Good Aerobic or Muscular Fitness Protects Overweight Men from Elevated Oxidized LDL

JUSSI KOSOLA[1,2], MARKKU AHOTUPA[2], HEIKKI KYRÖLÄINEN[3], MATTI SANTTILA[4], and TOMMI VASANKARI[5,6]

[1]Department of Health and Exercise, Paavo Nurmi Center, University of Turku, Turku, FINLAND; [2]MCA Research Laboratory, Department of Biochemistry and Food Chemistry, University of Turku, Turku, FINLAND; [3]Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, FINLAND; [4]Defence Command, Personnel Division, Finnish Defence Forces, Helsinki, FINLAND; [5]UKK Institute for Health Promotion Research, Tampere, FINLAND; and [6]National Institute for Health and Welfare, Helsinki, FINLAND

ABSTRACT

KOSOLA, J., M. AHOTUPA, H. KYRÖLÄINEN, M. SANTTILA, and T. VASANKARI. Good Aerobic or Muscular Fitness Protects Overweight Men from Elevated Oxidized LDL. *Med. Sci. Sports Exerc.*, Vol. 44, No. 4, pp. 563–568, 2012. **Introduction**: Oxidized LDL (ox-LDL) is associated with lifestyle diseases such as cardiovascular diseases, metabolic syndrome, and type 2 diabetes. The present study investigated the association between ox-LDL and overweight/obesity and how cardiorespiratory or muscle fitness affects this association. **Methods**: Healthy young (mean age = 25.1 yr, range = 18–48 yr) men (n = 831) were divided into normal-weight (n = 486), overweight (n = 269), and obese (n = 76) groups according to their body mass index (BMI). The participants underwent physical fitness tests (maximal oxygen uptake with bicycle ergometer and muscle fitness index using series of muscle endurance tests), a general health examination including determination of lipid profile, and a detailed questionnaire. Subjects were further divided into six subgroups according to BMI (normal vs overweight) and physical fitness (fitness tertiles: unfit, average, fit). Age and smoking were used in the statistical analysis as covariates. **Results**: In overweight and obese participants, the concentrations of ox-LDL (14%/32%) and the ratio of ox-LDL/HDL cholesterol (32%/68%) were higher compared with subjects with normal weight ($P < 0.005$, in all). In BMI and cardiovascular fitness subgroups, ox-LDL (23%, $P < 0.0001$) and the ox-LDL/HDL cholesterol ratio (45%, $P < 0.0001$) were higher in the overweight/unfit subgroup when compared with the normal-weight/unfit subgroup, whereas no differences were observed between the overweight/fit and normal-weight/fit subjects. Among the BMI and muscle fitness subgroups, ox-LDL (24%, $P < 0.0001$) and the ox-LDL/HDL cholesterol ratio (51%, $P < 0.0001$) were higher in the overweight/unfit group compared with the normal-weight/unfit group. **Conclusions**: Overweight and obesity are associated with ox-LDL lipids and serum conventional lipids. However, both good cardiorespiratory fitness and muscular fitness seem to protect overweight subjects from the atherogenic lipid profile. **Key Words:** OXIDIZED LDL, BODY MASS INDEX, OBESITY, MAXIMAL OXYGEN UPTAKE, MUSCLE FITNESS, SERUM LIPIDS

Obesity is a constantly increasing problem, especially in the Western world (22). Today, more than 1.6 billion people are overweight, and 400 million people are obese; and these numbers are predicted to grow to 2.3 billion overweight and 700 million obese people by the year 2015 (32). Obesity is known to be accompanied by an atherogenic lipid profile, insulin resistance, and the metabolic syndrome, leading to development of cardiovascular disease (11,26).

Address for correspondence: Tommi Vasankari, M.D., Ph.D., UKK Institute for Health Promotion Research, Box 30, 33501 Tampere, Finland; E-mail: tommi.vasankari@uta.fi.
Submitted for publication April 2011.
Accepted for publication September 2011.

0195-9131/12/4404-0563/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e31823822cc

Oxidized LDL (ox-LDL) is a significant cardiovascular risk factor (4,20,27) and is also known to be associated with obesity (20,21). We have earlier found that the reduction of ox-LDL lipids can be achieved through weight reduction and physical activity intervention (18,28,29). The favorable ox-LDL levels were maintained after successful weight maintenance (2 yr), whereas weight regain caused the concentration of ox-LDL to increase again (18). Previous studies have shown that exercise intervention can effectively reduce obesity (25) and an epidemiological study conducted in the United States suggests that good cardiorespiratory fitness lowers the risk of all-cause mortality (7).

