Oxidative stress and endothelial function: effects of physical exercise on results of postprandial lipemia

Estresse oxidativo e a função endotelial: efeitos do exercício físico associado à lipemia pós-prandial

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Abstract

It is extremely important for public health to identify strategies that can prevent development of atherosclerosis. There are several modifiable metabolic risks that can induce onset of this disease, but the most investigated of these risk is increased postprandial lipemia after a high fat meal because this factor can increase oxidative damage and endothelial dysfunction. Physical exercise is indicated for prevention of development of these risk factors. The objective of this study was to search the literature for published studies investigating the acute and subacute effects on oxidative stress and endothelial function of physical exercise associated with postprandial lipemia and compare their results. Articles published up to February 2015 in Portuguese, Spanish or English were included. After an extensive review, it was concluded that the acute and subacute effects of physical could be capable of attenuating parameters of cardiovascular risk after consumption of a high fat meal.

Keywords: physical exercise; postprandial lipemia; oxidative stress; endothelial function.

Resumo

Estratégias que possam prevenir o aparecimento da aterosclerose são de extrema importância para a saúde pública. Dentre os fatores de risco modificáveis para o desenvolvimento dessa doença, o aumento da lipemia pós-prandial tem sido investigado, pois pode induzir dano oxidativo e disfunção endotelial. Nesse sentido, o exercício físico é indicado na prevenção do desenvolvimento desses fatores de risco. Esta revisão tem como objetivo realizar um levantamento e comparar os estudos publicados na literatura acerca dos efeitos agudos e subagudos do exercício físico associado à lipemia pós-prandial sobre o estresse oxidativo e a função endotelial. A busca foi realizada nos idiomas português, espanhol e inglês, compreendendo trabalhos publicados até fevereiro de 2015. Com base nos estudos selecionados, conclui-se que os efeitos agudos e subagudos do exercício físico podem ser capazes de atenuar os parâmetros de risco cardiovascular após o consumo de refeição hiperlipídica.

Palavras-chave: exercício físico; lipemia pós-prandial; estresse oxidativo; função endotelial.

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Financial support: None.
Conflicts of interest: No conflicts of interest declared concerning the publication of this article.
Submitted: March 25, 2015. Accepted: September 09, 2015.

The study was carried out at the Department of Physical Education of Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil.

 http://dx.doi.org/10.1590/1677-5449.01715

INTRODUCTION

To an ever-increasing extent the world's population is adopting a sedentary lifestyle and consuming an excessive calorie intake, with a negative impact on health. The metabolic syndrome (MS) is defined as a combination of interrelated risk factors, including abdominal obesity, insulin resistance, dyslipidemia and arterial hypertension.[1] Interactions between these risk factors increase the likelihood of emergence and/or acceleration of the progression of atherosclerotic disease, resulting in a high cost burden on the public purse.[2] In turn, atherosclerosis is characterized as a complex pathological process that takes place at the artery walls, triggering an inflammatory process and with the potential to provoke a series of other cardiovascular diseases (CVDs).[3] According to the World Health Organization, CVDs are ranked first out of the ten greatest causes of death globally, causing the deaths of seven million people in 2011.[4] Strategies that can prevent the onset of atherosclerosis are therefore extremely important for public health.

One of many different metabolic risk factors is elevated cholesterol levels in the blood.[3] This can be explained by the fact that greater quantities of cholesterol molecules originating from a high fat meal (HFM) can accumulate in the vascular endothelium during the postprandial period, triggering an atherosclerotic process. It can therefore be stated that atherogenesis is a result of elevated postprandial lipemia (PPL).[5] The literature suggests that an HFM can even be atherogenic in healthy young people.[6] An HFM also creates a lipid metabolism imbalance soon after it is eaten, which may cause greater susceptibility to oxidative damage and dysfunction of the vascular endothelium at several levels.[7,8]

Physical exercise has been identified as an important intervention against cardiovascular risk factors as a means of preventing onset of CVDs.[9,10] Indeed, exercise can be effective both for removing postprandial triglyceride (TG) concentrations and for reducing duration of exposure to them in the circulation. It has been speculated that this mechanism is linked to the energy expenditure demanded by exercise, with the result that TG are removed more rapidly, to replace energy stocks. It is also known that lipoprotein lipase (LLP) is a key enzyme for hydrolysis of TG and so increases in LLP activity appear to be of great importance.[10-12]

Studies have demonstrated that aerobic exercise performed the night before eating an HFM attenuates the PPL curve.[13-18] This residual post-exercise effect is defined as subacute, in order to differentiate it from the acute effect that occurs during exercise and from the chronic effects that results from a sequence of exercise sessions. Additionally, some studies have demonstrated that exercise may be able to attenuate oxidative damage and also the inflammation and coagulation curves, which are elevated after an HFM.[19-22] However, there is little information on the intensity, volume and duration of the exercise session that would be most effective for attenuating the lipemic curve and concomitantly attenuating oxidative stress and improving endothelial function. The lack of studies on the subject leaves a large gap in the literature relating to the true effects of different types of physical exercise sessions on oxidative stress and endothelial function, when associated with high fat meals.

In view of the above, the objective of the present study was to search the literature for studies that have been published on the acute and subacute effects on oxidative stress and endothelial function of physical exercise associated with postprandial lipemia and compare their results.

METHODS

This article is based on the results of a careful survey of studies published to date identified by searching the following databases: Medical Literature Analysis and Retrieval System Online (MEDLINE) (accessed via PubMed), Scopus, Web of Science and Cochrane collaboration. The criteria for inclusion of studies identified by the searches were: cross-sectional studies that assessed the effects of postprandial lipemia in combination with the acute/subacute effects of physical exercise on oxidative stress and endothelial function parameters. Studies were excluded if they did not report the outcome at baseline or if data were incomplete. The searches were limited to studies published up to February 2015 in Portuguese, Spanish or English.

