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The Effects of Exercise Intensity on the Low-Density Lipoprotein Profile: Quantitative vs. Qualitative Changes

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Abstract: The purpose of this study was to determine the effects of aerobic exercise intensity on the quantitative and qualitative changes of serum Low-Density Lipoprotein (LDL). In 2005, thirty low active men aged 25-42 years were randomly allocated to three high intensity (HI, N = 10), moderate intensity (MI, N = 9) and control (CO, N = 11) groups. The high and moderate intensity groups participated in an 8 week aerobic program which consisted of aerobic activities lasting 45-60 min; three times a week at an estimated 75-80% and 60-65% of their age-predicted maximum heart rate, respectively. Both programs began at a prescribed intensity and maintained constant according to the improvement of subjects during the program. In order to control the training intensity, heart rate was monitored and recorded in 10 min intervals by a cardio frequency meter. After 8 week, LDL particle size increased significantly in the MI group whereas, LDL concentration was not changes significantly in the MI group. There were no significant changes regarding LDL particle size and concentration in the HI and CO groups ($p>0.05$). These data suggest that MI training can be more effective in increasing LDL particle size than HI training.

Key words: Training intensity, LDL particle size, LDL concentration

INTRODUCTION

Increased physical activity and fitness are clearly associated with reductions in the risk of cardiovascular disease (Jacobs *et al*., 2006; Duscha *et al*., 2005; Duncan *et al*., 2005; Al-Ajlan and Mehdi, 2005; Beard *et al*., 1996), but the optimal intensity of exercise necessary for reductions in risk or risk factors is unknown Because of apparently conflicting information (Kelley and Kelley, 2007; Branth *et al*., 2006; Duncan *et al*., 2005; Shono *et al*., 2002), there is confusion about what recommendations to make for exercise that will confer specific health benefits. In spite of the importance of this issue, there have been no comprehensive prospective studies investigating the effects of different intensities of exercise.

Although regular exercise is known to decrease the risk of cardiovascular disease, comprehensive reviews (Durstine and Haskell, 1994) suggest that exercise has little effect on Low-Density Lipoprotein (LDL) cholesterol concentrations (Leon and Sanchez, 2001). Some authors suggest that the concentrations of LDL particles and small LDL particles are better indicators of cardiovascular risk than are the elements of the traditional lipid profile (Kamigaki *et al*., 2001; Pascot *et al*., 2001; Vakkilainen *et al*., 2000; Lamarche *et al*., 1997).

Some researches suggest that changes in lipoproteins profiles are similar in high-intensity interventions and in moderate-intensity interventions of longer duration if the energy cost of exercise is similar (Duscha *et al*., 2005; Duncan *et al*., 2005; Al-Ajlan and Mehdi, 2005; Paffenbarger *et al*., 1993). On the other hand, authors have concluded that high-intensity training is more effective in improving lipoproteins profiles because of increased enzymes activities (Kelley and Kelley, 2007; O'Donovan *et al*., 2005; Duscha *et al*., 2005; De Groot *et al*., 2003; Kraus *et al*., 2002; Gossard *et al*., 1986).

LDL mean particle diameter has been classified into two phenotypes: A and B (Williams *et al*., 1992a). The mean particle diameter of Type B is less than or equal to 265.0 angstrom. Mean particle diameter has been inversely correlated with plasma triglycerides in both men and women (Austin *et al*., 1993). Smaller, denser sub fractions of LDL have been associated with an increased risk of atherosclerosis (Austin *et al*., 1988; Kwiterovich *et al*., 1993). Several studies have supported the hypothesis that the smaller, denser particles are more susceptible to oxidation and thus more atherogenic (De Graaf *et al*., 1993, 1991; Tribble *et al*., 1992; Chait *et al*., 1993).

Because of apparently conflicting information regarding the effects of training intensity on the

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lipoproteins profile and also determination the effects of exercise intensity on the quantitative and qualitative changes of serum LDL, this study was designed to test the effects of 8 week aerobic exercise intensity (75-80% vs. 60-65% of age-predicted maximum heart rate) on the LDL concentrations and particle size.