Lee et al. (16) have shown that cardiorespiratory fitness may protect obese individuals from cardiovascular mortality. The aims of the present study were to investigate ox-LDL and serum lipids among normal-weight, overweight, and obese individuals in a population-based cross-sectional study and, in particular, to find out whether good cardiorespiratory and

muscular fitness could protect overweight and obese subjects from the atherogenic lipid profile.

MATERIALS AND METHODS

Participants. Participants were healthy young (mean age = 25.1 yr, range = 18–48 yr) Finnish men participating in reserve refresher courses of the Finnish Defence Forces during the year 2008. Reservists were gathered from the nationwide compulsory military service, which makes the study cohort population based and nationally representative of the population of healthy young Finnish men. Of 1155 invited reservists, 922 participated in the courses, and 846 of them volunteered for the present study. Data of weight were missing from four participants, and 11 participants were excluded because of their low body mass index (BMI) (under 18.5 $kg \cdot m^{-2}$). Thus, the total number of participants analyzed in the present study was 831, which corresponds to 72% of invited reservists. Some of the participants could not execute all of the fitness tests because of medical reasons, and therefore, the statistical analysis of the BMI versus cardiorespiratory/muscle fitness was done with 785 (95%, cardiorespiratory) and 745 (90%, muscle fitness) participants. The participants signed a written consent form indicating that they were aware of the risks and stress associated with the study. The study was approved by the ethical committees of the University of Jyväskylä and the Central Finland Health Care District as well as the Headquarters of the Finnish Defence Forces. The characteristics of the participants are shown in Table 1. Of 831 participants, 320 (38.6%) were smokers.

Laboratory analysis. Venous blood samples were taken after an overnight fast. Analysis of ox-LDL was based on determination of the baseline level of conjugated dienes in LDL lipids (1,2). The appearance of conjugated diene double bonds is characteristic of peroxidation of all polyunsaturated fatty acids, and in *in vitro* and *ex vivo* studies on LDL oxidation, diene conjugation has commonly been used as the index of LDL oxidation. The assay procedure consisted of isolation of the lipoprotein fraction, extraction of lipoprotein lipids, and spectrophotometric analysis of conjugated dienes in the lipoprotein lipids. The isolated LDL fraction was used for direct measurement of LDL cholesterol using cholesterol oxidase-phenol+aminophenazone method (CHOD-PAP method) and LDL oxidized lipids. The isolation procedure was validated for the purpose and did not affect the level of oxidized lipids (2). Lipids were extracted from isolated LDL by chloroform–methanol (2:1), dried under nitrogen, and redissolved in cyclohexane. The amount of peroxidized lipids in LDL was assessed spectrophotometrically at 234 nm.

TABLE 1. Characteristics of the participants (n = 831).

Characteristic	Mean (Range)
Age (yr)	25.1 (18–48)
Height (m)	1.80 (1.62–1.99)
Body weight (kg)	80.9 (49.8–157.8)
BMI	24.9 (18.5–45.1)
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	41.6 (19.5–72.5)
MFI	12.4 (2.5–20.0)

Validation studies for the assay have ruled out interference by nonspecific substances and have shown that diene conjugation is a measure of oxidative LDL modification found in all LDL lipid classes. The coefficient of variation (CV) for within-assay precision for determination of ox-LDL lipids was 4.4%, and the CV for the between-assay precision was 4.5%.

Serum total cholesterol, HDL cholesterol, and triglycerides were analyzed with Konelab 20 XTi (Thermo Electron Corp., Vantaa, Finland) through enzymatic photometric assay. The precisions of within-assay/between-assay CV were 0.5%/1.4% for total cholesterol, 3.4%/2.0% for HDL cholesterol, and 2.5%/2.5% for triglycerides.

General health examination. Body weight (kg) and height (cm) of the participants wearing light indoor clothes were measured after an overnight fast. Body weight was measured with a bioimpedance analysis scale (InBody720; Biospace, Seoul, South Korea), and height was measured with a commercial scale at 1-mm precision. BMI was calculated, and cutoff points for normal-weight (18.50–24.99), overweight (25.00–29.99), and obese (≥30.00) groups were selected according to the World Health Organization's standards (32). A detailed questionnaire was used to collect information on diseases diagnosed by physicians.