The following keywords in English were used to search the databases: postprandial lipemia ("Lipidemia" OR "Lipidemias" OR "Lipemia" OR "Lipemias" OR "Postprandial Lipemia" OR "PostprandialLipaemia"); physical exercise ("Exercise" [MeSH] OR "Exercises" OR "Exercise, Physical" OR "Exercises, Physical" OR "Physical Exercise" OR "PhysicalExercises" OR "Exercise, Isometric" OR "Exercises, Isometric" OR "IsometricExercises" OR "Isometric Exercise" OR "Exercise, Aerobic" OR "AerobicExercises" OR "Exercises, Aerobic" OR "Aerobic Exercise"); oxidative stress ("Oxidative stress" [MeSH]); and endothelial function ("Endothelium, Vascular" [MeSH] OR "Vascular Endothelium" OR "Endotheliums, Vascular" OR

"Vascular Endotheliums" OR "CapillaryEndothelium" OR "CapillaryEndotheliums" OR "Endothelium, Capillary" OR "Endotheliums, Capillary" OR "vascular function" OR "endothelialfunction" OR "endothelialdysfunction" OR "endotheliumdysfunction" OR "endotheliumfunction" OR "pulse wavevelocity" OR "flow-mediateddilation" OR "Arterial stiffness").

Two electronic searches were run on the databases listed above with the keywords "Postprandial lipemia" and "Physical exercise". In the first search the descriptor "Endothelial Function" was added and 226 articles were identified. Eight of these studies were selected for the review. In the second search the term "Oxidative Stress" was employed and 28 articles were located, five of which were selected. Figure 1 contains an organogram illustrating the complete manual electronic search process. The studies selected as a result are listed in Table 1.

Table 1. List of studies analyzing markers of oxidative stress and endothelial function selected for review.

Study	Population	Exercise protocol*	Postprandial lipemia	Oxidative stress	Endothelial function
Gill et al.[15]	Middle-aged, lean men (10); Middle-aged, obese men (10)	Subacute on treadmill at 50%; VO_{2max} - 90min	↓**TG** exercise vs. control ↓**TG AUC** exercise Obese subjects: ↑**TG** AUC ↑**INS** AUC ↑**NEFA** AUC	NA	**microvascular function** = in both groups; **ACh Response** 25% ↑ in exercise group
Mc Clean et al.[23]	Trained men (10)	Acute on treadmill at 60% of HR_{max} - 1h	↑**TG** 2 h, 3 h and 4 h ↓**TG** 3 h and 4 h vs. 2 h in exercise group ↓**HDL** 3 h and 4 h in controls ↑**HDL** 3 h in exercise group = **LDL**	↑**NOx** - 4h ↓**SOD** 2 h and 3 h ↓**SOD** 3 h control vs. exercise ↑**LOOH** 2 h, 3 h and 4 h ↓**LOOH** 3 h exercise vs. control	↑**PWV** 1 h, 2 h, 3 h and 4 h ↓**PWV** 3 h and 4 h vs. 2 h in exercise group
Clegg et al.[24]	Trained young men (8)	Acute on cycle ergometer at 60% of HR_{max} - 1h	= **TG** = **HDL** = **LDL**	↑**LOOH** 2 h and 4 h vs. pre	↑**PWV** 2 h and 4 h in controls ↓**PWV** 2 h and 4 h exercise vs. 2 h for controls
Silvestre et al.[25]	Trained young men (12)	Subacute resistance and aerobic exercise for 75 min up to 450 Kcal Acute resistance and aerobic exercise for 75 min up to 450 Kcal	↓**TG** 2 h, 3 h and 4 h exercise vs. control ↓**TG AUC** exercise vs. control ↑**NEFA AUC** exercise vs. control ↓**INS AUC** subacute exercise vs. control	NA	↑**Dilation** 6 h in subacute (2.2%) and acute (2.8%) exercise groups ↑ **BAD** progressive in exercise vs. controls
Bloomer et al.[26]	African-American women (10) White women (10)	Acute on cycle ergometer at 65% HR_{max} - 45 min	↑**TG** African-American vs. white	↑**MDA** African-American vs. white ↑H_2O_2 African-American vs. white = **XO**	NA
Tyldum et al.[22]	Middle-aged men (8)	Subacute interval exercise on treadmill at 85%-90% HR_{max} Subacute on treadmill at 60%-70% HR_{max} - 47min until same energy expenditure	= **TG** = **HDL**	↓**TAS** 2 h and 4 h in controls ↑**TAS** 30 min, 2 h and 4 h in interval exercise group ↑**TAS** 30 min, 2 h and 4 h interval vs. control and walking ↑**TAS** 30 min, 2 h and 4 h walking vs. control	↑ **BAD** 30 min, 2 h and 4 h interval exercise group vs. controls and walking ↓**FMD** 2 h and 4 h in controls ↑**FMD** 30 min, 2 h and 4 h in interval group ↑**FMD** 30 min, 2 h and 4 h walking vs. control

*In all studies there was an additional protocol used as control in which subjects did not do any physical exercise, remaining at rest. **Key:** NA: not analyzed; HR_{max}: maximum heart rate; VO_{2max}: maximum oxygen uptake; Rec: recovery; BM: body mass; TG: triglycerides; INS: insulin; NEFA: nonesterified fatty acids; AUC: area under the curve; ACh: acetylcholine; BAD: brachial artery diameter; FMD: flow-mediated dilation; HDL: high density lipoprotein; LDL: low density lipoprotein; VLDL: very low density lipoprotein; NOx: nitrite/nitrate levels; SOD: superoxide dismutase; CAT: catalase; LOOH: lipid hydroperoxides; PWV: pulse wave velocity; TAS: total antioxidant status; ROS: reactive oxygen species; LDL-Ox: oxidized LDL; MDA: malondialdehyde; XO: xanthine oxidase; H_2O_2: hydrolipid peroxides; TBARS: thiobarbituric acid reactive substances; SR: shear rate; IL-6: interleukin 6; TNFα: tumor necrosis factor alpha; CRP: C-reactive protein.

