Differential effects on cholesterol and lipid profile of physical activity, aerobic exercise, resistance training and combined exercise modalities: A review and synthesis

Steven Mann[1], Christopher Beedie[2] & Alfonso Jimenez[3]

1. Centre for Sport Science and Human Performance. University of Greenwich. Chatham Maritime. UK. 2. Department of Sport & Exercise Sciences, Aberystwyth University, Wales. 3. Institute of Sports, Exercise and Active Living, ISEAL, Victoria University, Melbourne, Australia. Correspondence: S. Mann, School of Science, University of Greenwich, Chatham Maritime, ME4 4TB. UK, Email: ms55@gre.ac.uk, Tele: 020 8331 9800, Fax: 020 8331 9805

There is a direct relationship between chronically elevated cholesterol levels (dyslipidemia) and coronary heart disease. Reduction in total cholesterol is considered the gold standard in preventative cardiovascular medicine. Exercise has been shown to positively impact the pathogenesis, symptomatology and physical fitness of individuals with dyslipidemia, and to reduce cholesterol levels. The optimal mode, frequency, intensity and duration of exercise for the improvement of cholesterol levels are however yet to be identified. This review assesses the evidence from 18 published investigations and three review articles that have addressed the effects on cholesterol levels and lipid profile of physical activity (PA), aerobic exercise (AE), resistance training (RT) and AE and RT combined (COM). Data reviewed confirms the benefits of regular activity on cholesterol levels and describes the impacts of differing volumes and intensities of exercise upon lipid profile. Evidence-based exercise recommendations are presented, these aimed at facilitating the prescription and delivery of interventions in order to optimise cholesterol levels.

Introduction

The term 'lipid profile' describes the varying levels of lipids in blood, the most commonly reported being Low-Density Lipoprotein (LDL), High-Density Lipoprotein (HDL) and Triglycerides (TRI). High levels of LDL indicate surplus lipids in the blood that in turn increase the risk of cardiovascular complications. HDL transports lipids back to the liver for recycling and disposal; consequently high levels of HDL are an indicator of a healthy cardiovascular system [1]. Triglycerides (TRI) in plasma are derived from fats eaten in foods or other energy sources. An excess of TRI in plasma is positively associated with cardiovascular disease [2].

The most commonly used measure of cholesterol is arguably 'total cholesterol' (TOT), a measure that includes LDL and HDL. However, given the different effects of LDL and HDL cholesterol on health, TOT can be misleading. More sensitive measures report for example the ratio TOT:HDL, or non-HDL cholesterol (i.e., in the latter all cholesterol variables positively associated with cardiovascular diseases [3]).

There is a direct relationship between chronically elevated cholesterol levels (Dyslipidemia) and Coronary Heart Disease (CHD) [4]. In a meta analysis of 170,000 participants, [5] it was reported that reductions in LDL decreased the incidence of heart attacks, revascularisation and ischaemic strokes. Individuals with elevated total cholesterol levels – above 200mg/dl (5.172mmol/L) – have approximately twice the risk of CHD as those with optimal levels (<180mg/dl / 4.66mmol/L) [6]. The Centre for Disease Control (CDC) suggested that this is the case with 71 million US adults, equating to 33.5% of the population [7]. The prevalence of elevated total cholesterol is even higher in Europe, where 54% of adults aged 25 and over have total cholesterol levels above the recommended levels [8].

As long as ten years ago one third of all ischaemic heart disease globally was attributed to high cholesterol levels [9]. Whilst age-adjusted prevalence of high cholesterol in the United States lowered from 26.6% (1988-1994) to 25.3% (1994-2004), the most recent data [10], suggest that the use of pharmacological cholesterol lowering substances increased from 11.7% to 40.8% of the adult population during this period. It has long been recognised that reductions in serum cholesterol can reduce CHD risk, for example, reductions of around 0.6mmol/L can reduce incidence of ischaemic heart disease by 54% at the age of 40 years reducing to 19% at

80 years [11]. Reduction in total cholesterol is therefore still considered the "gold standard" in preventative cardiovascular medicine [12]. This highlights the importance of interventions aimed at reducing serum cholesterol levels. Furthermore, the advantage of early intervention have been demonstrated; long term exposure to 1mmol/L lower Low Density Lipoprotein (LDL) was associated with a 55% reduction in CHD risk, while treatment with Statin starting in later life required a threefold reduction in LDL to achieve the same magnitude risk reduction [13].

Pedersen and Saltin [14], citing thirteen meta-analyses, reported improvements in lipid profile following exercise. They described this as Category A evidence that exercise can have a positive effect on the pathogenesis, symptomatology and physical fitness of individuals with dyslipidemia. Whilst the mechanisms underlying the effect are unclear, exercise appears to enhance the ability of skeletal muscles to utilise lipids as opposed to glycogen, thus reducing plasma lipids [15].

Physical activity and types of exercise

The terms ''physical activity'' and 'exercise'' are often used interchangeably in the literature. However it is suggested that the two terms denote two different concepts [16]. ''Physical activity'' (PA) refers to any bodily movement produced by skeletal muscles that results in an expenditure of energy (expressed in kilocalories), and which includes a broad range of occupational, leisure and daily activities. ''Exercise" instead refers to planned or structured PA, performed for a reason, which can be aerobic (AE), resistance (RT) or the two combined (COM).