MATERIALS AND METHODS

Subjects and design: In 2005, thirty low active men who volunteered to participate in the study read and signed an informed consent document prepared and approved by the Board for Protection of Human Rights affiliated to the University of Mohaghegh Ardabili. All the subjects were screened and homogenized for absence of cardiovascular disease, substance use, surgery histories by the expert physician and the subjects self-report procedure and then randomly divided into three groups of high (HI, N = 10), moderate intensity (MI, N = 9) and control (CO, N = 11) groups, before completing a physical activity readiness questionnaire. The subjects had encouraged to maintain their habitual diets. Diet (three days) was requested from each subject prior to experimental trial. The diet logs were analyzed using the Nutritionist III Version 7.0 (N-squared computing, Salem, OR). This was done in order to determine the calorie intake and the percentages of carbohydrate, fat and protein which were ingested prior to the treatment trials.

VO_{2max} and body composition measurements: To evaluate the $VO_{2\ max}$, Ebbling submaximal treadmill protocol and equation was used. To administer this test, subjects warmed up on the treadmill with the speed of 4.8 km h^{-1} for 4 min. During second 4 min walking, the slope of the treadmill sets in 5% and the walking speed increases so that 70% of maximum heart rate reviled.

Body height (cm) and weight (kg) was determined by an electronic SECA scale. Three point Jackson-Pollack equation and mechanical Lange skinfold caliper was used to prediction of body fat.

Training program: Once enrolled, the subjects underwent education and orientation to the program. The HI (High Intensity exercise) and MI (moderate intensity exercise) groups participated in an 8 week aerobic program which consisted of aerobic activities lasting 45-60 min; three times a week at an estimated 75-80 and 60-65% of their age-predicted maximum heart rate, respectively. Formal exercise classes were held included 3-5 min of walking and gagging (slow running), 5-7 min of stretching, 4-8 min of gagging, 6-9 min of calisthenics, three 10 min of running with the 2 min of relaxation activities intervals and 5-10 min of cool down. The participants also were encouraged to put away their own physical training program especially on the weekends throughout of study. Both programs began at a prescribed intensity and maintained constant according to the improvement of subjects during the 8 week aerobic program. In order to control the training intensity, heart rate was monitored and recorded in 10 min intervals by a cardio frequency meter during each training session.

Determination of serum lipids and lipoproteins: Immediately before the start and immediately at the conclusion of the 8 week program, 14 h fasting blood samples were taken in two 5 mL Vacutainers (Becton-Dickinson Vacutainer Systems) containing SST clot activating gel between 9 to 10 am. The samples were allowed to clot and the serum separated by high-speed centrifugation for 15 min. One tube was analyzed for serum lipids while the second tube constituted the experimental sample from which LDL was isolated. Prior to serum separation in tube No. 2, a protease inhibitor cocktail was added to prevent degradation of the apolipoproteins.

Triglyceride, HDL-cholesterol and total cholesterol levels were measured using standard enzymatic procedures on an Olympus Auto analyzer (Smith-Kline Beecham Laboratories). The LDL-cholesterol concentration was calculated by Friedewald and Fredrickson equation (Friedewald *et al*., 1972).

LDL size determination: Frozen serum was used to determine the effect of the program on mean LDL particle diameter. The size of the LDL particles was determined via electrophoresis (Krauss and Burke, 1982). The serum was adjusted to 20% (wt./vol) sucrose and 10 μL placed in each lane of a polyacrylamide gradient gel. The sample was run at 12-14°C and 125 V for 24 h in Tris-boric acid-Na_2 EDTA buffer, pH 8.3 along with two standards supplied and two control samples. Pre and post samples were run at the same time. The gels were fixed in a solution containing methanol, acetic acid and Coomassie brilliant blue R-250. They were then destined with 20% methanol followed by 9% acetic acid. The gels were then analyzed by densitometry. The diameter of the absorbance maxima was calculated from a calibration curve using the Krauss standards of known diameters.

Data analysis: All data are expressed as mean±SD. The data were analyzed using ANOVA and Paired t-test to assess the all cardio-vascular variables changes among

three groups and the inter groups changes, respectively. Pearson simple correlation procedures were used to assess the relationship between changes in LDL particle size and Triglycerides. All statistics were run using the SPSS13 statistical package. Treatment effects are considered significant at a value of $p \leq 0.05$.

RESULTS

There were no significant differences in the baseline lipid profile (LDL particle size and concentrations, HDL, Tg, Total-cholesterol, ApoB, $ApoA_1$, $ApoB/ApoA_1$ ratio), body composition variables ($p>0.05$) and cardio-respiratory fitness ($p>0.05$) among groups.