Table 1. Continued...

Study	Population	Exercise protocol*	Postprandial lipemia	Oxidative stress	Endothelial function
Melton[27]	Prediabetic women (16)	Acute at 65% of $HR_{reserve}$ – 45 min	↑**TG** 1 h-6 h	↓**TROLOX** 4 h ↑**H_2O_2** 1 h-6 h ↑**XO** 1 h-6 h ↑**MDA** 1 h-6 h	NA
Jenkins et al.[21]	Trained young men (10)	Subacute on cycle ergometer at 70% VO_{2max}	↑**TG** 3 h and 4 h in controls ↓**TG** 1 h and 3 h exercise group vs. controls ↓**TG AUC** exercise vs. control	↑**ROS** ($CD31^+/CD14^-/CD34^-$) 4 h in controls ↑**LDL-Ox** 4 h in controls = **NO** ($CD31^+/CD14^-/CD34^-$)	NA
Gabriel et al.[20]	Active young men (9)	Subacute on treadmill at 7 km/h - 30min Subacute interval exercise on cycle ergometer at 7.5% of the BM – 30 s x 4 min Rec	= **TG** = **INS** ↓ **TG AUC** interval exercise group vs. controls	↑ **Carbonyls** 2 h and 5 h in controls and walking ↑**TBARS** 2 h and 5 h ↓**TBARS** 2 h and 5 h interval exercise group vs. walking and control	NA
Sedgwick et al.[28]	Adolescent boys (13)	Subacute interval exercise on treadmill at 60% VO_{2max} – 4 x 60 min	↑**TG** 1 h, 2 h, 4 h, 4h30 and 6h30 ↓**TG AUC** exercise group vs. controls = **NS**	NA	↓**FMD** 32% after breakfast and 24% after lunch in controls ↓**FMD** 6% after breakfast and 10% after lunch in exercise group
Canale et al.[29]	Trained young men (12)	Acute on cycle ergometer at 70% FC_{max} - 60min Acute interval exercise on cycle ergometer at 100% W_{max} - 60 s x 225 s Rec Acute interval exercise on cycle ergometer 200% W_{max} – 15 s x 116 s Rec	↑**TG** 2 h and 4 h	↑**MDA** 2h and 4h ↑**H_2O_2** 2h and 4h = **GPx** ↓**CAT** 2 h and 4 h ↓**SOD** 2 h and 4 h ↑**TAS** interval exercise 15 s vs. controls and 60 min aerobic	NA
Sedgwick et al.[30]	Active adolescents (14)	Subacute interval exercise on treadmill at 70% VO_{2max} - 6 x 10 min	↑**TG** 1 h, 3 h, 4 h, 4h30 and 6h30 ↓**TG AUC** exercise group vs. controls = **INS**	NA	↓**FMD** 3 h and 6h30 controls vs. exercise ↑ **BAD** 3 h and 6h30 ↑**SR** 6h30
Augustine et al.[31]	Active young men (10)	Acute resistance training	↑ **TG** after meal, controls vs. exercise group **= HDL**	NA	↓ **PWV** after exercise vs. before exercise ↑ **PWV** after meal vs. before meal in controls

*In all studies there was an additional protocol used as control in which subjects did not do any physical exercise, remaining at rest. **Key:** NA: not analyzed; HR_{max}: maximum heart rate; VO_{2max}: maximum oxygen uptake; Rec: recovery; BM: body mass; TG: triglycerides; INS: insulin; NEFA: nonesterified fatty acids; AUC: area under the curve; ACh: acetylcholine; BAD: brachial artery diameter; FMD: flow-mediated dilation; HDL: high density lipoprotein; LDL: low density lipoprotein; VLDL: very low density lipoprotein; NOx: nitrite/nitrate levels; SOD: superoxide dismutase; CAT: catalase; LOOH: lipid hydroperoxides; PWV: pulse wave velocity; TAS: total antioxidant status; ROS: reactive oxygen species; LDL-Ox: oxidized LDL; MDA: malondialdehyde; XO: xanthine oxidase; H_2O_2: hydrolipid peroxides; TBARS: thiobarbituric acid reactive substances; SR: shear rate; IL-6: interleukin 6; TNFα: tumor necrosis factor alpha; CRP: C-reactive protein.

POSTPRANDIAL LIPEMIA

Since Zilversmit[5] proposed that atherogenesis is a postprandial phenomenon, it has been known that triglyceride-rich lipoproteins (TRLs) originating in the diet can accumulate in the vascular endothelium, triggering an atherosclerotic process and increasing the likelihood of cardiovascular events.[5] Plasma concentrations of lipids and TRLs are generally measured with the subject in a postprandial state because we eat meals regularly and continuously