Fitness variables. In addition to associations with BMI and lipids, we investigated how BMI together with the maximal oxygen uptake ($\dot{V}O_{2max}$)/muscle fitness was associated with ox-LDL and serum lipids. For these analyses, subjects were divided into six subgroups according to BMI (normal vs overweight) and tertiles of cardiorespiratory fitness (unfit, average, fit). Similarly, six subgroups were formed on the basis of BMI (normal vs overweight) and tertiles of muscular fitness (unfit, average, fit). Both cardiorespiratory fitness (bicycle ergometer; Ergoline® 800-S and Ergoselect® 100 or 200 K; Ergoline Corp., Bitz, Germany) and muscle fitness tests were performed under supervision by professionals. In the cardiorespiratory test, the $\dot{V}O_{2max}$ was measured using a procedure where the participants started with the workload of 50 W, which was increased by 25 W every 2 min until exhaustion (8–10). Participants were divided into tertiles of cardiorespiratory fitness according to their $\dot{V}O_{2max}$: 1) <37.87 $mL \cdot kg^{-1} \cdot min^{-1}$, 2) 37.87–44.87 $mL \cdot kg^{-1} \cdot min^{-1}$, and 3) >44.87 $mL \cdot kg^{-1} \cdot min^{-1}$.

For muscular fitness, the muscle fitness index (MFI) was calculated using the results of each muscle test according to the standards of the Finnish Defence Forces (23). The order of the tests was 1) grip strength (antebrachial muscles); 2) sit-ups (abdominal muscles and hip flexors); 3) push-ups (arms and shoulder extensors); and 4) repeated squats (gluteus, posterior and anterior femoral muscles, triceps surae). Grip strength was determined twice from both hands, and the final score was the average of the highest scores of both hands (sitting, elbow in 90 degrees; Dynamometer, Saehan Corporation, Masan, South Korea) (9,15). In the starting position of the sit-up test, the participant was lying supine on the floor with knees flexed in 90 degrees and hands behind his neck. The ankles were fixed to the floor by an assistant,

TABLE 2. ox-LDL, the ratio of ox-LDL/HDL cholesterol, and serum lipids in different BMI groups.

	BMI Groups			
	Normal Weight (18.5–24.99, n = 486)	Overweight (25–29.99, n = 269)	Obese (≥30.00, n = 76)	ANCOVA-1
ox-LDL (μmol·L^{-1})	22.9 ± 6.4	26.2 ± 8.9**	30.3 ± 12.5**	<0.0001
ox-LDL/HDL cholesterol	15.3 ± 5.4	20.2 ± 10.1**	25.7 ± 14.1**	<0.0001
Total cholesterol (mmol·L^{-1})	4.39 ± 0.80	4.67 ± 0.85*	5.01 ± 1.03**	<0.0001
LDL cholesterol (mmol·L^{-1})	2.29 ± 0.57	2.58 ± 0.63**	2.82 ± 0.72**	<0.0001
HDL cholesterol (mmol·L^{-1})	1.57 ± 0.35	1.40 ± 0.34**	1.29 ± 0.35**	<0.0001
Triglycerides (mmol·L^{-1})	0.89 ± 0.34	1.13 ± 0.60**	1.54 ± 0.83**	<0.0001
$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	44.4 ± 7.6	39.1 ± 6.6**	31.9 ± 5.6**	<0.0001
MFI	13.1 ± 3.6	11.9 ± 3.8**	9.7 ± 3.7**	<0.0001

Age and smoking were used as covariates (ANCOVA-1). Data are presented as mean ± SD.
Difference between normal BMI and overweight groups and normal BMI and obese groups using Bonferroni correction:
* $0.0001 \leq P \leq 0.05$.
** $P < 0.0001$.

and a repetition was counted after the participant's elbows touched the flexed knees (30). To execute one repetition of push-ups, the participant got into a shoulder-wide stance with fingers pointing forward. From this starting position, elbows were flexed at 90 degrees with the torso touching the floor; next, the upper extremities were fully extended while the upper body was straight and fully extended (5). Repeated squat movement started while standing straight and lowering the upper body until the thighs were at horizontal level. After this, the participant flexed his lower extremities to stand straight again (24). Every muscle fitness test had a time limit of 60 s. Both cardiorespiratory and muscular fitness tests have age-specific reference values used in the Finnish Defence Forces since 2000, and they are based on data of 3635 civilians (23).

Statistical analysis. For statistical analysis, the PASW software version 18.0 (IBM, Armonk, NY) was used. Means and SD were used for results and calculated with standard procedures. Means of lipid variables in BMI groups were examined with ANOVA where age and smoking were used as covariates (ANCOVA-1). Further, subjects were divided into six subgroups on the basis of BMI (normal vs overweight) and cardiorespiratory/muscular fitness (unfit, average, and fit) tertiles. ANCOVA-2 (BMI × $\dot{V}O_{2max}$ / MFI) was applied to determine differences in lipids, where age and smoking were used as covariates. The Bonferroni correction was used in *post hoc* tests. The subjects who did not take part either in the cardiorespiratory fitness test or in the muscle fitness tests did not differ in age, weight, height, and BMI from the subjects who took part in the tests.