The results of the paired samples t-tests yielded no significant ($p>0.05$) differences among the groups for total calories; grams of carbohydrate, fats and proteins and percentage of calories from carbohydrates, fats and proteins during the baseline (Table 1).

Results also showed significant increases of $VO_{2\,max}$ in the MI and HI groups after 8 weeks of training ($p \leq 0.01$); whereas there was no significant differences observed in the body composition variables (body weight, LBM, % fat) during treatments ($p>0.05$) (Table 2).

LDL particle diameter: After 8 week, the mean diameter of the LDL particles increased significantly from 260.8±5.6 to 263.6±4.9 Angstrom in the MI group ($p \leq 0.05$). The mean increase was 2.85±0.2 Angstrom. Whereas, there was no significant increase observed in the HI group (Pre test: 258.5±2.5; Post test: 259.6±5.9 Angstrom; $p>0.05$); the mean diameter of the LDL particles was constant in the CO group (Pre test: 257.6±4.3; Post test: 257.4±7.3 Angstrom; $p>0.05$) (Fig. 1).

The changes in LDL size were not correlated with the changes in triglycerides among the three groups.

LDL concentrations: There were no significant changes in the LDL concentrations in the MI, HI and CO groups (MI: Pre test: 98.1±35.5; Post test: 106.7±37.9; HI: Pre test: 117.9±32.1; Post test: 106.2±21.3; CO: Pre test: 134.1±28.9; Post test: 133.8±34.1 mg dL^{-1}; $p>0.05$) (Fig. 2).

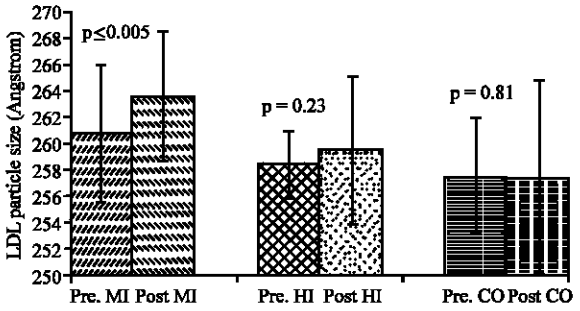

Fig. 1: LDL particle size changes among three groups (Mean±SD)

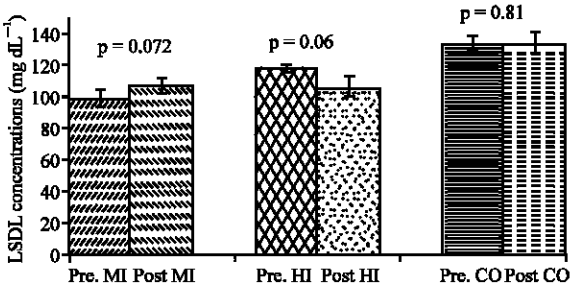

Fig. 2: LDL concentrations changes among three groups (Mean±SD)

Table 1: The physical, body composition and physiological characteristics of the subjects

	Groups		
Variables	Control	Moderate intensity	High intensity
Age (year)	34.00±7.10	33.00±7.80	31.00±7.600
Height (cm)	167.20±3.50	169.80±4.30	183.90±25.60
Weight (kg)	72.00±9.90	74.75±12.3	72.39±10.42
BMI (kg m^{-2})	25.68±3.20	25.98±4.60	26.02±3.700
Body fat (%)	14.10±5.50	16.10±7.20	15.80±5.200
Fat free mass (kg)	61.30±5.20	62.20±7.40	67.30±5.600
$VO_{2\,max}$ (mL kg^{-1} min^{-1})	35.47±5.59	38.13±4.32	41.03±6.170

All values are mean±SD

Table 2: The body composition and physiological changes among three groups

	Groups					
	Control		Moderate intensity		High intensity	
	Pre. T		Pre. T		Pre. T	
Variables	Post. T	p	Post. T	p	Post. T	p
Weight (kg)	72.00±9.900	0.78	74.75±12.3	0.630	72.39±10.42	0.470
	73.50±10.54		73.23±9.43		70.29±1.640	
BMI (kg m^{-2})	25.68±3.200	0.67	25.98±4.60	0.430	26.02±3.700	0.450
	26.35±7.200		25.13±5.71		25.53±6.600	
Body fat (%)	14.10±5.500	0.75	16.10±7.20	0.610	15.80±5.200	0.760
	15.15±7.410		15.54±3.44		14.21±3.970	
$VO_{2\,max}$ (mL kg^{-1} min^{-1})	35.47±5.590	0.84	38.13±4.32*	0.003	41.03±6.170*	0.007
	35.11±7.170		46.28±5.69		47.11±3.580	