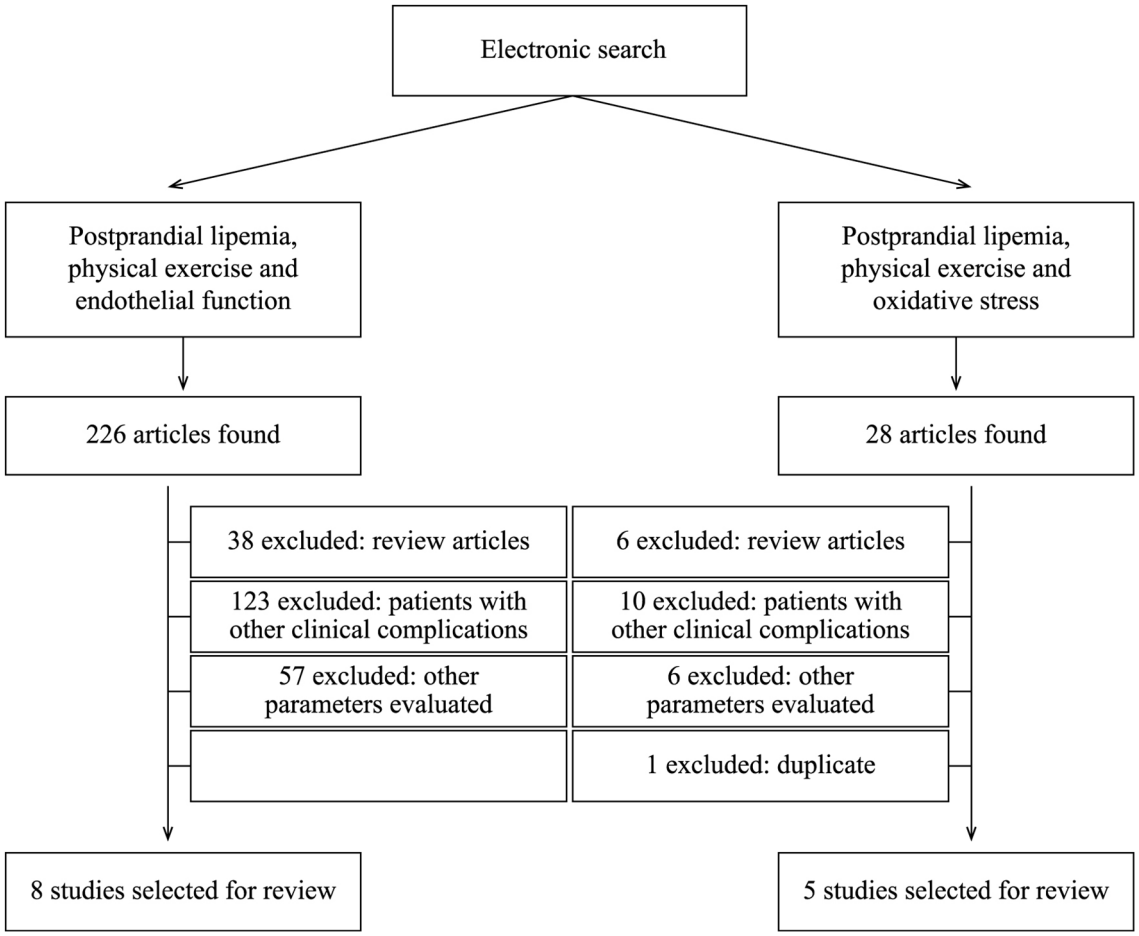

Figure 1. Organogram illustrating manual electronic search.

and spend most of the time in a fed state.[32] After a meal that is rich in lipids, the TG supplied by the diet are hydrolyzed by LLP in the intestine into free fatty acids (FFA) and glycerol, which are absorbed by enterocytes and transported to the endoplasmic reticulum to be once more resynthesized into TG. These TG are enveloped by apolipoprotein (apo) B-48 in a large chylomicron particle, which is secreted into circulation via lymphocytes. Chylomicrons are responsible for exogenous transport of the lipids from the intestine. After lipolysis by LLP, they form TRL remnant particles.[32,33]

The major classes of TRLs include: chylomicrons derived from the intestine, which transport cholesterol; very low density lipoproteins (VLDL), basically synthesized in the liver to export TG to the tissues; low density lipoproteins (LDL), capable of transporting cholesterol from the liver to the cells of the various other tissues; and high-density lipoproteins (HDL), which basically arise in the liver and intestine.[34] Since LDL is the major transporter of plasma cholesterol, this lipoprotein appears to be the most strongly linked to the atherosclerosis process.

After consumption of an HFM, there is an increase in the quantity of circulating cholesterol particles, primarily LDL.[32,33] When these particles of LDL suffer oxidative modification caused by reactive oxygen species (ROS), they migrate to the subendothelial space and cause formation of foam cells in the tunica intima.[35] As part of the inflammatory response, LDL (ox-LDL) causes activation of monocytes by chemotaxis, which are transformed into macrophages in the subendothelial space. Oxidized LDL has a great affinity for the macrophage scavenger receptor. As macrophages continue to phagocytose and process the lipids, plaques composed primarily of lipids and fibrous tissue begin to form atheromas. These can obstruct the arterial lumen and reduce its elasticity, affecting endothelial function.[36-38]

ENDOTHELIAL FUNCTION

The endothelium is an extremely important vascular structure because of its position between the blood circulation and the vascular smooth muscle. The endothelium is also the source of a wide variety of vasoactive agents that control vascular tone, growth factors, platelet function and coagulation.[39,40] These vasoactive substances can be divided into two classes: endothelium-derived relaxing factors (EDRF) and endothelium-derived contracting factors (EDCF). Among the EDRFs, nitric oxide (NO) performs an important protective function against the atherosclerotic process, maintaining the blood vessel in a constant state of vasodilation.[41]

Nitric oxide is produced from L-arginine by a reaction that is catalyzed by the endothelium-derived nitric oxide synthase isoform (eNOS), mediated by Ca^{2+}/calmodulin (CaM),[42] and dependent on other factors such as tetrahydrobiopterin (BH_4). Vascular NO production can be stimulated by a variety of agonist receptors, and also by shear forces caused by blood flow, insulin and acetylcholine (ACh). The first two work via calcium-independent signaling that is in part mediated by phosphoinositide 3-kinase (PI-3 Kinase), whereas ACh works via a calcium-dependent pathway[7] (Figure 2).