RESULTS

BMI groups. The three BMI groups differed in all lipid variables when controlled for age and smoking. Cardiorespiratory and muscle fitness were lower in the higher BMI groups (Table 2). Interactions between BMI and cardiorespiratory and muscle fitness were significant for all serum lipid variables. Overweight and obese men had higher ox-LDL, ratio of ox-LDL/HDL cholesterol, total cholesterol, LDL cholesterol, and triglycerides and lower HDL cholesterol.

BMI and cardiorespiratory fitness subgroups. Low–cardiorespiratory fitness/overweight subjects (first tertile) had higher ox-LDL, ratio of ox-LDL/HDL cholesterol, serum total cholesterol, LDL cholesterol, and triglycerides and lower HDL cholesterol compared with low–cardiorespiratory fitness/normal-weight participants (Table 3, Figs. 1 and 2). In the subgroup with average cardiorespiratory (second tertile) fitness, the ratio of ox-LDL/HDL cholesterol and the concentration of triglycerides were higher, and HDL cholesterol was lower in the overweight compared with the normal-weight subgroup. No differences in lipids were identified between the overweight and normal-weight subjects among the highest cardiovascular fitness tertile.

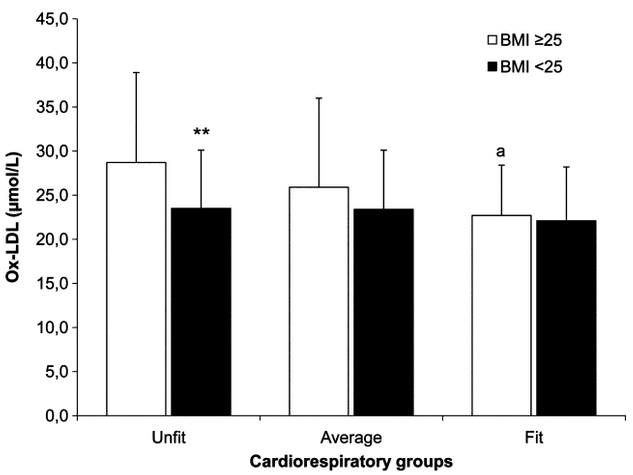
The concentration of ox-LDL and triglycerides and the ratio of ox-LDL/HDL cholesterol were higher in the overweight/unfit subgroup compared with the overweight/fit subgroup (Table 3, Figs. 1 and 2). No significant differences were seen in ox-LDL or serum lipids within the normal-weight group between the cardiorespiratory fitness tertiles or between the normal-weight/unfit and overweight/fit subgroups.

TABLE 3. Serum lipids in BMI and cardiorespiratory fitness subgroups.

			Normal Weight (BMI < 24.99)	Overweight (BMI ≥ 25.00)	P
Cardiorespiratory fitness	Fit (third tertile)		(n = 215)	(n = 45)	
		Total cholesterol (mmol·L^{-1})	4.32 ± 0.76	4.56 ± 0.89	**1.00, NS**
		HDL cholesterol (mmol·L^{-1})	1.59 ± 0.35	1.48 ± 0.32	**0.48, NS**
		LDL cholesterol (mmol·L^{-1})	2.27 ± 0.55	2.47 ± 0.61	**1.00, NS**
		Triglycerides (mmol·L^{-1})	0.84 ± 0.32	0.87 ± 0.28*	**1.00, NS**
	Average fit (second tertile)		(n = 156)	(n = 110)	
		Total cholesterol (mmol·L^{-1})	4.44 ± 0.83	4.61 ± 0.88*	**1.00, NS**
		HDL cholesterol (mmol·L^{-1})	1.59 ± 0.33	1.46 ± 0.38*	**0.032**
		LDL cholesterol (mmol·L^{-1})	2.31 ± 0.56	2.50 ± 0.67*	**1.00, NS**
		Triglycerides (mmol·L^{-1})	0.90 ± 0.33	1.12 ± 0.67*	**0.042**
	Unfit (first tertile)		(n = 96)	(n = 163)	
		Total cholesterol (mmol·L^{-1})	4.49 ± 0.87	4.88 ± 0.90	**0.010**
		HDL cholesterol (mmol·L^{-1})	1.49 ± 0.35	1.29 ± 0.30	**<0.0001**
		LDL cholesterol (mmol·L^{-1})	2.37 ± 0.62	2.75 ± 0.63	**<0.0001**
		Triglycerides (mmol·L^{-1})	0.98 ± 0.37	1.38 ± 0.72	**<0.0001**

Age and smoking were used as covariates (ANCOVA-2). Data are presented as mean ± SD.
Differences within the respective BMI group between the fitness tertiles (compared with the unfit subgroup): * $P \leq 0.05$.
NS, not significant.