All values are mean±SD, Statistical analysis with Paired t-test, *: Different is significant at the 0.01 level (2-tailed)

Table 3: Cardiovascular risk factors changes among three groups

	Groups					
	Control		Moderate intensity		High intensity	
	Pre. T		Pre. T		Pre. T	
Variables	Post.T	p	Post. T	p	Post. T	p
$ApoA_1$ (mg dL^{-1})	172.10±59.49	0.08	151.94±33.28	0.750	161.39±37.43	0.09
	145.61±23.08		154.97±16.62		154.47±21.03	
ApoB (mg dL^{-1})	104.21±17.84	0.07	89.09±27.71	0.130	94.08±27.50	0.65
	102.70±13.17		80.07±19.09		88.79±16.09	
$ApoB/ApoA_1$ (%)	0.67±0.240	0.05	0.61±0.190*	0.003	0.61±0.240	0.06
	0.73±0.170		0.52±0.130		0.59±0.170	
Triglyceride (mg dL^{-1})	148.55±52.60	0.14	158.60±64.51	0.230	151.44±60.94	0.07
	181.64±68.16		164.90±99.08		200.56±65.96	
Cholesterol (mg dL^{-1})	194.55±29.96	0.72	156.50±41.97*	0.020	173.11±33.24	0.23
	198.55±29.83		137.60±44.79		162.33±86.76	
HDL (mg dL^{-1})	36.59±7.880	0.59	36.35±9.160	0.540	34.61±8.830	0.68
	35.95±7.520		33.95±7.390		33.83±9.090	

All values are mean±SD Statistical analysis with Paired t-test, *: Different is significant at the 0.05 level (2-tailed)

Lipids and lipoproteins: There were significant changes in the cholesterol and $ApoB/ApoA_1$ ratio in the MI group ($p = 0.05$); whereas, no significant changes observed in the ApoB, $ApoA_1$, $ApoB/ApoA_1$ ratio, Triglycerides, Cholesterol, HDL values in the HI and CO groups ($p>0.05$; Table 3).

DISCUSSION

Current guidelines suggest that changes in cardiorespiratory fitness are independent of exercise intensity (American College of Sports Medicine, 1998). However, few studies have tested this hypothesis by comparing changes in cardiorespiratory fitness in previously sedentary individuals following moderate and high-intensity exercise interventions of equal energy cost. While the present study examined improvements in cardiorespiratory fitness by prescribing exercise after 8 weeks fitness tests, it is not in agreement with controlled (Gossard *et al*., 1986; Kraus *et al*., 2002) and uncontrolled (Crouse *et al*., 1997) trials demonstrating that high-intensity training is more effective in increasing $VO_{2\ max}$ than moderate-intensity training of the same energy cost. Collectively, these findings suggest that both MI and HI intensity exercise should be performed if the goal of training is to improve cardiorespiratory fitness.

Lipid and lipoprotein concentrations were unchanged because participants were encouraged not to lose weight (Kraus *et al*., 2002). However, exercise-induced changes in CHD risk factors are often observed in the absence of weight loss (Tran and Weltman, 1985). It is also possible that changes in triglyceride and HDL-C concentrations are independent of body fat percent. In the present study, exercise training was not accompanied by reductions in body fat percent. In agreement with other randomized controlled trials (Halbert *et al*., 1999), changes in body fat did not correlate with changes in lipids and lipoproteins.

When the investigators examined the correlation between the concentration of small LDL particles and the distance run by subjects within the running group, they found a significant, albeit small, inverse relation. It is important to note that weight loss was permitted in that study and the investigators ascribed most of the change to weight loss. However, in those studies, exercise induced larger weight losses and the effect was generally attributed to or correlated with weight loss (Williams *et al*., 1982, 1989, 1990, 1992a, b; Wood *et al*., 1988). In this study, we were able to minimize greatly, although not to eliminate completely, weight differences and weight loss as confounding factors.

