protocol. The exercise protocol commenced with a

warm-up period of 5 min at 30 W for 5 min, and thereafter the external work load was increased to elicit a heart rate response corresponding to 60–65% $\text{VO}_{2\text{peak}}$ and arm cranking exercise continued at this intensity for 30 min. A cranking frequency of 60–65 per minute was maintained and the heart rate was monitored. At the end of the $\text{VO}_{2\text{peak}}$ test, subjects were asked to rate their perception of effort using the Bar Scale. Rating of perception of effort was also recorded for every 5-min interval during the submaximal exercise test.

Exercise conditioning programme

The training programme was individually supervised for each subject in both the SCI and able-bodied groups. All exercise sessions were performed using arm cranking ergometer and each training session started out with a 5-min warm-up at a light workload. Thereafter, the workload was increased to elicit a heart rate corresponding to 60–65 $\text{VO}_{2\text{peak}}$ for each subject. The external resistance to arm cranking during each training session was continuously adjusted to maintain the preassigned heart rate and all subjects exercised at this intensity for 30 min. The exercise sessions were continuous, and supervised and monitored regularly. Each subject's training heart rate was adjusted as submaximal heart rate was decreased with training. All exercise trials and training sessions were performed in a temperature-controlled environment ($22 \pm 1^\circ\text{C}$). All subjects exercised for 30 min on three nonconsecutive days/week for 12 weeks. No cardiovascular problems or unusual episodes occurred during training. With the exception of some early attrition by one subject with SCI, the attendance rate was 100% in both the SCI and able-bodied groups with no complaints of excess or intolerable muscle soreness or fatigue. No dietary changes were recommended, but subjects were instructed to consume their normal diet and maintain their normal activity and lifestyle patterns throughout the study. Subjects were also asked to standardise and replicate their dietary intake in the 24-h prior to each submaximal exercise at the start and at the end of the training programme.

During the training programme, all subjects were instructed to follow their normal routine and refrain from strenuous exercise.

Submaximal arm cranking exercise test protocol after conditioning

The same submaximal arm cranking exercise, as described above, was used after conditioning to determine the effects of exercise and training on lipid profiles at rest and in response to acute exercise. Although the subjects' cardiorespiratory fitness was improved due to conditioning (Table 1), the acute arm cranking following conditioning was performed at the same relative exercise intensity in relation to $\text{VO}_{2\text{peak}}$ (60–65% $\text{VO}_{2\text{peak}}$).

Blood sampling and analysis

All subjects were instructed to refrain from food, caffeine or strenuous physical activity during the 12 h preceding blood sampling. Blood samples were obtained at the same time of day in an ambient temperature of $20 \pm 1^\circ\text{C}$ and relative humidity of $55 \pm 5\%$. After reporting to the laboratory, subjects were requested to remain in the sitting position for 15 min, after which a resting 10 ml of venous blood sample was removed with no stasis. A second 10 ml of venous blood sample was removed immediately after the submaximal arm cranking exercise test for 30 min. Blood samples were transferred into plastic centrifuge tubes internally coated with EDTA and used for the measurement of lipid variables. To avoid interassay variability, over the duration of the study, blood samples were coded and analysed using the same batch of reagents. Total cholesterol and triglycerides were determined in whole blood, while high-density lipoprotein cholesterol (HDL-C) was assayed in plasma (Reflotron, Boehringer, Mannheim, Germany). Based on the laboratory control procedures of repetitive determination of samples with known concentration of lipids, the coefficient of variation for total cholesterol, triglycerides and HDL-C were

Table 1 Physiological responses to maximal arm cranking exercise before and after training in SCI individuals ($N=5$) and able-bodied subjects ($N=7$)

	SCI individuals		Normal subjects	
	BT	AT	BT	AT
$\text{VO}_{2\text{peak}}$ (l min^{-1})	1.81 ± 0.10	$1.94 \pm 0.05^*$	1.82 ± 0.11	$2.1 \pm 0.1^*$
$\text{VO}_{2\text{peak}}$ (l kg min^{-1})	24.12 ± 2.60	$26.2 \pm 1.36^*$	26.79 ± 1.85	$29.1 \pm 1.05^*$
HR_{peak} (beat min^{-1})	173 ± 8.2	173.2 ± 10.8	169 ± 5.9	169.8 ± 7.3
VE_{peak} (l min^{-1})	75.3 ± 9.1	$83.56 \pm 10.2^*$	68.4 ± 5.4	$80.3 \pm 7.7^*$
WL_{peak} (W)	168 ± 37.6	$185 \pm 24.1^*$	160 ± 16.5	$204 \pm 11.2^*$