The Physical Activity Guidelines Advisory Committee Report [17] highlighted the need to design a programme that will provide appropriate exercise in order to attain maximal benefit at the lowest level of risk. However, despite a large number of related publications, a comprehensive overview of optimal modes, intensities and frequencies of PA in the context of lipid profile has yet to be published by any of the agencies involved. The authors of a recent meta analysis [18] in fact highlighted the lack of evidence for training programmes that optimally improve cardiovascular risk, drawing particular attention to the effects of AE, RT and COM on cardiovascular risk factors.

The present review synthesises the current published evidence regarding the impact of PA, AE, RT and COM on cholesterol levels. From this synthesis, evidence-based recommendations for activity in the improvement of lipid profile are presented.

Method

Selection Criteria

A comprehensive PubMed search with terms 'physical activity', 'aerobic exercise', resistance training', 'combined aerobic and resistance training' 'intervention' and 'cholesterol' was conducted for articles published between 1975 and December 2012. Reference lists of identified articles were also searched and relevant papers identified. Articles were selected if they assessed the impact of at least one mode of PA on cholesterol levels. Articles were only selected if they contained data regarding the mode, intensity, frequency and duration of PA. An example of an article not included is Hansen et al. [19], which compared AE and COM interventions. However, participants were receiving medication for CAD, therefore observed effects could not be unambiguously attributed to the PA intervention alone.

Article Search Methodology		
Selection Criteria	• Original Published Research • 1975 – 07/11/2012	
		Articles Located
PubMed Search Terms	• Physical Activity Intervention Cholesterol • Aerobic Exercise Intervention Cholesterol • Resistance Training Intervention Cholesterol • Combined Aerobic and Resistance Training Intervention Cholesterol	**2145**
Filtering	• Meta-Analysis of Exercise / Physical Activity	

	interventions impact upon Cholesterol levels • Randomised Controlled Trials / Original Investigations • Specific Detail of Mode, Intensity, Frequency and Duration of Physical Activity / Exercise	**3 Review** **31 Original research**
Final Checks	• Examination of identified papers reference lists for other articles meeting selection criteria & check for duplication	**3 Review** **18 Original research**

Table 1. Article selection criteria and search methodology.

The findings of all studies meeting the inclusion criteria are presented below. These are classified by PA, AE, RT and COM. Care has been taken to ensure that information is not 'counted' twice, that is as an original research investigation and as part of a review (characteristics and findings of all included studies are also presented in Table. 2). Following the review, evidence-based recommendations for best practice are presented. It is recognised by the authors that these guidelines should be considered tentative given the range of research methods, interventions and populations described (in short, the relative lack of programmatic research). However, these will provide a basis for current practice and, we hope, a platform for future research and recommendations.

Physical Activity (PA)

Kesaniemi et al. [20] reviewed 51 papers describing PA interventions and reported a mean increase in HDL of 4.6%. Effects on LDL and TRI were reported as inconsistent. The authors concluded that the most likely PA-induced improvement in lipid profile is an increase in HDL. Studies subsequent to or not included in this meta-analysis are reported below.

Aadahl et al., [21] reported a PA intervention based on lifestyle consultations in 1693 sedentary men and women aged between 33 – 64 years. Participants taking lipid lowering medication were excluded from the analysis. At the three year follow-up a significant positive association was observed between self-reported 24-hour PA and HDL ($p=0.0001$), whilst a significant negative association was reported between PA and TRI levels ($p=0.0001$). Interestingly the association between PA and HDL and TRI ceased in those reporting PA of above 45 METs per day. No associations were observed with TOT or LDL, and no dietary implications were reported. Overall, data suggested a dose-response relationship between increases in PA and improvements in TRI and HDL in previously sedentary populations. Five year follow-up of a subsequent study Aadahl et al., [22] reported significant associations between PA and improvements in TOT ($p=0.006$), LDL ($p=0.007$), TRI ($p=0.02$) and HDL ($p=0.01$) among 4039 participants aged between 30 and 60 years, although significant improvements in HDL levels were found in men only. The authors suggest hormone replacement as a factor that may have elicited this gender difference (see [23]). The authors reported no associations between dietary alterations and reductions in cholesterol levels, although it is noted that there was a risk that associations were confounded by the relatively crude self reporting of changes in dietary habits. Data were adjusted however to negate the impact of lipid lowering medication, suggesting that changes in PA levels were the mechanism behind improvements in lipid profile.

Various community-based strategies have been employed to increase levels of PA, and several report lipids. Gerstel et al., [24] reported an intervention with employees ($n=149$) of a nursing agency who were enrolled to an education programme. The intervention aimed to increase PA levels and promote healthy nutrition. Controls ($n=44$) were asked to maintain their habitual dietary and PA levels. It was reported that body weight, waist circumference and systolic blood pressure improved significantly in both groups while LDL (-0.36mmol/L; $p<0.01$), TOT:HDL ratio (-0.57mmol/L; $p<0.01$), HDL (+0.22mmol/L; $p<0.01$) and fasting glucose (-0.4mmol/L; $p<0.05$) improved significantly in the intervention group only. Incidence of metabolic syndrome was reported to have fallen by 50% in the intervention group. Gerstel et al. reported that the intervention increased PA levels and reduced self reported calorific intake, both of which positively impacted upon lipid levels.

Pagels et al., [25] examined moderate PA (brisk walking for 30 minutes daily, approx. 191kcal/3669 steps per bout) for three weeks among participants (N=33, age 25-45) randomised to control and intervention groups.