Eight weeks of aerobic exercise in the moderate-intensity group resulted in significant increase of the LDL particles diameter; whereas, we showed increase (but no significant) in the high-intensity group. Significant increase of the LDL particles diameter is consistent with prior results of Jacobs *et al*. (2006), Vuorimaa *et al*. (2005), Shono *et al*. (2002), Spate-Douglas and Keyser (1999) and Sunami *et al*. (1999). On the other hand, authors have indicated that high-intensity training is more effective in improving lipoproteins profiles because of increased enzymes activities (Kelley and Kelley, 2007; O'Donovan *et al*., 2005; Duscha *et al*., 2005; De Groot *et al*., 2003; Kraus *et al*., 2002; Gossard *et al*., 1986). In addition, some reports suggested that changes in lipoproteins profiles are similar in high and moderate intensity interventions (Duscha *et al*., 2005; Duncan *et al*., 2005; Al-Ajlan and Mehdi, 2005; Paffenbarger *et al*., 1993).

Reduction in Cardio Respiratory Disease (CRD) risk is indicated from the qualitative changes in the LDL. Austin *et al*. (1988) reported that individuals with LDL phenotype B had a threefold increase in myocardial infarction risk and that this phenotype was associated with reduced HDL-cholesterol and increased plasma

triglyceride, VLDL and IDL levels. Subsequent studies (Campos *et al*., 1992; Coresh *et al*., 1993) have confirmed that subjects with CAD generally exhibit the smaller, denser type B LDL more often than do non-CAD control subjects.

The size of LDL appears to be influenced by both genetics (Austin *et al*., 1990) and lifestyle factors such as body weight, smoking and plasma triglyceride, Apo B and VLDL levels (Campos *et al*., 1992; Austin *et al*., 1990; De Graaf *et al*., 1992; McNamara *et al*., 1992; Watson *et al*., 1994). The significant increase in moderate intensity mean particle diameter, which was indicate a shift from the B phenotype to the A phenotype in this study is very important from a clinical point of view. The decrease in small, dense particles agrees with an earlier study by Williams *et al*. (1994), which also emphasized the importance of moderate aerobic exercise. The actual mechanism for such an effect is unclear but may be an altered interaction of the LDL with endothelial cells or affinity for the LDL receptor.

In addition, another mechanism in which moderate intensity exercise may affect LDL particle size is by altering metabolism of small, atherogenic LDL species. Alternation in LDL composition associated with moderate intensity exercise may be mediated by changes in Hepatic Triglyceride Lipase (HTGL) activity. High intensity exercise results in increased HTGL activity which induces the smaller and denser LDL particle size; this may be explained why MI exercise is more effective than HI exercise.

According to this study results, the two proposed intensities of aerobic exercise probably did not play a major role in the changes in serum triglycerides. However, it has been shown that aerobic exercise reduces serum triglycerides independent of other factors (Oscai *et al*., 1972). Several studies (Kwiterovich *et al*., 1993; Coresh *et al*., 1993; Campos *et al*., 1992) have reported that plasma triglyceride level is the single most significant predictor of LDL phenotype. However, there is no significant correlation observed between serum triglycerides and LDL particle size among three groups. In the Framingham study, change in LDL phenotype over a 3-4 year period was highly correlated with change in triglycerides (McNamara *et al*., 1992). Thus, it was surprise to find that the change in particle size in the present study was not significantly correlated with the change in triglycerides. Triglycerides changes among three groups can be attributed to dietary factors because of lack of subjects encourage controlling their body weight, though exercise likely played a role in reducing serum triglyceride concentrations.

As HDL-cholesterol, not changed significantly after 8 weeks of aerobic exercise in the three groups, $ApoA_1$ and ApoB did not change significantly among three groups. It has been suggested that reduction in HDL-cholesterol due primarily to a modification in $ApoA_1$ production by the liver and intestines, while differences in HDL between individuals appear to be due to an elevated clearance of $ApoA_1$ and HDL particles associated with a reduced ratio of lipoprotein lipase to hepatic lipase. The apparent resistance of HDL-C to training is unusual, given that an increase in HDL-C is the most common lipid change. This intransigence may be explained by the fact that, like LDL-C, change in HDL-C is related to baseline concentration.

CONCLUSION

In summary, a number of risk factors were unchanged by the high-intensity aerobic exercise in the present study. However, the moderate exercise protocol used in this study significantly altered quality of LDL; whereas, LDL concentration was not changes significantly in the moderate-intensity group. These data suggest that MI training can be more effective in increasing LDL particle size than HI training. MI exercise may be more effective in increasing LDL particle size than HI exercise.