Nitric oxide causes dilation in all types of blood vessel by means of activation of the protein soluble guanylate cyclase, which triggers conversion of guanosine triphosphate (GTP) into cyclic guanosine monophosphate (GMPc) in smooth muscle cells. This causes relaxation of the vascular smooth muscle and concomitant vasodilation, the principal marker of endothelial function.[43] At the same time, changes in endothelial function may be precursors of vascular diseases such as atherosclerosis. The erm "endothelial dysfunction" refers to both an imbalance between the vasoactive agents that act to control vascular tone (EDRFs and EDCFs) and to platelet aggregation, coagulation and fibrinolysis, but vascular tone is the element that has been most studied. These factors lead to a worsening of dependent relaxation of the endothelium, caused, among other aspects, by reduced bioavailability of NO. Diseases such as arterial hypertension, diabetes mellitus and hypercholesterolemia can damage the endothelium, causing endothelial dysfunction that in a

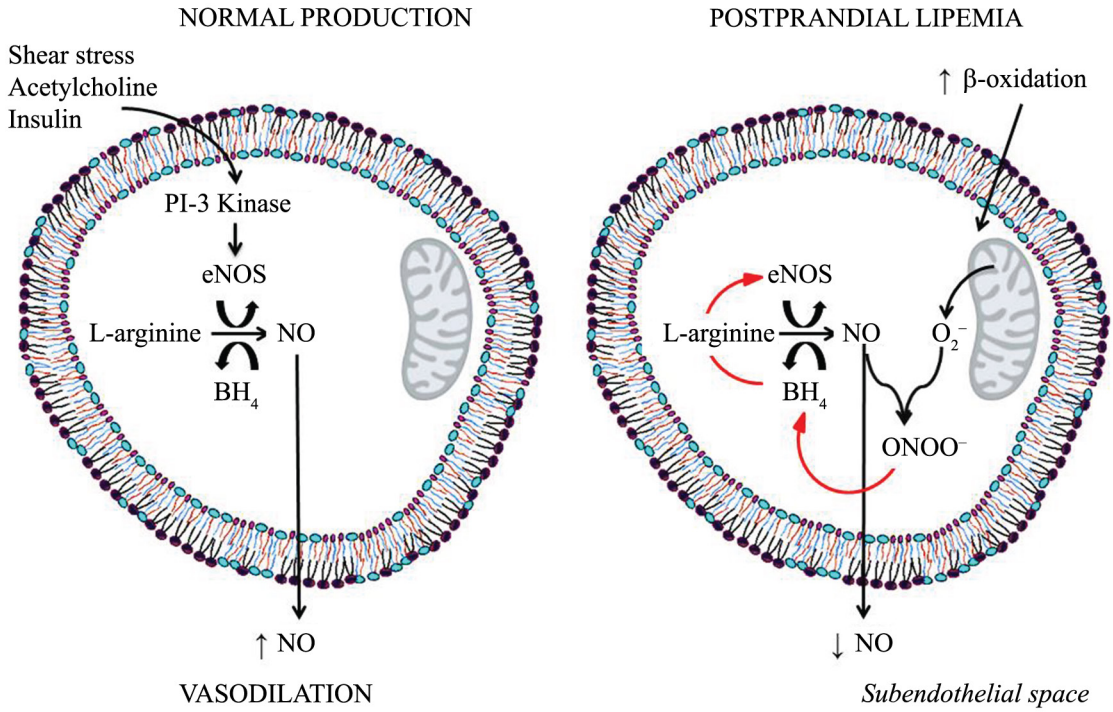

Figure 2. Normal nitric oxide production (NO) inside the vascular endothelial cell and in the postprandial lipemic state. The NO is produced from L-arginine in a reaction catalyzed by the endothelium-derived nitric oxide synthase isoform (eNOS) and is dependent on other factors, such as tetrahydrobiopterin (BH_4). Vascular NO production can be stimulated by shear forces caused by blood flow, insulin and acetylcholine (ACh). Nitric oxide maintains the blood vessel in a constant state of vasodilation. When there is an increase in postprandial lipemia, accumulated superoxide radicals (O_2^-) produced by lipid oxidation (β-oxidation) interact with NO, forming peroxynitrite ($ONOO^-$), and affecting vascular tone.

large proportion of cases is related to atherosclerosis and cardiovascular events.[44]

In view of this, diagnostic methods that are capable of detecting changes in vascular configuration should prove beneficial for identification of possible endothelial dysfunctions.[45]

FREE RADICALS, OXIDATIVE STRESS AND ANTIOXIDANT SYSTEM

Free radicals are atoms or molecules that have one or more unpaired electrons in their valency layers, giving them a strong tendency to oxidize other molecules. Excessive production of these molecules is associated with development of a variety of diseases: cancer, atherosclerosis and cerebral vascular accident (stroke), among others.[46] Notwithstanding, it should also be pointed out that physiological levels of free radicals are important for important body functions to function correctly.[47]

The oxygen molecule (O_2) is one of the best known radicals found in our bodies, because in its stable form it has two unpaired electrons in antibonding orbitals, making it a potent agent of oxidation. Formation of O_2 free radicals in our bodies is strongly associated with oxidative processes that take place at the terminal part of the electron transport chain. As part of this process, around 95%-99% of the O_2 consumed is reduced to water through a tetravalent reaction catalyzed by the oxidase cytochrome.[48]

The remaining 1%-5% of O_2 are reduced in a univalent form to metabolites known as reactive oxygen species (ROS).[49] The O_2 molecule has a strong tendency to accept only one electron at a time because of its electronic configuration, forming the radical superoxide ($O_2^{\bullet-}$). If this then bonds with one electron and two hydrogen ions, hydrogen peroxide (H_2O_2) is formed. In turn, if H_2O_2 receives one more electron and one hydrogen ion, it forms the hydroxyl radical ($OH^{\bullet}$), which is the most reactive of the intermediate radicals.[50] Furthermore, ROS such as $O_2^{\bullet-}$ can react with NO to form peroxynitrite ($ONOO^-$), contributing to reduce the availability of this potent EDRF. In turn, $ONOO^-$ is a powerful oxidative agent that can also cause formation of an oxidant acid with the characteristics of the hydroxyl radical.[51]