BMI and muscle fitness subgroups. Low–muscle fitness/overweight subjects (first tertile) had higher ox-LDL, ratio of ox-LDL/HDL cholesterol, serum total cholesterol, LDL cholesterol, and triglycerides and lower HDL cholesterol compared with low–muscle fitness/normal-weight participants (Table 4, Figs. 1 and 2). In the second tertile of muscle fitness (average fit), the ratio of ox-LDL/HDL cholesterol and the concentrations of ox-LDL, LDL cholesterol, and triglycerides were higher and HDL cholesterol was lower in the overweight compared with the normal-weight subgroup. In the third tertile of muscular fitness (fit), the ratio of ox-LDL/HDL cholesterol was higher and HDL cholesterol was lower in the overweight subgroup compared with the normal-weight subgroup. The ratio of ox-LDL/HDL cholesterol and the concentration of triglycerides were higher in the overweight/unfit subgroup compared with the overweight/fit subgroup (Table 4, Figs. 1 and 2).



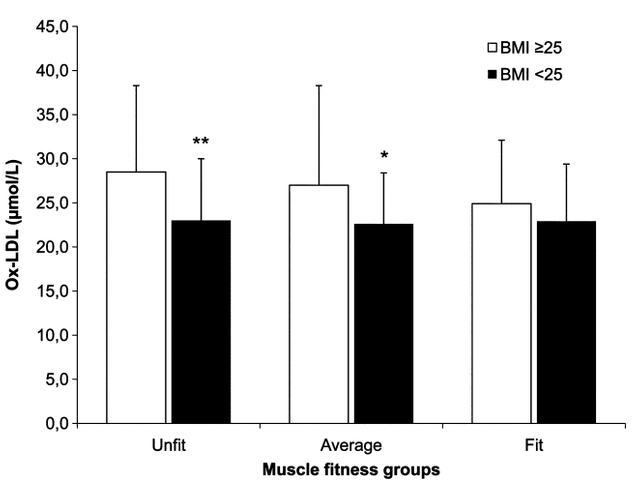
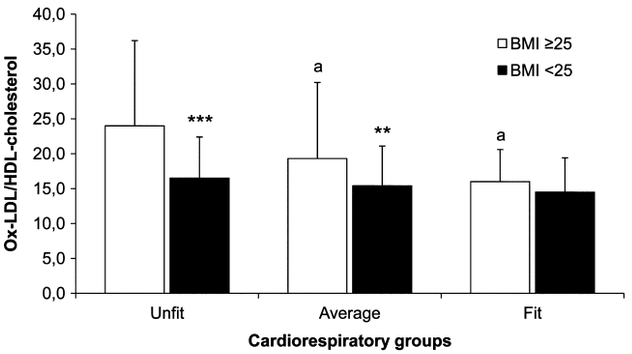


FIGURE 1—Concentration of ox-LDL in BMI (normal vs overweight)/cardiorespiratory fitness subgroups and BMI (normal vs overweight)/muscle fitness subgroups. Differences between overweight and normal-weight subgroups within fitness tertiles: *0.0001 < $P \leq 0.05$, **$P \leq 0.0001$. Differences between overweight/unfit subgroup and other overweight subgroups within the respective BMI group: a) $P < 0.05$.



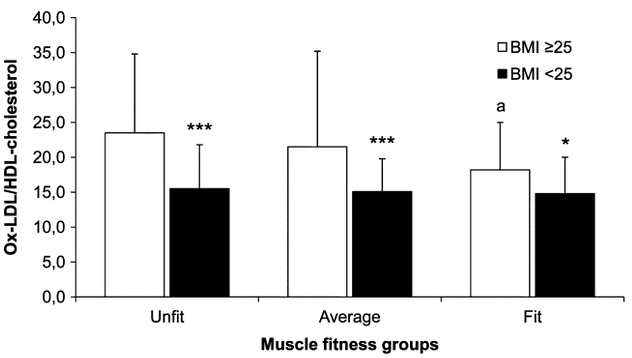


FIGURE 2—The ratio of ox-LDL/HDL cholesterol in BMI (normal vs overweight)/cardiorespiratory fitness subgroups and BMI (normal vs overweight)/muscle fitness subgroups. Differences between overweight and normal-weight subgroups within fitness tertiles: *0.001 < $P \leq 0.05$, **0.0001 < $P \leq 0.001$, ***$P \leq 0.000$. Differences between overweight/unfit subgroup and other overweight subgroups within the respective BMI group: a) $P < 0.05$.

No significant differences were seen in ox-LDL or serum lipids within the normal-weight group between the muscle fitness subgroups or between the normal-weight/unfit and overweight/fit subgroups.