REFERENCES

Al-Ajlan, A.R. and S.R. Mehdi, 2005. Effects and a dose response relationship of physical activity to high density lipoprotein cholesterol and body mass index among Saudis. Saudi Med. J., 26 (7): 1107-1111.

American College of Sports Medicine, 1998. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness and flexibility in healthy adults. Med. Sci. Sports Exerc., 30 (6): 975-991.

Austin, M.A., J. Breslow, C. Hennekins, J. Buring, W. Willett and R. Krauss, 1988. Low-density lipoprotein subclass patterns and risk of myocardial infarction. JAMA., 260 (13): 1917-1921.

Austin, M.A., M.C. King, K.M. Vranizan and R.M. Krauss, 1990. Atherogenic lipoprotein phenotype: A proposed genetic marker for coronary heart disease risk. Circulation, 82 (2): 495-506.

Austin, M.A., B. Newman, J.V. Selby, K. Edwards, E.J. Mayer and R.M. Krauss, 1993. Genetics of LDL subclass phenotypes in women twins: Concordance, heritability, commingling analysis. Arterioscler. Thromb. Vasc. Biol., 13 (5): 687-695.

Beard, C.M., R.J. Barnard, D.C. Robbins, J.M. Ordovas and E.J. Schaefer, 1996. Effects of diet and exercise on qualitative and quantitative measures of LDL and its susceptibility to oxidation. Arterioscler. Thromb. Vasc. Biol., 16 (2): 201-207.

Branth, S., A. Sjodin, A. Forslund, L. Hambraeus and U. Holmback, 2006. Minor changes in blood lipids after 6 weeks of high-volume low-intensity physical activity with strict energy balance control. Eur. J. Applied Physiol., 96 (3): 315-321.

Campos, H., J. Genest, E. Blijlevens, J.R. McNamara, J.L. Jenner, J.M. Ordovas, P.W.F. Wilson and E.J. Schaefer, 1992. Low density lipoprotein particle size and coronary artery disease. Arterioscler. Thromb. Vasc. Biol., 12 (2): 187-195.

Chait, A., R.L. Brazg, D.L. Tribble and R.M. Krauss, 1993. Susceptibility of small, dense, low-density lipoproteins to oxidative modification in subjects with the atherogenic lipoprotein phenotype, pattern B. Am. J. Med., 94 (4): 350-356.

Coresh, J., P. Kwiterovich, H. Smith and P. Bachorik, 1993. Association of plasma triglyceride concentration and LDL particle diameter, density and chemical composition with premature coronary artery disease in men and women. J. Lipid Res., 34 (10): 1687-1697.

Crouse, S.F., B.C. O'Brien, P.W. Grandjean, R.C. Lowe, J.J. Rohack, J.S. Green and H. Tolson, 1997. Training intensity, blood lipids and apolipoproteins in men with high cholesterol. J. Applied Physiol., 82 (1): 270-277.

De Graaf, J., H. Hak-Lemmers, M.P. Hectors, P. Demacker, J.C. Hendriks and A.F. Stalenhoef, 1991. Enhanced susceptibility to *in vitro* oxidation of the dense low density lipoprotein subfraction in healthy subjects. Arterioscler. Thromb. Vasc. Biol., 11 (2): 298-306.

De Graaf, J., D.W. Swinkels, A.F.J. de Haan, P.N.M. Demacker and A.F.H. Stalenhoef, 1992. Both inherited susceptibility and environmental exposure determine the low-density lipoprotein-subfraction pattern distribution in health Dutch families. Am. J. Hum. Genet., 51 (6): 1295-1310.

De Graaf, J., J. Hendriks, P. Demacker and A. Stalenhoef, 1993. Identification of multiple dense LDL sub-fractions with enhanced susceptibility to *in vitro* oxidation among hypertriglyceridemic subjects: Normalization after clofibrate treatment. Arterioscler. Thromb. Vasc. Biol., 13 (5): 712-719.

De Groot, P.C., N. Hjeltnes, A.C. Heijboer, W. Stal and K. Birkeland, 2003. Effect of training intensity on physical capacity, lipid profile and insulin sensitivity in early rehabilitation of spinal cord injured individuals. Spinal Cord., 41 (12): 673-679.

Duncan, G.E., S.D. Anton, S.J. Sydeman, R.L. Newton, J.A. Corsica, P.E. Durning, T.U. Ketterson, A.D. Martin, M.C. Limacher and M.G. Perri, 2005. Prescribing exercise at varied levels of intensity and frequency: A randomized trial. Arch. Int. Med., 165 (21): 2362-2369.