When there is an imbalance between the oxidative agents and the antioxidant system, the result is oxidative stress, which is a condition characterized by an imbalance in favor of a prooxidant state, resulting in damage to membrane proteins and lipids, damage to DNA structure and a cascade of many different inflammatory signals.[52]

Reactions between radicals are generally chain termination reactions, resulting in formation of non-radical stable products. The most important free radical chain reaction that occurs in biological systems is oxidation of lipids, i.e. lipid peroxidation.[53]

When a polyunsaturated lipid reacts with a ROS or with nitrogen, lipid peroxidation is triggered. This reaction can lead to changes in the configuration of the cell membrane. One of these relatively stable subproducts is malondialdehyde (MDA).[54] As a result, MDA is one of the most often used markers of lipid peroxidation, in the thiobarbituric acid reactive substances assay (TBARS). Oxidation of proteins and/or amino acids by ROS is accompanied by an increase in the levels of carbonyls and oxidized amino acids, which are used as indicators in determination of protein damage.[47] Antioxidants are substances that reduce, retard or prevent the harmful effects of radicals and ROS. The antioxidant defense system is divided into enzymatic and non-enzymatic components. Enzymatic antioxidants include superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx). Non-enzymatic antioxidants are primarily supplied by the diet and include vitamins A, C and E, the thiols and others. Measurement of total antioxidant capacity (TAS) has been used with the aim of providing a global analysis of the quantity of the many different non-enzymatic antioxidant markers.[47,54,55]

POSTPRANDIAL LIPEMIA, OXIDATIVE STRESS AND ENDOTHELIAL FUNCTION

After a high fat meal is eaten, there is an increase in the influx of AGL to muscle, adipose and hepatic tissues, and also in endothelial cells. This increases β-oxidation and, as a consequence, increases oxidative processes that take place at the termination of the electron transport chain. The greater part of the O_2 that is consumed is reduced to water through a tetravalent reaction catalyzed by the oxidase cytochrome, although the increase in β-oxidation creates an overproduction of electron donors, overloading the transport chain. As a result, there is an accumulation of electrons, and the remaining O_2 is reduced univalently to metabolites called ROS.[49,56]

Morel et al.[35] suggested that ROS play an important role in development of atherosclerosis by increasing oxidation of LDL.[57] An LDL is an oily droplet that contains a hydrophobic core of cholesterol esters and a single layer of phospholipids and free cholesterol that covers around 70% of its surface. The remaining 30% of its surface is covered by a single large apolipoprotein (apo) B-100 which stabilizes the particle in the aqueous

phase of the blood.[58] Cellular absorption of LDL is mediated by classical B/E receptors or by scavenger receptors. The specific interactions between apoB-100 and cellular receptors are the primary focus of interest because this recognition mechanism is intimately involved in the emergence and progression of many diseases, such as hypercholesterolemia, hyperlipidemia and atherosclerosis.[59]

In the initial phase of LDL modification, the lipid components react with oxidative agents, resulting in a chain reaction that produces several types of oxidative products of lipids. These products then react directly with apoB, resulting in changes to the amino acid chains and cleavage of peptide bonds. Minimally modified LDL (MM- LDL) can contain lipid oxidation products without protein modification because it has a greater affinity with the LDL receptor than with the scavenger receptor. Modification of the apoB protein continues until it loses its affinity for the LDL receptor, when it is recognized by macrophage scavenger receptors.[60] In inflammatory response, oxidized LDL (ox-LDL) leads to activation of monocytes by chemotaxis, which are transformed into macrophages in the subendothelial space. As the macrophages begin to phagocytose the lipids, foam cells derived from the macrophages are formed, which contain lipids that are primarily in the form of free cholesterol. Formation of these cells can obstruct the arterial lumen and reduce its elastic potential. After rupture of the plaque, ox-LDLs are rapidly released from the lesion into circulation, provoking a temporary increase in the levels of ox-LDL in circulation[36,37,60] (Figure 3).

Additionally, after consumption of an HFM, the vascular endothelium can be damaged directly by the oxidative stress generated by the reduced bioavailability of NO (Figure 2). Accumulated superoxide radicals, originating from the lipid oxidation, interact with NO, forming peroxynitrite, further contributing to reducing the levels of this EDRF and, consequently, affecting vascular tone.[42,51]

EFFECTS OF PHYSICAL EXERCISE ASSOCIATED WITH POSTPRANDIAL LIPEMIA ON OXIDATIVE STRESS

It is known that excessive consumption of glucose and AGL can overload the Krebs cycle, leading to excessive $O_2^{\bullet-}$ production in the electron transport chain and, consequently, causing an increase in the damage related to oxidative stress.[61] Postprandial hypertriglyceridemia stimulates production of O_2 by