DISCUSSION

In the present study, we found that the concentration of ox-LDL, the ratio of ox-LDL/HDL cholesterol, and serum conventional lipids (excluding HDL cholesterol) increase gradually from normal weight through overweight to obese in young healthy men. Interestingly, we found that both good cardiovascular fitness and muscular fitness modify this association by improving the lipid profiles in fit overweight subjects. However, no differences were seen between fitness tertiles (cardiorespiratory or muscular) within normal-weight subgroups. The present data further suggest that ox-LDL and the ratio of ox-LDL/HDL cholesterol are useful markers when estimating cardiovascular lipid risk factors in overweight and obese subjects.

In our cross-sectional study, obese young men had a 32% higher concentration of ox-LDL compared with young men with normal weight. Several studies using direct *in vivo* measurement (baseline level of conjugated dienes in LDL

TABLE 4. Serum lipids in BMI and muscle fitness subgroups.

			Normal Weight (BMI < 24.99)	Overweight (BMI ≥ 25.00)	*P*
Muscle fitness	Fit (third tertile)		**(*n* = 176)**	**(*n* = 74)**	
		Total cholesterol (mmol·L^{-1})	4.41 ± 0.81	4.67 ± 0.92	**1.00, NS**
		HDL cholesterol (mmol·L^{-1})	1.61 ± 0.34	1.45 ± 0.36	**0.012**
		LDL cholesterol (mmol·L^{-1})	2.29 ± 0.57	2.55 ± 0.70	**1.00, NS**
		Triglycerides (mmol·L^{-1})	0.87 ± 0.36	1.03 ± 0.46*	**0.90, NS**
	Average fit (second tertile)		**(*n* = 163)**	**(*n* = 92)**	
		Total cholesterol (mmol·L^{-1})	4.44 ± 0.85	4.72 ± 0.88	**0.42, NS**
		HDL cholesterol (mmol·L^{-1})	1.56 ± 0.31	1.39 ± 0.34	**0.003**
		LDL cholesterol (mmol·L^{-1})	2.33 ± 0.59	2.64 ± 0.66	**0.005**
		Triglycerides (mmol·L^{-1})	0.90 ± 0.32	1.29 ± 0.85	**<0.0001**
	Unfit (first tertile)		**(*n* = 107)**	**(*n* = 133)**	
		Total cholesterol (mmol·L^{-1})	4.37 ± 0.75	4.82 ± 0.93	**0.035**
		HDL cholesterol (mmol·L^{-1})	1.56 ± 0.37	1.30 ± 0.31	**<0.0001**
		LDL cholesterol (mmol·L^{-1})	2.30 ± 0.55	2.69 ± 0.66	**0.001**
		Triglycerides (mmol·L^{-1})	0.91 ± 0.34	1.29 ± 0.63	**<0.0001**

Age and smoking were used as covariates (ANCOVA-2). Data are presented as mean ± SD.
Differences within the respective BMI group between the fitness tertiles (compared with the unfit subgroup): * $P \leq 0.05$.

lipids, LDL-baseline diene conjugation) to evaluate the level of ox-LDL have shown that ox-LDL is related to BMI. This has been demonstrated among veteran athletes and their controls ($r = 0.47$) (13), among healthy middle-age men ($r = 0.65$) (14), and in sedentary middle-age women ($r = 0.24$) (29). Further, weight reduction correlated with the decrease of ox-LDL ($r = 0.24$) during a 12-wk weight reduction in 77 obese premenopausal women (28). Njajou et al. (21) used a method that measures the presence of modified apolipoprotein B and showed that obesity was associated with ox-LDL. The present and earlier studies suggest that oxidative stress is implicated in the increased risk for metabolic diseases among obese individuals (12), whereas weight loss interventions seem to decrease atherogenic ox-LDL (18,28). These results indicate that body weight has a significant influence on the concentration of the atherogenic ox-LDL particles.

The evidence concerning the influence of physical fitness on ox-LDL is limited. Cardiorespiratory fitness did not correlate with concentration of baseline level of conjugated dienes in LDL lipids in sedentary men and women (29). To our knowledge, the present study is among the first studies to report the association between ox-LDL and fitness (both cardiorespiratory and muscular fitness). Different methodologies to measure the level of ox-LDL may not be the major cause of different results in cross-sectional studies like the present study, but in intervention and follow-up studies containing several time points, the direct *in vivo* measurements (like LDL-BDC) might be a more accurate indicator to measure the change of concentration of ox-LDL (4).