Both LDL (3.83 [pre] – 3.55 [post] mmol/L) and TOT (5.69 – 5.41mmol/L) were significantly reduced in the intervention group ($p<0.05$), while no changes were observed in controls. Once again, a significant inverse correlation between energy expenditure and LDL was observed ($r=-0.39$; $p<0.05$).

Sassesn et al., [26], in investigating PA among 1298 subjects ranging in age between 18 and 62 years, suggested that PA within a threshold of 1200 to 2200 kcal/week elicited favourable changes in HDL. They suggested that greater changes may be found with additional training and the progression to more structured form of PA such as AE.

Aerobic Exercise (AE)

Leon and Sanchez., [27] conducted a meta-analysis of 51 interventions involving 12 weeks or more of AE (n=4700). It was reported that on average HDL increased by 4.6% while TRI levels fell by 3.7% and LDL by 5%. TOT remained unchanged although the HDL:LDL ratio improved considerably, suggesting that the increased intensity and structure of AE has a more consistent impact upon TRI and LDL than PA. Studies subsequent to or not included in this meta-analysis are reported below.

It was suggested above that HDL is the component of lipid profile most likely to improve as the result of PA. This is supported by evidence relating to AE presented by Banz et al., [28], who reported a 13% increase in HDL (29.8 – 33.7mg/dl; $p<0.05$) following a relatively short 10 week protocol - training three times a week at 85% HRmax (from the second week onwards) for 40 minutes on ski style exercise equipment. The authors reported that HDL was the only component of lipid profile to improve. Nybo et al., [29] reported that the TOT:HDL ratio was the only component of lipid profile significantly improved by 150 minutes of exercise a week at 65% VO_{2max} in previously untrained participants (3.41 – 2.92; $p<0.05$). This investigation compared a prolonged (150min/wk) AE protocol with an intense interval running protocol (40min/wk) (n=36). No improvements in lipid profile were reported following the intense interval programme. The authors consequently suggest that training volume as opposed to training intensity is the key to improving in lipid profile. Furthermore, these authors suggested that there may be a relationship between body fat – which was only lowered in the prolonged group – and cholesterol levels, whereby a volume sufficient to elicit changes in fat mass is required needed to favourably alter lipid profile.

When the intensity of AE is increased during continuous effort, the effects upon HDL cholesterol appear to become more consistent. Dunn et al., [30] investigated the effects of a six month AE training programme that progressed from 50 – 85% maximum aerobic power for 20 – 60 minutes three times a week and reported a significant decrease in TOT (-0.3 mmol/L; $p<0.001$) as well as TOT:HDL ratio (-0.3; $p<0.001$). In this case the intervention period was relatively long as well as the intensity being relatively high. In a 16 week study, LeMura et al., [31] reported significant reductions in plasma TRI (1.4 – 1.2mmol/L; $p<0.05$) and increases in HDL (1.4 – 1.8mmol/L; $p<0.05$) after training three times a week at 70-75% HRmax for 30 minutes for the first 8 weeks, progressing to four times at 85% HRmax for 45 minutes thereafter. Data suggested that shorter term interventions will be effective also if training volume is high enough. Increasing the frequency of training to four times per week may have elicited the additional benefits seen by LeMura et al in comparison with Banz et al (three training sessions per week). Further LeMura et al observed a 13% reduction in body fat percentage (26.4 – 22.9; $p<0.05$), suggesting the additional volume of training generated an additional metabolic response, a parameter not reported by Banz et al.

Kraus et al., [32] investigated the impact of increasing the volume and intensity of AE upon lipid profile among 111 sedentary overweight participants, all with mild to moderate dyslipidemia. Participants were allocated to either six months in a control group or 8 months in one of three AE groups. The three groups were; high intensity/high volume (jogging the calorific equivalent of 20 miles per week at an intensity of 65-80% VO2peak), high intensity/low volume (jogging the calorific equivalent of 12 miles per week at an intensity of 65-80% VO2peak), and moderate intensity/low volume (walking the calorific equivalent of 12 miles per week at an intensity of 40-55% VO2peak). It was reported that the high intensity/high volume training combination resulted in the greatest improvements in 10 of 11 lipid variables (LDL: 130.1 – 128.2mg/dl; $p<0.05$, HDL: 44.3 – 48.6mg/dl; $p<0.05$, TRI: 166.9 – 138.5mg/dl; $p<0.05$, along with the size of molecules). This data suggests that in relation to AE both total energy expenditure of and intensity are factors in lipid reduction.

O'Donovan et al., [33] controlled training volume to directly assess the impact of training intensity. 64 previously sedentary men were randomly allocated to either a control group, a moderate intensity exercise

group (60% $VO2_{max}$) or a high intensity group (80% $VO2_{max}$). Both exercising groups completed three 400kcal sessions per week for 24 weeks. By setting the session volume in calories, the overall training volume was controlled. Participants were instructed to maintain their dietary habits. It was reported that significant lipid profile improvements occurred only in the high intensity group, with TOT (6.02 – 5.48mmol/L), LDL (4.04 – 3.52mmol/L) and non HDL (4.58 – 4.04mmol/L) all decreasing significantly ($p<0.05$).

Evidence suggests that a moderate intensity exercise programme will be effective in increasing HDL. This will have a positive impact upon artherosclerosis (hardening of artery walls through plaque and fat accumulation [12]) via HDL facilitated removal of LDL. To reduce LDL and TRI levels, the intensity of aerobic exercise must be increased, something that may not be possible in individuals with limited exercise capacity.