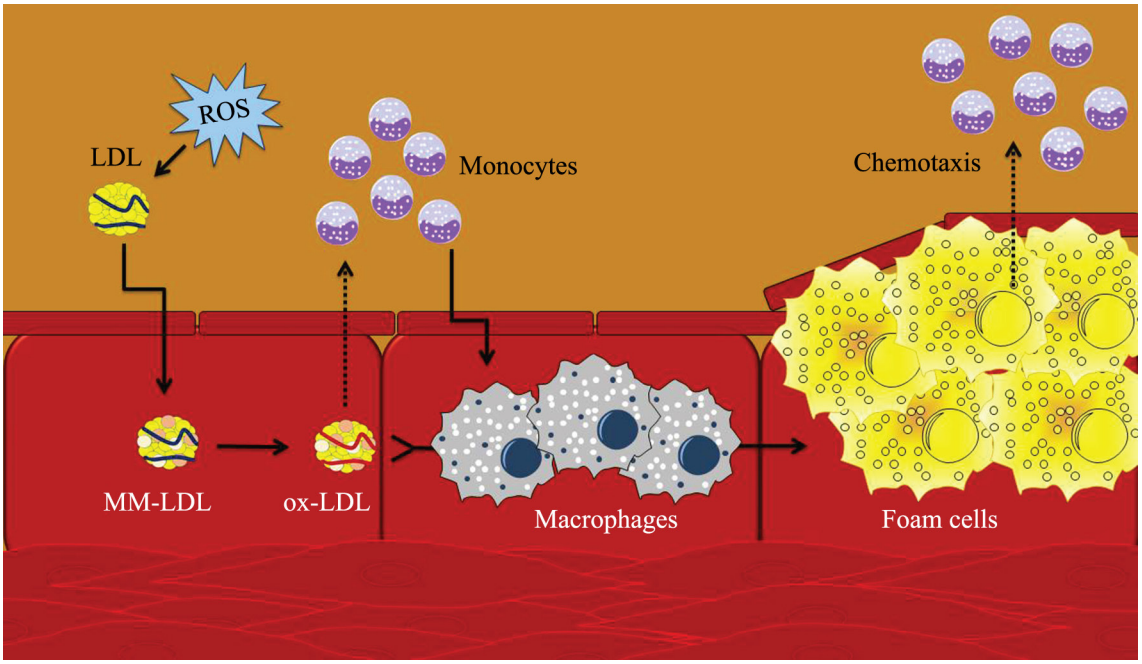

Figure 3. Process of atherosclerotic plaque formation. Low density lipoprotein undergoes gradual oxidation until formation of minimally modified LDL (MM-LDL), which can contain products of lipid oxidation without protein modification. The LDL will only become oxidized LDL (ox-LDL) when the apoB protein has been modified and it loses the affinity for its receptor, when it is recognized by macrophage scavenger receptors. In inflammatory response, ox-LDL leads to activation of monocytes, which are transformed into macrophages in the subendothelial space. As the macrophages begin to phagocytose the lipids, foam cells are formed, derived from the macrophages, which contain lipids that are primarily in the form of free cholesterol.

leukocytes, possibly through increased production of inflammatory markers such as interleukin-6 and interleukin-8.[23,62] Indeed, increased ROS production caused by catabolism of macronutrients is known as postprandial oxidative stress.[63] It is from this perspective that the possible acute and subacute effects of a physical exercise session in attenuating postprandial oxidative stress have been investigated (Figure 4).

In one study involving men who trained recreationally, 60 minutes' walking at an intensity of 60% of maximum heart rate (HR_{max}) hours before an HFM did not prevent oxidative stress associated with hypertriglyceridemia, when compared with control conditions.[24] Additionally, physical exercise did not prevent oxidative stress associated with postprandial hypertriglyceridemia in prediabetic women.[27] In contrast, an investigation following a very similar study protocol and using the same population showed that physical exercise did result in increased SOD activity 3 hours after the HFM and in lower levels of lipoperoxidation, at the same point in time, when compared with the control conditions.[23] The authors linked this result to