The ratio of atherogenic ox-LDL to protective HDL cholesterol was 68% higher in obese men than in normal-weight men in the present study. When comparing together the normal-weight/fit and overweight/unfit subgroups, the ratio of ox-LDL/HDL cholesterol showed the greatest relative difference from all measured lipid variables. In earlier studies, serum HDL cholesterol was negatively associated with ox-LDL and obesity. HDL cholesterol thereby plays an important role in LDL oxidation (3,19,31), which makes this ratio especially useful.

In the men with normal weight, no difference was seen in the level of ox-LDL and ratio of ox-LDL/HDL cholesterol between unfit (first tertile) and fit (third tertile) subjects in either the cardiorespiratory or the muscle fitness subgroups. However, in overweight men, the concentration of lipids differed between fit and unfit subjects. In the cardiorespiratory fitness subgroups, the overweight/unfit subgroup had a higher concentration of ox-LDL and triglycerides and a higher ratio of ox-LDL/HDL cholesterol compared with the overweight/fit subgroup, whereas no differences were seen in other serum lipids. Also, in the muscle fitness subgroups, the concentration of triglycerides and ratio of ox-LDL/HDL cholesterol differed between the overweight/unfit and overweight/fit subgroups.

These results suggest that ox-LDL, triglycerides, and the ratio of ox-LDL/HDL cholesterol are more sensitive lipid markers than other serum lipids in detecting interaction of body composition and physical fitness as cardiovascular risk factors. Our findings also suggest that good physical fitness could prevent the development of an atherogenic lipid profile in overweight or obese subjects and counteract highly potential individual risk factors for atherosclerosis such as smoking and age (6,17).

It has been reported earlier that normal weight/unfit individuals have higher rates of cardiovascular disease mortality than overweight/fit individuals (16). In the present study, no differences in ox-LDL and serum lipids were seen between the normal-weight/unfit and the overweight/fit subgroups. However, we discovered a higher ratio of ox-LDL/HDL cholesterol and a higher concentration of most lipid variables in overweight subgroups compared with normal-weight subgroups within the cardiorespiratory and muscular fitness tertiles excluding the fit tertiles. The results underline that within average and unfit fitness tertiles (both in cardiorespiratory and in muscular fitness), overweight subjects have a more atherogenic lipid profile, whereas within fit fitness tertiles, only the ratio of ox-LDL/HDL cholesterol and HDL cholesterol differed between overweight and normal-weight subjects.

In conclusion, overweight and obesity are associated with significantly higher concentrations of ox-LDL and serum conventional lipids. However, good cardiorespiratory fitness and muscular fitness seem to protect overweight subjects from the atherogenic lipid profile.

The present study was supported by the Scientific Committee for National Defence, and the results of the study do not constitute endorsement by the American College of Sports Medicine.

The authors thank biostatistician Elina Kokkonen for her advice and expertise toward the statistical analysis.

None of the authors have any conflicts of interests regarding the article in question.