Resistance Training (RT)

Theoretically RT may be a more assessable form of exercise for less mobile groups as well as providing an alternative to aerobic training for more mobile individuals [34]. Prabhakaran et al., [35] investigated the effect of 14 weeks RT in premenopausal women (n=24). RT was at an intensity of 85% of one maximal repetition (85%1RM), where one maximal repetition is the maximal load that can be lifted once for a given exercise [36]. Participants were randomised to either RT or to a non-exercising control. Supervised exercise sessions lasted between 40-50 minutes and were completed three times weekly. Significant ($p<0.05$) decreases in TOT (4.6 - 4.26mmol/L) and LDL (2.99 - 2.57mmol/L) were observed, along with lowered body fat (27.9% - 26.5%). Acute changes in lipid profile among following different intensities of RT were examined by Lira et al., [37]. Untrained males (n=30) were randomised to intensity groups at baseline. Measures of cholesterol were collected at time points of one, 24, 48 and 72 hours following RT at intensities of 50%, 75%, 90% and 110% (in the later scenario in the eccentric phase only, performance was assisted during the concentric phase). Total training volume was equalised between the groups to ensure that RT intensity was the factor being assessed. TRI clearance was significantly ($p<0.05$) greater following 50% (-14.6mg/dl) and 75% (-10.7mg/dl) 1RM compared 90% (+9.5mg/dl) and 110% (+12.1mg/dl) at 72 hours. Further, increases in HDL were significantly greater following 50% and 75% 1RM compared to 110% ($p=0.004$ and 0.03 respectively). The authors concluded that low to moderate intensity RT results in the greater benefit to lipid profile than high intensity RT.

Sheikholeslami Vatani et al., [38] examined the effects of various intensities of RT on lipid profile over six weeks. Healthy male participants (n=30) were randomised to either a moderate intensity RT programme (MOD) (45-55% 1RM) or a high intensity RT programme (HIGH) (80-90% 1RM). Both groups were supervised during training sessions and attended three sessions per week. Significant ($p<0.05$) reductions in LDL (MOD:-13.5mg/dL vs HIGH:-12.1mg/dL), TOT (MOD:-12.2mg/dL vs HIGH:-11.3mg/dL) and the ratio of TOT to HDL (MOD:-0.38 vs HIGH:-0.47) were found in both groups with no significant difference between them. Significant increases in HDL however were only observed in the high intensity group (+5.5mg/dL). This is perhaps surprising considering that previous research indicates that increased HDL is likely the first lipid profile response to exercise, even at low intensities of activity [20]. This study once again demonstrated the limited additional benefit of increasing the intensity of resistance training when equalising the training load by reducing the sets and repetitions completed to compensate for the increased weight being lifted. Consequently the overall training volume is lowered and fewer muscle contractions are generated.

Fett et al., [39] incorporated RT into circuit training sessions in which no specific weight was designated but in which specific time is allocated to each exercise. Sessions lasted 60 minutes per week and were completed three times a week for one month and four times a week for the second month. Significant reductions were reported in TOT (203 – 186mg/dl; $p<0.01$) and TRI (122 – 91mg/dl; $p<0.05$), further adding to the argument that the amount of movement its self may be more important than the amount of weight lifted.

Combined modalities (COM)

The evidence presented above demonstrates the effectiveness of both AE and RT in controlling and improving cholesterol levels through various modes, frequencies, intensities and durations of PA and exercise, in different populations. There is limited literature that has examined the two modalities combined, although a recent review by Tambalis et al., [40] suggests that although some combination protocols have been effective in lowering LDL and increasing HDL, others have not.

Shaw et al.,[41] examined the effect of a 16 week moderate intensity COM protocol in previously untrained but otherwise healthy young men. The protocol lasted 45 minutes and combined AE at 60% HRmax with RT (two sets of 15 repetitions) at 60% 1RM. It was reported that LDL significantly reduced following the COM training (4.39 – 3.23mmol/L; $p<0.05$), although the improvements were not significantly different to those gleaned by 45 minutes AE alone (3.64 – 2.87mmol/L; $p<0.05$). It can therefore be concluded that no additional LDL reduction resulted from combining the modes of exercise. However, this investigation does demonstrate that RT might successfully compensate for reductions in AE. Further, the authors suggest that additional physiological systems saw benefit with RT making it potentially more effective.

Yang et al., [42] reported a study investigating relationships between exercise, cholesterol and arterial stiffness in obese middle aged women (n=40, BMI>25kg/m^2, age 30-60 years). The experimental protocol consisted of 45 minutes AE at an intensity of 60-75% HRmax (300kcal per session) and 20 minutes RT (100kcal per session) five times a week over a 12 week period. Reductions were observed in TOT (5.2 – 4.2mmol/L; $p=0.655$), LDL (3.2 – 2.6mmol/L; $p=0.172$), TRI (3.0 – 2.5mmol/L; $p<0.001$), and in arterial stiffness measured via brachial-ankle pulse wave velocity (1286 – 1195cm/s; $p<0.001$). Whilst no controls were used, these data suggest the potential clinical significance of reductions in cholesterol, that is, the reduction in the arterial stiffness associated with heart attacks and strokes.

Ha and So., [43] combined 30 minutes AE at 60 – 80% HR reserve, with 30 minutes RT between 12-15 repetition maximum in 16 participants aged between 20 and 26 years for 12 weeks. The intervention significantly reduced waist circumference, body fat percentage and blood pressure when compared to non-exercising controls. Lipid profile improved in the exercising condition (TOT: 180.29 – 161mg/dl, LDL: 112.14 – 103.57mg/dl, TRI: 97.14 – 50.43mg/dl), although changes did not reach significance when compared with controls. The authors suggested that the age of the study cohort was too young to find the clinical and significant effects shown by previous research in predominantly elderly or middle aged participants.