$\text{VO}_{2\text{peak}}$ = maximum amount of oxygen consumed at the end of the incremental arm cranking test; HR_{peak} = maximum heart rate achieved at the end of the incremental arm cranking test; VE_{peak} = maximum ventilation at the end of the incremental arm cranking test; WL_{peak} = maximum workload achieved at the end of the incremental arm cranking test; BT = before training and AT = after training

*Significant difference ($P < 0.05$) compared to before training

1.9, 1.4 and 2.9%, respectively. Accuracy of lipid measurements was established by using control sera.

Statistical analysis

All statistical analyses were performed using the software statistical package SPSS version 11 (SPSS, Chicago, USA). A two-way analysis of variance (ANOVA) with repeated measurements was used to detect differences in mean values. When ANOVA indicated the presence of an overall significant difference, Tukey's *post hoc* tests were employed to ascertain which mean values were statistically significant. The alpha level of $P < 0.05$ was the minimum level required to reject the null hypothesis. Values in the text are mean $\pm$ SD, unless otherwise stated.

Results

Physiological results

Physiological and performance-related results of arm cranking exercise before and after training for subjects with SCI and able-bodied individuals are shown in Table 1. Before the conditioning programme, the mean values for VO_{2peak} , maximal exercise duration and power output were similar for the two groups. All SCI and able-bodied subjects exhibited a significant increase in VO_{2peak} , maximum exercise duration and maximum power output following training (Table 1).

Blood lipid profiles at rest and following acute submaximal arm cranking exercise before and after conditioning

Total cholesterol The resting and post submaximal arm cranking exercise mean values of total cholesterol are shown in Figure 1a (before training) and b (after training). Before training, the resting mean value of total cholesterol in individuals with SCI was nonsignificantly ($P > 0.05$) higher than that found in able-bodied subjects. No demonstrable change in total cholesterol concentration was found after arm cranking exercise in either the SCI or the able-bodied groups (Figure 1a). Following training, the higher resting mean value of total cholesterol in individuals with SCI compared with the able-bodied persisted and reached the designated level of significance ($P < 0.05$). Furthermore, the resting and post submaximal arm cranking exercise mean values of total cholesterol were significantly lower than those observed before training only in able-bodied individuals (Figure 1b).

Triglyceride The resting and post submaximal arm cranking exercise mean values of triglyceride are shown in Figure 2a (before training) and b (after training). Before training, the resting mean value of triglyceride in individuals with SCI was significantly ($P < 0.05$) higher than that found in able-bodied subjects. Although triglyceride concentration exhibited an increase after exercise in both groups, this rise was not significant

Figure 1 Mean ($\pm$ SE) values of total cholesterol (mmol.l⁻¹) at rest and after arm cranking exercise. (a) Represents before training and (b) Signifies after training. Open bars represent the group with SCI while solid bars denote the able-bodied group. *Denotes significantly higher ($P > 0.05$) resting mean value in SCI individuals than that in able-bodied subjects after training. \$ Signifies lower mean values ($P > 0.05$) at rest and in response to exercise in normal subjects after training compared with the corresponding values before training. AT represents after training

Figure 2 Mean ($\pm$ SE) values of triglycerides (mmol.l⁻¹) at rest and after arm cranking exercise. (a) Represents before training and (b) Signifies after training. Open bars represent the SCI group while solid bars denote the able-bodied group. *Denotes significantly a higher ($P > 0.05$) resting mean value in SCI individuals than that in able-bodied subjects before training. AT represents after training

($P > 0.05$). Following training, the higher resting mean value of triglyceride in individuals with SCI compared with the able-bodied persisted (Figure 2b) but this difference did not reach the designated level of significance ($P > 0.05$). No further alterations in the mean values of triglyceride were found with training.