REFERENCES

1. Ahotupa M, Marniemi J, Lehtimäki T, et al. Baseline diene conjugation in LDL lipids as a direct measure of *in vivo* LDL oxidation. *Clin Biochem*. 1998;31(4):257–61.
2. Ahotupa M, Ruutu M, Mäntylä E. Simple methods of quantifying oxidation products and antioxidant potential of low density lipoproteins. *Clin Biochem*. 1996;29(2):139–44.
3. Ahotupa M, Suomela JP, Vuorimaa T, Vasankari T. Lipoprotein—specific transport of circulating lipid peroxides. *Ann Med*. 2010; 42(7):521–9.
4. Ahotupa M, Vasankari TJ. Baseline diene conjugation in LDL lipids: an indicator of circulating oxidized LDL. *Free Radic Biol Med*. 1999;27(11–12):1141–50.
5. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. Philadelphia (PA): Lippincott Williams & Wilkins; 2000. p. 84–5.
6. Berenson GS, Srinivasan SR, Bao WH, Newman WP, Tracy RE, Wattigney WA. Association between multiple cardiovascular risk factors and atherosclerosis in children and young adults: the Bogalusa Heart Study. *N Engl J Med*. 1998;338(23): 1650–6.
7. Blair SN, Kampert JB, Kohl HW, et al. Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. *JAMA*. 1996;276(3):205–10.
8. Fogelholm M, Malmberg J, Suni J, et al. International Physical Activity Questionnaire: validity against fitness. *Med Sci Sports Exerc*. 2006;38(4):753–60.
9. Fogelholm M, Malmberg J, Suni J, Santtila M, Kyröläinen H, Mäntysaari M. Waist circumference and BMI are independently associated with the variation of cardiorespiratory and neuromuscular fitness in young adult men. *Int J Obes (Lond)*. 2006;30:962–9.
10. Hakkinen A, Rinne M, Vasankari T, Santtila M, Hakkinen K, Kyrolainen H. Association of physical fitness with health-related quality of life in Finnish young men. *Health Qual Life Outcomes*. 2010;8:15.
11. Haslam DW, James WPT. Obesity. *Lancet*. 2005;366(9492):1197–209.
12. Keaney JF Jr, Larson MG, Vasan RS, et al. Obesity and systemic oxidative stress, clinical correlates of oxidative stress in the Framingham Study. *Arterioscler Thromb Vasc Biol*. 2003;23:434–9.
13. Kujala UM, Ahotupa M, Vasankari T, Kaprio J, Tikkanen MJ. Low LDL oxidation in veteran endurance athletes. *Scand J Med Sci Sports*. 1996;6(5):303–308.
14. Kujala UM, Ahotupa M, Vasankari T, Kaprio J, Tikkanen MJ. Familial aggregation of LDL oxidation. *Scand J Clin Lab Invest*. 1997;57(2):141–6.
15. Kyrolainen H, Hakkinen K, Kautiainen H, Santtila M, Pihlainen K, Hakkinen A. Physical fitness, BMI and sickness absence in male military personnel. *Occup Med (Lond)*. 2008;58(4):251–6.
16. Lee CD, Blair SN, Jackson AS. Cardiorespiratory fitness, body composition, and all-cause and cardiovascular disease mortality in men. *Am J Clin Nutr*. 1999;69(3):373–80.
17. Lee HY, Oh BH. Aging and arterial stiffness. *Circ J*. 2010;74(11): 2257–62.
18. Linna MS, Borg P, Kukkonen-Harjula K, et al. Successful weight maintenance preserves lower levels of oxidized LDL achieved by weight reduction in obese men. *Int J Obes (Lond)*. 2007;31(2): 245–53.
19. Mackness MI, Durrington PN. HDL, its enzymes and its potential to influence lipid peroxidation. *Atherosclerosis*. 1995;115(2): 243–53.
20. Meisinger C, Baumert J, Khuseyinova N, Loewel H, Koenig W. Plasma oxidized low-density lipoprotein, a strong predictor for acute coronary heart disease events in apparently healthy, middle-aged men from the general population. *Circulation*. 2005;112(5): 651–7.
21. Njajou OT, Kanaya AM, Holvoet P, et al. Association between oxidized LDL, obesity and type 2 diabetes in a population-based cohort, the Health, Aging and Body Compossition Study. *Diabetes Metab Res Rev*. 2009;25(8):733–9.
22. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA*. 2006;295(13):1549–55.
23. Pihlainen K, Santtila M, Ohrankammen O, Ilomäki J, Rintakoski M, Tiainen S, editors. *Manual for Fitness Tester of Finnish Defence Force*. 1st ed. Helsinki (Finland): General Staff of Defence Force, Department of Personnel; 2009. p. 66.
24. Pohjonen T. Age-related physical fitness and the predictive values of fitness tests for work ability in home care work. *J Occup Environ Med*. 2001;43(8):723–30.
25. Ross R, Dagnone D, Jones PJH, et al. Reduction in obesity and related comorbid conditions after diet-induced weight loss or exercise-induced weight loss in men. A randomized, controlled trial. *Ann Intern Med*. 2000;133(2):92–103.
26. Shoelson S, Herrero L, Naaz H. Obesity, inflammation, and insulin resistance. *Gastroenterology*. 2007;132(6):2169–80.
27. Stocker R, Keaney JF Jr. Role of oxidative modifications in atherosclerosis. *Physiol Rev*. 2004;84(4):1381–478.
28. Vasankari T, Fogelholm M, Kukkonen-Harjula K, et al. Reduced oxidized low-density lipoprotein after weight reduction in obese premenopausal women. *Int J Obes Relat Metab Disord*. 2001; 25(2):205–11.
29. Vasankari TJ, Kujala UM, Vasankari TM, Ahotupa M. Reduced oxidized LDL levels after a 10-month exercise program. *Med Sci Sports Exerc*. 1998;30(10):1496–501.
30. Viljanen T, Viitasalo JT, Kujala UM. Strength characteristics of a healthy urban adult population. *Eur J Appl Physiol Occup Physiol*. 1991;63(1):43–7.
31. Watson AD, Berliner JA, Hama SY, et al. Protective effect of high density lipoprotein associated paraoxonase. Inhibition of the biological activity of minimally oxidized low density lipoprotein. *J Clin Invest*. 1995;96(6):2882–91.
32. World Health Organization Web site [Internet]. Geneva (Switzerland): World Health Organization; 2006. Obesity and overweight. Fact sheet No. 311; [cited 2007 Oct 1]. Available from: http://www.who.int/mediacentre/factsheets/fs311/en/index.html.