Author (year)	N	Design	Intervention	Measure	Effect		P Value
Aahahl (2007) [21]	1693	Correlational	Lifestyle consultations – 3 year follow up	HDL	Positive Association with ↑ PA		p<0.001*
				TRI	Negative Association with ↑ PA		p<0.001*
				TOT	No Association with ↑ PA		p=0.62
				LDL	No Association with ↑ PA		P=0.93
Aadahl (2009) [22]	4039	Correlational	Lifestyle consultations – 5 year follow up	HDL	Positive Association with ↑ PA		p=0.01*
				TRI	Negative Association with ↑ PA		p=0.02*
				TOT	Negative Association with ↑ PA		p=0.006*
				LDL	Negative Association with ↑ PA		p=0.007*
Gerstal (2012) [24]	173	RCT	Education programme – increase PA and promote nutrition	LDL	↓	3.6mmol/L	p<0.01*
				HDL	↑	2.2mmol/L	p<0.01*
				TOT:HDL	↓	0.57	p<0.01*
				TRI	↑	0.1mmol/L	Not reported

Pagels (2012) [25]	33	RCT	30min walking daily – 3 weeks	TOT	↓	0.28mmol/L	p<0.05*
				HDL	↓	0.01mmol/L	Not reported
				LDL	↓	0.3mmol/L	p<0.05*
				TRI	↓	0.02mmol/L	Not reported
				TOT:HDL	↓	0.21mmol/L	Not reported
				VLDL	↓	0.01mmol/L	Not reported
Banz (2003) [28]	26	Quasi-experimental	AE 10 weeks 3 sessions per week 85% HRmax 40 minutes	TOT	↑	4.1mg/dL	Not reported
				HDL	↑	3.9 mg/dL	p<0.05*
				LDL	↑	3.4 mg/dL	Not reported
Nybo (2010) [29]	36	RCT	AE (Prolonged) 12 weeks 150 min/week 65% VO2max	TOT	↓	0.3mmol/L	Not reported
				HDL	↑	0.1mmol/L	Not reported
				LDL	↓	0.1mmol/L	Not reported
				TOT:HDL	↓	0.49	p<0.005*
			AE (Intense Interval) 12 weeks 40min/week HR>95% during sprints	TOT	↓	0.1mmol/L	Not reported
				HDL	/	0mmol/L	Not reported
				LDL	↓	0.1mmol/L	Not reported
				TOT:HDL	↓	0.08	Not reported
Dunn (1997) [30]	235	Quasi-experimental	AE 24 weeks 3 sessions per week 50-85% max aerobic power 20-60minutes	TOT	↓	0.3mmol/L	p<0.001*
				HDL	/	0mmol/L	p=0.54
				LDL	↓	0.2mmol/L	p<0.001*
				TOT:HDL	↓	0.3mmol/L	p<0.001*
LeMura (2000) [31]	48	RCT	AE 16 weeks 3 sessions per week 70-75% HRmax (weeks 1-8) 85% HRmax (weeks 8-16) 30 minutes (weeks 1-8) 45 minutes (weeks 8-16)	TOT	↓	0.3mmol/L	Not reported
				HDL	↑	0.4mmol/L	p<0.005*
				LDL	↓	0.2mmol/L	Not reported
				TRI	↓	0.2mmol/L	p<0.005*
				TOT:HDL	↓	1	Not reported
Kraus (2002) [32]	111	RCT	AE 24 weeks 65-80% VO2peak Jogging	TOT	↑	0.4mg/dL	Not reported
				LDL	↓	1.9mg/dL	p<0.005*

			Calorific equivalent of 20 miles per week	HDL	↑	4.3mg/dL	p<0.005*
				TRI	↓	28.4mg/dL	p<0.005*
O'Donovan (2005) [33]	64	RCT	AE (MOD) 24 weeks 3 sessions per week 60% VO2max 400kcal per session	TOT	↑	0.3mmol/L	Not reported
				LDL	↑	0.17mmol/L	Not reported
				HDL	↑	0.08mmol/L	Not reported
				nonHDL	↑	0.23mmol/L	Not reported
				TRI	↑	0.12mmol/L	Not reported
			AE (HIGH) 24 weeks 3 sessions per week 80% VO2max 400kcal per session	TOT	↓	0.54mmol/L	p<0.005*
				LDL	↓	0.52mmol/L	p<0.005*
				HDL	↓	0.01mmol/L	Not reported
				nonHDL	↓	0.54mmol/L	p<0.005*
				TRI	↓	0.05mmol/L	Not reported
Prabhakaran (1999) [35]	24	RCT	RT 14 weeks 3 sessions per week 85% 1RM	TOT	↓	0.42mmol/L	p<0.005*
				LDL	↓	0.42mmol/L	p<0.005*
				HDL	↑	0.07mmol/L	Not reported
				TRI	↓	0.16mmol/L	Not reported
				LDL:HDL	↓	0.42mmol/L	p=0.057
				TOT:HDL	↓	0.54mmol/L	p<0.005*
Sheikoleslami Vatani (2011) [38]	30	RCT	RT (MOD) 6 weeks 3 sessions per week 45-55% 1RM	HDL	↑	2.3mg/dL	Not reported
				LDL	↓	13.5mg/dL	p<0.005*
				TRI	↓	11.4mg/dL	Not reported
				TOT	↓	12.4mg/dL	p<0.005*
				TOT:HDL	↓	0.38mg/dL	p<0.005*
			RT (HIGH) 6 weeks 3 sessions per week 80-90% 1RM	HDL	↑	5.5mg/dL	p<0.005*
				LDL	↓	12.1mg/dL	p<0.005*
				TRI	↑	0.1mg/dL	Not reported
				TOT	↓	11.3mg/dL	p<0.005*
				TOT:HDL	↓	0.47mg/dL	p<0.005*
Fett (2009) [39]	50	Quasi-experimental	RT Circuit Training 8 weeks 3 sessions per week (1-4) 4 sessions per week (4-8) 60 minutes	TOT	↓	17mg/dL	p<0.01*
				LDL	↓	11mg/dL	Not reported
				HDL	↓	6mg/dL	Not reported
				TOT:HDL	↓	0.2mg/dL	Not reported
				TRI	↓	31mg/dL	p<0.05*
Shaw (2009)	28	RCT	COM	LDL	↓	2.16mmol/L	p<0.05*