High-density lipoprotein cholesterol The resting and post submaximal arm cranking exercise mean values of HDL-C are shown in Figure 3a (before training) and b (after training). Although the resting mean value of HDL-C before training in individuals with SCI was lower than that found in the able-bodied (Figure 3a), this difference did not reach the designated level of significance ($P > 0.05$). Acute arm cranking exercise was followed by a significant ($P < 0.05$) increase in HDL-C in both groups (Figure 3a). Compared to pretraining, the resting level of HDL-C increased significantly only in the SCI group. Furthermore, results indicated a significant ($P < 0.05$) increase in HDL-C following an acute bout of arm cranking exercise in the group with SCI, but not in the able-bodied group (Figure 3b).

Discussion

Acute arm cranking exercise and lipid profiles before training

The study herein was designed to determine the acute effects of arm cranking exercise on lipid profiles before

and after training in individuals with SCI and able-bodied individuals. The question remains as to whether there is a single best exercise intensity and duration for inducing favourable changes in blood lipid profiles. The results demonstrated no significant alterations in total cholesterol and triglyceride in response to a single bout of arm cranking exercise in individuals with SCI or able-bodied subjects. These results are in agreement with earlier reports indicating that acute exercise bouts of short duration induce no change in plasma cholesterol concentration immediately after exercise or during recovery.^{7,8} Similar to cholesterol, triglyceride concentration was not altered following an acute bout of arm cranking exercise of short duration. This is consistent with previous results in the literature indicating no significant change in the triglyceride level following running or cycling exercise of short durations in normal subjects.^{7,8} Unlike intramuscular stores of triglycerides, which have been shown to contribute significantly to energy metabolism,⁹ the importance of blood-borne triglycerides to energy metabolism during exercise of relatively short duration has not as yet been established and is still an issue of debate. We believe that blood-borne triglycerides played a negligible role during arm cranking exercise trials.

The results of the present study also revealed that acute arm cranking exercise in individuals with SCI and able-bodied subjects were associated with a significant increase in HDL-C. Earlier studies on the interaction between exercise and HDL-C in able-bodied individuals have yielded contrasting results. For example HDL-C either increased¹⁰ following repeated sessions of endurance exercise or remained unaltered⁹ after running exercise in trained runners. Other studies employed different exercise protocols and showed an increase in HDL-C in response to a single bout of submaximal exercise at 60% $\text{VO}_{2\text{max}}$ ¹¹ or prolonged exercise for 120 min at 30% $\text{VO}_{2\text{max}}$.¹² Earlier studies designed to determine plasma lipolytic activity also demonstrated an increase in lipoprotein lipase, which may have been responsible for the post exercise increase in HDL-C concentration.^{13,14} It is reasonable to suggest therefore that the acute arm cranking exercise protocol employed in the present study may have induced acute modifications and intracellular redistribution of HDL-C. This may have led to an increase in the flux of lipid to HDL-C molecule under the influence of lipoprotein lipase.

Arm cranking training and performance-related indices

The trauma caused by SCI to an individual is usually associated with extreme changes in his/her lifestyle where there is a striking decline in physical activity. Wheelchair users employ their relatively small and weak upper body musculature for locomotion and most other physical activities of daily living. This is disadvantageous due to the limited maximal power output capability and peak oxygen uptake for arm exercise. The evidence reported in the study herein support the

Figure 3 Mean ($\pm$ SE) values of HDL (mmol l^{-1}) at rest and after arm cranking exercise. (a) Represents before training and (b) Signifies after training. Open bars represent the SCI group while solid bars denote the able-bodied group. *Denotes a significantly higher ($P > 0.05$) mean value following exercise as compared to the mean value following rest. AT represents after training

notion that arm cranking exercise training in individuals with SCI improves their health status and exercise performance capacity as reflected by a significant increase in the peak amount of oxygen they are able to consume during maximal exercise, thus indicating that the physical conditioning programme had induced favourable cardiovascular improvements with a resultant significant increase in the maximal aerobic capacity.

In addition, participation of individuals with SCI in the arm cranking training programme led to a significant increase in power output in parallel with a marked increase in aerobic power and physical capability (Table 1). These results are in agreement with previous studies on individuals with SCI, indicating that endurance-type arm cranking exercise training for several weeks can significantly increase power output, peak oxygen consumption and aerobic power.^{15–17} It is possible that the enhanced aerobic power as reflected by an increase in peak oxygen consumption was due to peripheral adaptation, augmented arterial vasodilatation and increase in capillary density and/or metabolic efficiency within the skeletal muscles of the arms. Although recommendations of exercise training for individuals with SCI have been, for the most part, quite conservative, it is clear that not only is it possible for these individuals to tolerate exercise training but also that constant repetition of intense arm cranking exercise may be necessary to induce favourable cardiovascular responses in this population.