Durstine, J.L. and W.L. Haskell, 1994. Effects of exercise training on plasma lipids and lipoproteins. Exerc. Sport Sci. Rev., 22 (1): 477-521.

Duscha, B.D., C.A. Slentz, J.L. Johnson, J.A. Houmard, D.R. Bensimhon, K.J. Knetzger and W.E. Kraus, 2005. Effects of exercise training amount and intensity on peak oxygen consumption in middle-age men and women at risk for cardiovascular disease. Am. College of Chest Phys., 128 (4): 2788-2793.

Friedewald, W.T., R.L. Levy and D.S. Fredrickson, 1972. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. Clin. Chem., 18 (6): 499-502.

Gossard, D., W.L. Haskell, C.B. Taylor, J.K. Mueller, F. Rogers, M. Chandler, D.K. Ahn, N.H. Miller and R.F. DeBusk, 1986. Effects of low-and high-intensity home-based exercise training on functional capacity in healthy middle-aged men. Am. J. Cardiol., 57 (6): 446-449.

Halbert, J.A., C.A. Silagy, P. Finucane, R.T. Withers and P.A. Hamdorf, 1999. Exercise training and blood lipids in hyperlipidemic and normolipidemic adults: A meta-analysis of randomized, controlled trials. Eur. J. Clin. Nutr., 53 (7): 514-522.

Jacobs, K.A., R.M. Krauss, J.A. Fattor, M.A. Horning, A.L. Friedlander, T.A. Bauer, T.A. Hagobian, E.E. Wolfel and G.A. Brooks, 2006. Endurance training has little effect on active muscle free fatty acid, lipoprotein cholesterol, or triglyceride net balances. Am. J. Physiol. Endocrinol. Metab., 291 (3): E656-665.

Kamigaki, A.S., D.S. Siscovick and S.M. Schwartz, 2001. Low density lipoprotein particle size and risk of early-onset myocardial infarction in women. Am. J. Epidemiol., 153 (10): 939-945.

Kelley, G.A. and K.S. Kelley, 2007. Aerobic exercise and lipids and lipoproteins in children and adolescents: A meta-analysis of randomized controlled trials. Atherosclerosis, 191 (2): 447-453.

Kraus, W.E., J.A. Houmard, B.D. Duscha, K.J. Knetzger, M.B. Wharton, J.S. McCartney, C.W. Bales, S. Henes, G.P. Samsa, J.D. Otvos, K.R. Kulkarni and C.A. Slentz, 2002. Effects of the amount and intensity of exercise on plasma lipoproteins. N. Engl. J. Med., 347 (19): 1483-1492.

Krauss, R. and D. Burke, 1982. Identification of multiple subclasses of plasma low density lipoproteins in normal humans. J. Lipid. Res., 23 (1): 97-104.

Kwiterovich, P.O., J. Coresh and P.S. Bachorik, 1993. Prevalence of hyperapobetalipoproteinemia and other lipoprotein phenotypes in men (aged 50 years) and women (60 years) with coronary artery disease. Am. J. Cardiol., 71 (8): 631-639.

Lamarche, B., A. Tchernof and S. Moorjani, 1997. Small, dense low-density lipoprotein particles as a predictor of the risk of ischemic heart disease in men: Prospective results from the Quebec Cardiovascular Study. Circulation, 95 (1): 69-75.

Leon, A.S. and O.A. Sanchez, 2001. Response of blood lipids to exercise training alone or combined with dietary intervention. Med. Sci. Sports Exerc., 33 (6) Suppl: S502-S515.

McNamara, J.R., J.L. Jenner, Z. Li, P.W. Wilson and E.J. Schaefer, 1992. Change in LDL particle size is associated with change in plasma triglyceride concentration. Arterioscler. Thromb., 12 (11): 1284-1290.

O'Donovan, G., A. Owen, S.R. Bird, E.M. Kearney, A.M. Nevill, D.W. Jones and K. Woolf-May, 2005. Changes in cardio respiratory fitness and coronary heart disease risk factors following 24 week of moderate- or high-intensity exercise of equal energy cost. J. Applied Physiol., 98 (5): 1619-1625.