[41]			16 weeks 3 sessions per week AE – 60% HRmax RT – 60% 1RM 45 minutes				
Yang (2011) [42]	40	Pre-post	COM 12 weeks 5 sessions per week AE – 300kcal RT – 100kcal	TOT	↓	1mmol/L	p=0.655
				LDL	↓	0.6mmol/L	p=0.172
				TRI	↓	0.5mmol/L	p<0.01*
Ha (2012) [43]	16	RCT	COM 12 weeks 3 sessions per week AE – 60-80% HRreserve RT – 12-15 rep maximum AE – 30 minutes RT – 30 minutes	TRI	↓	46.71mg/dL	p<0.05*
				HDL	↓	3.71mg/dL	Not reported
				TOT	↓	19.29mg/dL	p<0.05*
				LDL	↓	8.57mg/dL	p<0.05*

Table. 2 Full details from interventions reported upon. RCT = Randomised Controlled Trial, TOT = Total Cholesterol, LDL = Low Density Lipoprotein, HDL = High Density Lipoprotein, TRI = Triglycerides, TOT:HDL = Total Cholesterol to High Density Lipoprotein Ratio, VLDL = Very Low Density Lipoprotein, PA = Physical Activity, AE = Aerobic Exercise, RT = Resistance Training, COM = Combined Aerobic and Resistance Training. *Represents significant (p<0.05) interaction or pre – post change in change in cholesterol level. All comparisons are to baseline.

Exercise Recommendations

Based upon the data above relating to the effect of this exercise on cholesterol levels, exercise recommendations have been formulated (Table. 3). Interventions that have demonstrated particular effectiveness i.e. higher intensity AE [33] and moderate intensity RT [37] have been incorporated. The evidence presented for PA highlights a dose-response relationship between activity levels and increases in HDL [21] therefore the PA recommendations made are to be considered a minimum. These evidence-based recommendations should aid in the prescription and delivery of interventions to lower cholesterol levels.

Cholesterol Level Maintenance / Reduction: Exercise Recommendations	
Healthy **(Maintaining low LDL & TRI – increasing HDL)**	Increase PA to more than 30 minutes a day 5 times a week [21, 22]. Prolonged moderate intensity AE – 70-80% HRreserve [39] combined with low intensity RT – 50% 1RM [37].
Elevated Cholesterol / Dyslipidemia **(Clearance of LDL & TRI – increasing HDL)**	Increase PA to more than 30 minutes a day 5 times a week [21, 22]. Prolonged moderate intensity AE – 70-80% HRreserve [39] progressing to 85% HRmax [30, 31] combined with moderate – high intensity RT – 75% - 85% 1RM [35, 37].

Elevated Cholesterol / Dyslipidemia - Limited Mobility (Disabled, Elderly Populations etc.)	Increase PA as much as is feasible [21, 22]. RT progressing from 50% - 75% in major muscle groups [37] – can be incorporated into circuit sessions and kept at a moderate intensity[39]

Table. 3 Evidence – based exercise recommendations for maintaining / improving cholesterol levels in different demographics.

Conclusion

Data reported above provides some support for the proposal that PA and exercise can be utilised to improve cholesterol levels. Regular PA has been shown to increase HDL while maintaining (and theoretically offsetting increases in) LDL and TRI. There appears to be an linear dose-response relationship between activity level and HDL concentration. More intense activity however is required to elicit reductions in LDL and TRI. AE at high intensities appears to be effective at improving lipid profile, the effects surpassing those of PA by initiating the clearance of plasma LDL and TRI. Prolonged moderate intensity AE should be recommended as a starting point for those previously sedentary or new to exercise. RT presents a viable alternative to AE or an effective intervention independently. High intensities (>85% 1RM) were shown to be no more effective than moderate intensities (50-85% 1RM). The addition of RT to AE will supplement – and possibly enhance - the effects on lipid profile, although there is limited literature comparing the three modes of exercise, rendering definitive statements problematic. There will however be no reduction in effect and the additional physiological and psychological systems impacted may elicit additional benefits when combining AE and RT.

Data reviewed confirm the benefits of regular PA on cholesterol levels. Such knowledge should aid in the prevention and management of dyslipidemia while reducing the risk of heart attacks, strokes and coronary artery disease. Having considered the baseline condition of their patients, clinicians should encourage as much PA as possible whilst, where feasible highlighting the additional impact or appropriateness of AE and/or RT and COM to obtain the optimal benefits in their patients.