Acute arm cranking exercise and lipid profiles after training

Diminished muscular and cardiopulmonary capacity resulting from a sedentary lifestyle further exacerbates the already deteriorated physical capability of individuals with SCI. Sedentary lifestyle can be a major factor leading to consequential degenerative changes in the cardiovascular system and this may explain the higher incidence of cardiovascular complications reported for individuals with SCI compared to age- and gender-matched able-bodied individuals.² Disruption of the spinal cord normal functions elicits complex effects on the sympatho-adrenal system, which may include alterations in catecholamines and lipid metabolism. Hyperlipidaemia, due to accumulation of triglycerides and cholesterol, is well documented in individuals with SCI. Recent evidence also indicated that higher coronary heart disease risk for sedentary individuals with SCI is associated with lower concentration of HDL-C in comparison to athletes with SCI, or sedentary able-bodied subjects.¹⁸

Meagre information is available to explain why the incidence of cardiovascular disease is high among individuals with SCI. The cause of this phenomenon and its relation to SCI are not as yet known. In light of the data of the present study, part of the answer to this question may be related to the depressed basal level of HDL-C (Figure 3a). These findings concur with earlier

reports, suggesting that the concentrations of HDL-C in SCI individuals are some of the lowest reported for any population.¹⁹ The low level of HDL-C was attributed to the extremely sedentary lifestyle adopted by SCI individuals. This explanation is supported by earlier evidence indicating that highly trained athletes with SCI exhibit higher level of HDL-C when compared with physically inactive individuals with SCI.¹⁹ Participation in sports activities and improvements in physical work capacity were the most important determinants responsible for the favourable changes in lipids and lipoprotein profiles in SCI individuals.²⁰

After arm cranking exercise training, the levels of HDL-C at rest and in response to acute arm cranking exercise were higher in the persons with SCI than before training and the increase occurred in each individual with SCI. Initiatives to identify mechanisms through which exercise training can increase HDL-C have sparked interest in recent years.^{21–23} Although the physiological pathways involved in the increase in HDL-C due to arm cranking training in individuals with SCI were not examined in the present study, several possible explanations have been proposed. There is evidence to suggest that lipoprotein lipase activity may be involved.^{21–23} Some investigators have also demonstrated that aerobic exercise training in able-bodied individuals increases plasma lipoprotein lipase and lecithin cholesterol acyltransferase activities.²³ Thus, a likely explanation of the current findings is that similar mechanisms responsible for HDL-C increase with training might have also been presented in individuals with SCI.

The nature of this prospective study may preclude firm conclusions regarding the mechanism responsible for the increase in HDL-C with training. Furthermore, the mechanism responsible for the increase in HDL-C with training in individuals with SCI is not known, but it is likely to be related to an increased activity of cholesterol transport enzymes lipoprotein lipase and acyltransferase. To clarify the exact responsible mechanism, more investigations are warranted. It is recognised that there are potential limitations to the study design. First, our study population consisted of a voluntary sample. Consequently, it may not be necessarily correct to generalise the results to other populations. Second, the sample size of the study populations examined was small and that may restrict the certainty of the conclusion reached and lowers the statistical power of accepting the null hypothesis. It is possible that a type II error was committed, and a larger sample size might be required in future studies to confirm or refute the results of the present investigation.

In summary, arm cranking exercise training in individuals with SCI has favourable effects on health status and exercise performance capacity as reflected by a significant increase in VO_{2peak} and an increase in power output. This occurred in parallel with a marked increase in HDL-C in response to arm cranking exercise, whereas total cholesterol and triglycerides were not altered.