Oscai, L.B., J.A. Patterson, D.L. Bogard, R.J. Beck and B.L. Rothermel, 1972. Normalization of serum triglycerides and lipoprotein electrophoretic patterns by exercise. Am. J. Cardiol., 30 (7): 775-780.

Paffenbarger, R.S., R.T. Hyde, A.L. Wing, I.M. Lee, D.L. Jung and J.B. Kampert, 1993. The association of changes in physical-activity level and other lifestyle characteristics with mortality among men. N Engl. J. Med., 328 (8): 538-545.

Pascot, A., I. Lemieux and D. Prud'homme, 2001. Reduced HDL particle size as an additional feature of the atherogenic dyslipidemia of abdominal obesity. J. Lipid. Res., 42 (12): 2007-2014.

Shono, N., H. Urata, B. Saltin, M. Mizuno, T. Harada, M. Shindo and H. Tanaka, 2002. Effects of low intensity aerobic training on skeletal muscle capillary and blood lipoprotein profiles. J. Atheroscler. Thromb., 9 (1): 78-85.

Spate-Douglas, T. and R.E. Keyser, 1999. Exercise intensity: Its effect on the high-density lipoprotein profile. Arch. Phys. Med. Rehabil., 80 (6): 691-695.

Sunami, Y., M. Motoyama, F. Kinoshita, Y. Mizooka, K. Sueta, A. Matsunaga, J. Sasaki, H. Tanaka and M. Shindo, 1999. Effects of low-intensity aerobic training on the high-density lipoprotein cholesterol concentration in healthy elderly subjects. Metabolism, 48 (8): 984-988.

Tran, Z.V. and A. Weltman, 1985. Differential effects of exercise on serum lipid and lipoprotein levels seen with changes in body weight. JAMA., 254 (7): 919-924.

Tribble, D., L. Holl, P. Wood and R. Krauss, 1992. Variations in oxidative susceptibility among six low density lipoprotein subfractions of differing density and particle size. Atherosclerosis, 93 (3): 189-199.

Vakkilainen, J., S. Makimattila and A. Seppala-Lindroos, 2000. Endothelial dysfunction in men with small LDL particles. Circulation, 102 (7): 716-721.

Vuorimaa, T., M. Ahotupa, K. Irjala and T. Vasankari, 2005. Acute prolonged exercise reduces moderately oxidized LDL in healthy men. Int. J. Sports Med., 26 (6): 420-425.

Watson, T.D., M.J. Caslake, D.J. Freeman, B.A. Griffin, J. Hinnie, C.J. Packard and J. Shepherd, 1994. Determinants of LDL subfraction distribution and concentrations in young normolipidemic subjects. Arterioscler. Thromb., 14 (6): 902-910.

Williams, P.T., P.D. Wood, W.L. Haskell and K.M. Vranizan, 1982. The effects of running mileage and duration on plasma lipoprotein levels. JAMA., 247 (19): 2674-2679.

Williams, P.T., R.M. Krauss, K.M. Vranizan, J.J. Albers, R.B. Terry and P.D. Wood, 1989. Effects of exercise-induced weight loss on low density lipoprotein subfractions in healthy men. Arterioscler. Thromb. Vasc. Biol., 9 (5): 623-632.

Williams, P.T., R.M. Krauss, K.M. Vranizan and P.D. Wood, 1990. Changes in lipoprotein subfractions during diet-induced and exercise-induced weight loss in moderately overweight men. Circulation, 81 (4): 1293-1304.

Williams, P.T., R.M. Krauss, K.M. Vranizan, J.J. Albers and P.D. Wood, 1992a. Effects of weight-loss by exercise and by diet on apolipoproteins A-I and A-II and the particle-size distribution of high-density lipoproteins in men. Metabolism, 41 (4): 441-449.

Williams, P.T., K. Vranizan and K. Krauss, 1992b. Correlations of plasma lipoproteins with LDL subfractions by particle size in men and women. J. Lipid Res., 33 (5): 765-774.

Williams, P.T., R.M. Krauss, M.L. Stefanick, K.M. Vranizan and P.D. Wood, 1994. Effects of low-fat diet, calorie restriction and running on lipoprotein subfraction concentration in moderately overweight men. Metabolism, 43 (5): 655-663.

Wood, P.D., M.L. Stefanick and D.M. Dreon, 1988. Changes in plasma lipids and lipoproteins in overweight men during weight loss through dieting as compared with exercise. N. Engl. J. Med., 319 (18): 1173-1179.