Acknowledgments

The authors wish to thank Dr. Judith Allgrove, Dr. Silvano Zanuso and Dr. Steffano Balducci for assistance in the early editing and proof reading of this review article. The authors report no conflict of interest.

References

1. Carroll MD, Kit BK, Lacher DA. Total and high-density lipoprotein cholesterol in adults: National Health and Nutrition Examination Survey, 2009-2010. NCHS Data Brief. 2012 Apr(92):1-8.
2. da Luz P, Favarato D, Faria-Neto JJ, Lemos P, Chagas A. High ratio of triglycerides to HDL-cholesterol predicts extensive coronary disease. Clinics (Sao Paulo). 2008 Aug;63(4):427-32.
3. Virani SS, Wang D, Woodard LD, Chitwood SS, Landrum CR, Zieve FJ, et al. Non-high-density lipoprotein cholesterol reporting and goal attainment in primary care. J Clin Lipidol. 2012 Nov;6(6):545-52.
4. Lloyd-Jones DM, Wilson PW, Larson MG, Beiser A, Leip EP, D'Agostino RB, et al. Framingham risk score and prediction of lifetime risk for coronary heart disease. Am J Cardiol. 2004 Jul;94(1):20-4.
5. Baigent C, Blackwell L, Emberson J, Holland LE, Reith C, Bhala N, et al. Efficacy and safety of more intensive lowering of LDL cholesterol: a meta-analysis of data from 170,000 participants in 26 randomised trials. Lancet. 2010 Nov;376(9753):1670-81.
6. Roger VL, Go AS, Lloyd-Jones DM, Benjamin EJ, Berry JD, Borden WB, et al. Heart disease and stroke statistics--2012 update: a report from the American Heart Association. Circulation. 2012 Jan;125(1):e2-e220.
7. CDC. Vital signs: prevalence, treatment, and control of high levels of low-density lipoprotein cholesterol. United States, 1999–2002 and 2005–2008. MMWR. *2011*;60(4):109–14.
8. World Health Organisation. "Global status report on nocommunicable diseases 2010: description of the global burden of NCDs, their risk factors and determinants. Chapter 1: Burden, mortality, morbidity and risk factors. Geneva: World Health Organisation; 2011.

9. Murray CJ, Lauer JA, Hutubessy RC, Niessen L, Tomijima N, Rodgers A, et al. Effectiveness and costs of interventions to lower systolic blood pressure and cholesterol: a global and regional analysis on reduction of cardiovascular-disease risk. Lancet. 2003 Mar;361(9359):717-25.
10. Go AS, Mozaffarian D, Roger VL, Benjamin EJ, Berry JD, Borden WB, et al. Heart disease and stroke statistics--2013 update: a report from the American Heart Association. Circulation. 2013 Jan;127(1):e6-e245.
11. Law MR, Wald NJ, Thompson SG. By how much and how quickly does reduction in serum cholesterol concentration lower risk of ischaemic heart disease? BMJ. 1994 Feb;308(6925):367-72.
12. Whayne TF. Atherosclerosis: current status of prevention and treatment. Int J Angiol. 2011 Dec;20(4):213-22.
13. Ference BA, Yoo W, Alesh I, Mahajan N, Mirowska KK, Mewada A, et al. Effect of long-term exposure to lower low-density lipoprotein cholesterol beginning early in life on the risk of coronary heart disease: a Mendelian randomization analysis. J Am Coll Cardiol. 2012 Dec;60(25):2631-9.
14. Pedersen B, Saltin B. Evidence for prescribing exercise as therapy in chronic disease. Scand J Med Sci Sports. 2006 Feb;16 Suppl 1:3-63.
15. Earnest CP, Artero EG, Sui X, Lee DC, Church TS, Blair SN. Maximal Estimated Cardiorespiratory Fitness, Cardiometabolic Risk Factors, and Metabolic Syndrome in the Aerobics Center Longitudinal Study. Mayo Clin Proc. 2013 Feb.
16. United States. Public Health Service. Office of the Surgeon General, Centers for Disease Control, Prevention (US), President's Council on Physical Fitness, & Sports (US). (1996). *Physical activity and health: a report of the Surgeon General*. Jones & Bartlett Learning.
17. Physical Activity Guidelines Advisory Committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary. Nutr Rev. 2009 Feb;67(2):114-20.
18. Pattyn N, Cornelissen VA, Eshghi SR, Vanhees L. The effect of exercise on the cardiovascular risk factors constituting the metabolic syndrome: a meta-analysis of controlled trials. Sports Med. 2013 Feb;43(2):121-33.
19. Hansen D, Eijnde BO, Roelants M, Broekmans T, Rummens JL, Hensen K, et al. Clinical benefits of the addition of lower extremity low-intensity resistance muscle training to early aerobic endurance training intervention in patients with coronary artery disease: a randomized controlled trial. J Rehabil Med. 2011 Sep;43(9):800-7.
20. Kesaniemi Y, Danforth EJ, Jensen M, Kopelman P, Lefèbvre P, Reeder B. Dose-response issues concerning physical activity and health: an evidence-based symposium. Med Sci Sports Exerc. 2001 Jun;33(6 Suppl):S351-8.
21. Aadahl M, Kjaer M, Jørgensen T. Associations between overall physical activity level and cardiovascular risk factors in an adult population. Eur J Epidemiol. 2007;22(6):369-78.
22. Aadahl M, von Huth Smith L, Pisinger C, Toft U, Glümer C, Borch-Johnsen K, et al. Five-year change in physical activity is associated with changes in cardiovascular disease risk factors: the Inter99 study. Prev Med. 2009 Apr;48(4):326-31.
23. Schubert CM, Rogers NL, Remsberg KE, Sun SS, Chumlea WC, Demerath EW, et al. Lipids, lipoproteins, lifestyle, adiposity and fat-free mass during middle age: the Fels Longitudinal Study. Int J Obes (Lond). 2006 Feb;30(2):251-60.
24. Gerstel E, Pataky Z, Busnel C, Rutschmann O, Guessous I, Zumwald C, et al. Impact of lifestyle intervention on body weight and the metabolic syndrome in home-care providers. Diabetes Metab. 2012 Oct.
25. Pagels P, Raustorp A, Archer T, Lidman U, Alricsson M. Influence of moderate, daily physical activity on body composition and blood lipid profile in Swedish adults. J Phys Act Health. 2012 Aug;9(6):867-74.
26. Sassen B, Cornelissen VA, Kiers H, Wittink H, Kok G, Vanhees L. Physical fitness matters more than physical activity in controlling cardiovascular disease risk factors. Eur J Cardiovasc Prev Rehabil. 2009 Dec;16(6):677-83.
27. Leon A, Sanchez O. Response of blood lipids to exercise training alone or combined with dietary intervention. Med Sci Sports Exerc. 2001 Jun;33(6 Suppl):S502-15; discussion S28-9.
28. Banz W, Maher M, Thompson W, Bassett D, Moore W, Ashraf M, et al. Effects of resistance versus aerobic training on coronary artery disease risk factors. Exp Biol Med (Maywood). 2003 Apr;228(4):434-40.
29. Nybo L, Sundstrup E, Jakobsen M, Mohr M, Hornstrup T, Simonsen L, et al. High-intensity training versus traditional exercise interventions for promoting health. Med Sci Sports Exerc. 2010 Oct;42(10):1951-8.
30. Dunn A, Marcus B, Kampert J, Garcia M, Kohl Hr, Blair S. Reduction in cardiovascular disease risk factors: 6-month results from Project Active. Prev Med. 1997 1997 Nov-Dec;26(6):883-92.