References

- 1 Glaser RM. Exercise and locomotion for the spinal cord injured. In: Terjung RL (ed). *Exercise and Sports Science Reviews*, Vol. 13. MacMillan Publishers: New York 1985, pp 263–303.
- 2 Hoffman MD. Cardiorespiratory fitness and training in quadriplegics and paraplegics. *Sport Medicine* 1986; **3**: 312–330.
- 3 Washburn RA, Figoni SF. Physical activity and chronic cardiovascular disease prevention in spinal cord injury: a comprehensive literature review. *Top Spinal Cord Injury Rehabil* 1998; **3**: 16–32.
- 4 DeVivo MJ, Black KJ, Stover SL. Causes of death during the first 12 years after spinal cord injury. *Arch Phys Med Rehabil* 1993; **74**: 248–254.
- 5 Nash MS. Exercise reconditioning of the heart and peripheral circulation after spinal cord injury. *Top Spinal Cord Injury Rehabil* 1997; **3**: 1–15.
- 6 Bauman WA, Spungen AM. Disorders of carbohydrate and lipid metabolism in veterans with paraplegia or quadriplegia: a model of premature aging. *Metabolism* 1994; **43**: 749–756.
- 7 El-Sayed MS, Rattu AJM. Changes in lipid profiles in response to submaximal and maximal exercise in trained cyclists. *Eur J Appl Physiol* 1996; **73**: 88–92.
- 8 Davis PG, Bartoli WP, Durstine JL. Effects of acute exercise intensity on plasma lipid and apolipoproteins in trained runners. *J Appl Physiol* 1992; **72**: 914–919.
- 9 Hurley BF *et al.* Muscle triglycerides utilisation during exercise: effect of training. *J Appl Physiol* 1986; **60**: 562–567.
- 10 Angelopoulos TJ, Robertson RJ, Goss FL, Metz KF, Laporte RE. Effect of repeated exercise bouts on high density lipoprotein cholesterol and its subfractions HDL2-C and HDL3-C. *Int J Sport Med* 1993; **14**: 196–201.
- 11 Hicks AL, MacDougall JD, Muckle TJ. Acute changes in high-density lipoprotein cholesterol with exercise of different intensities. *J Appl Physiol* 1987; **63**: 1956–1960.
- 12 Pay HE, Hardman AE, Jones CJ, Hudson A. The acute effects of low intensity exercise on plasma lipid in endurance trained and untrained young adults. *Eur J Appl Physiol* 1992; **64**: 182–186.
- 13 Park DH, Ransone JW. Effects of submaximal exercise on high-density lipoprotein cholesterol subfractions. *Int J Sports Med* 2003; **24**: 245–251.
- 14 Visich PS *et al.* Effects of exercise with varying energy expenditure on high-density lipoprotein cholesterol. *Eur J Appl Physiol Occup Physiol* 1996; **72**: 242–248.
- 15 Nilsson S, Staff PH, Pruett EDR. Physical work capacity and the effect of training on subjects with long-standing paraplegia. *Scand J Rehabil Med* 1975; **7**: 51–56.
- 16 DiCarlo SE, Supp MD, Taylor HC. Effect of arm ergometry training on physical work capacity of individuals with spinal cord injuries. *Phys Ther* 1983; **63**: 1104–1107.
- 17 Miles DS, Sawka MN, Wilde SW, Durbin RJ, Gotshall RW, Glaser RM. Pulmonary function changes in wheelchair athletes subsequent to exercise training. *Ergonomics* 1982; **25**: 239–246.
- 18 Boston AG, Toner MM, Mcardle WD, Montelione T, Brown CD, Stein PA. Lipid and lipoprotein profiles related to peak aerobic power in spinal cord injured men. *Med Sci Sports Exerc* 1991; **23**: 409–414.
- 19 Brenes G, Dearwater S, Shapera R, Laporte R, Collins E. High density lipoprotein cholesterol concentrations in physically active and sedentary spinal cord injured patients. *Arch Phys Med Rehabil* 1986; **67**: 445–450.
- 20 Hooker SP, Wells CL. Effects of low and moderate intensity training in spinal cord injured persons. *Med Sci Sports Exerc* 1989; **21**: 18–22.
- 21 Thompson PD, Cullinane EM, Henderson LO, Herbert PN. Acute effects of prolonged exercise on serum lipids. *Metabolism* 1980; **29**: 662–665.
- 22 Kantor MA, Cullinane EM, Sady SP, Herbert PN, Thompson PD. Exercise acutely increases high density lipoprotein cholesterol and lipoprotein lipase activity in trained and untrained men. *Metabolism* 1987; **36**: 188–192.
- 23 Williams PT, Albers JJ, Krauss RM, Wood PDS. Associations of lecithin:cholesterol acyltransferase (LCAT) mass concentration with exercise, weight loss, and plasma lipoprotein subfraction concentrations in men. *Atherosclerosis* 1990; **82**: 53–58.