31. LeMura L, von Duvillard S, Andreacci J, Klebez J, Chelland S, Russo J. Lipid and lipoprotein profiles, cardiovascular fitness, body composition, and diet during and after resistance, aerobic and combination training in young women. Eur J Appl Physiol. 2000 Aug;82(5-6):451-8.
32. Kraus W, Houmard J, Duscha B, Knetzger K, Wharton M, McCartney J, et al. Effects of the amount and intensity of exercise on plasma lipoproteins. N Engl J Med. 2002 Nov;347(19):1483-92.
33. O'Donovan G, Owen A, Bird S, Kearney E, Nevill A, Jones D, et al. Changes in cardiorespiratory fitness and coronary heart disease risk factors following 24 wk of moderate- or high-intensity exercise of equal energy cost. J Appl Physiol. 2005 May;98(5):1619-25.
34. Brooks N, Layne JE, Gordon PL, Roubenoff R, Nelson ME, Castaneda-Sceppa C. Strength training improves muscle quality and insulin sensitivity in Hispanic older adults with type 2 diabetes. Int J Med Sci. 2007;4(1):19-27.
35. Prabhakaran B, Dowling E, Branch J, Swain D, Leutholtz B. Effect of 14 weeks of resistance training on lipid profile and body fat percentage in premenopausal women. Br J Sports Med. 1999 Jun;33(3):190-5.
36. Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc. 2004 Apr;36(4):674-88.
37. Lira F, Yamashita A, Uchida M, Zanchi N, Gualano B, Martins EJ, et al. Low and moderate, rather than high intensity strength exercise induces benefit regarding plasma lipid profile. Diabetol Metab Syndr. 2010;2:31.
38. Sheikholeslami Vatani D, Ahmadi S, Ahmadi Dehrashid K, Gharibi F. Changes in cardiovascular risk factors and inflammatory markers of young, healthy, men after six weeks of moderate or high intensity resistance training. J Sports Med Phys Fitness. 2011 Dec;51(4):695-700.
39. Fett C, Fett W, Marchini J. Circuit weight training vs jogging in metabolic risk factors of overweight/obese women. Arq Bras Cardiol. 2009 Nov;93(5):519-25.
40. Tambalis K, Panagiotakos D, Kavouras S, Sidossis L. Responses of blood lipids to aerobic, resistance, and combined aerobic with resistance exercise training: a systematic review of current evidence. Angiology. 2009 2009 Oct-Nov;60(5):614-32.
41. Shaw I, Shaw B, Krasilshchikov O. Comparison of aerobic and combined aerobic and resistance training on low-density lipoprotein cholesterol concentrations in men. Cardiovasc J Afr. 2009 2009 Sep-Oct;20(5):290-5.
42. Yang SJ, Hong HC, Choi HY, Yoo HJ, Cho GJ, Hwang TG, et al. Effects of a three-month combined exercise programme on fibroblast growth factor 21 and fetuin-A levels and arterial stiffness in obese women. Clin Endocrinol (Oxf). 2011 Oct;75(4):464-9.
43. Ha CH, So WY. Effects of combined exercise training on body composition and metabolic syndrome factors. Iran J Public Health. 2012;41(8):20-6.