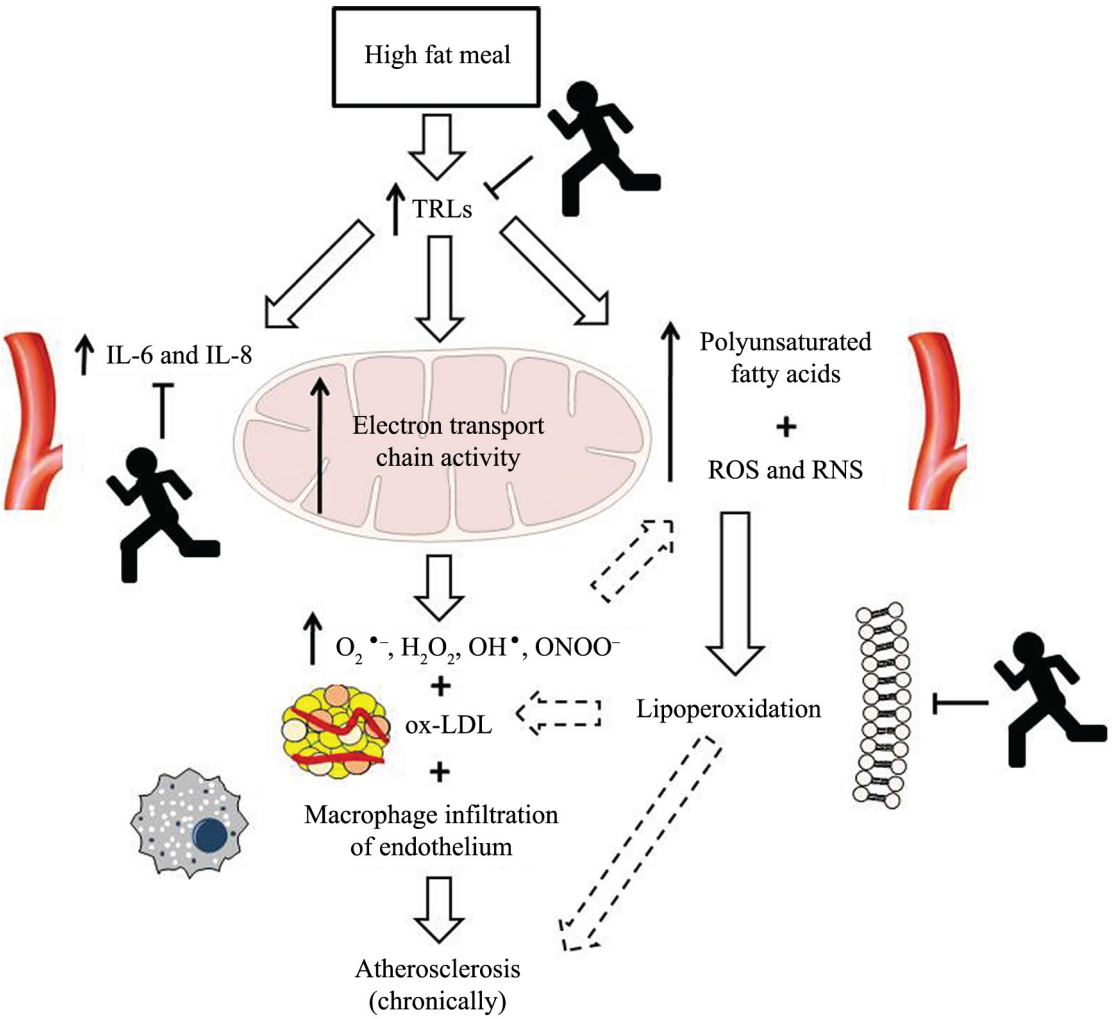

Figure 4. Possible benefits of exercise on postprandial oxidative stress. After eating a high fat meal, there is a rise in the levels of triglyceride-rich lipoproteins (TRLs), which stimulate production of cytokines (IL-6 and IL-8) by leukocytes and increase Krebs cycle and electron transport chain activity. In turn, polyunsaturated fatty acids supplied by the meal can react with reactive oxygen species (ROS) and reactive nitrogen species produced previously, such as superoxide ($O_2^{\bullet-}$), hydrogen peroxide (H_2O_2), hydroxyl radical ($OH^{\bullet}$) and peroxynitrite ($ONOO^-$). These ROS oxidize LDL (to ox-LDL) which, in turn, is phagocytosed by macrophages, triggering a long-term atherosclerotic process. Physical exercise can reduce the levels of TRLs and cytokines and can also prevent lipoperoxidation damage.

the higher rate of TG removal and the greater SOD activity provoked by exercise.[23,64]

Working from the assumption that physical exercise sessions have the capacity to acutely stimulate antioxidant defense,[29,65] interventions have investigated whether the effect is sustained after an HFM. It was demonstrated that a single session of physical exercise the previous day is capable of increasing TAS hours after an HFM.[22] Recently, a study compared the effects of a traditional aerobic exercise session and two sessions of high intensity interval exercise, hours before an HFM. It was observed that neither of these conditions was capable of altering serum/plasma activity of antioxidant enzymes or of reducing lipid and/or protein oxidation levels in well-trained men.[29] Among other speculations, the authors attributed these results to the absence of exercise-provoked modifications to postprandial TG removal.[29]

Notwithstanding, a moderate session of aerobic exercise the day before eating a high fat meal did prevent an increase in ROS levels in cells related to endothelial function.[21] However, the protective effects of prior physical exercise on postprandial ROS production in angiogenic cells appears to be mitochondria-dependent.[21] In consonance with this, a session of high intensity exercise the day before a high fat meal resulted in a reduction in TBARS and carbonyl levels, compared with a traditional walking exercise.[20] In contrast, a 45-minute session on a cycle ergometer did not attenuate postprandial oxidative stress in women.[26]

It should be pointed out that those studies that failed to detect significant differences between exercise and control protocols in terms of the parameters of oxidative stress during the postprandial period also failed to detect differences in PPL, demonstrating that the exercise was not effective at reducing the lipemic curve.[24,26,27] The variables representing oxidative stress that were analyzed in these studies are markers of lipid peroxidation, which are intimately related with high plasma TG levels. As such, it appears that in this case the effects of the markers of oxidative stress respond in a secondary manner that is similar to the behavior of PPL.[26]

In summary, the acute and subacute effects of a session of physical exercise on parameters of the oxidative stress associated with an HFM vary according to the type, duration and intensity of the exercise session and according to the time elapsed before the HFM, the markers chosen for analysis, the composition of the meal and the study population.

EFFECTS ON ENDOTHELIAL FUNCTION OF PHYSICAL EXERCISE ASSOCIATED WITH POSTPRANDIAL LIPEMIA

Eating an HFM can induce damage to endothelial function because of the increased production of ROS in the postprandial period.[66] The scientific literature has demonstrated that a single session of physical exercise is enough to attenuate the harmful effects of an HFM on the vascular endothelium.[23] Over the years, many studies have investigated the acute or subacute efficacy of a session of aerobic exercise or resistance training with relation to variables of endothelial function.

In general, all of the studies detected a significant difference between the control and physical exercise protocols, irrespective of the type of physical exercise, aerobic or resistance, or of the time of day at which the session occurred. However, the methodologies for assessment of endothelial function are still highly varied, and there is no consensus in the literature on the most appropriate for measuring vasodilation derived from the endothelium. The most widely used techniques include flow-mediated dilation (FMD) and/or brachial artery dilation (BAD)[22,28,30,66] and pulse wave velocity (PWV),[23,24,31] and it is also possible to assess Acetylcholine Response.[15]

After eating an HFM, the values of FMD and PWV tend to drop significantly from 2 h to 4 h postprandially,[22-24] and a reduction in endothelial function can be detected up to 6h30[30] afterwards. Both interval exercise at 85%-90% and continuous exercise at 60% of maximum oxygen uptake (VO_{2max}) have been shown to be effective at attenuating these figures, even when the session is conducted the previous day, which indicates that physical exercise has a prolonged and late effect as a cardioprotective agent.[15,22-24,30] Resistance training exhibits the same behavior in relation to attenuation of endothelial dysfunction.[25,31]

Therefore, in contrast with the effects of physical exercise on the parameters of oxidative stress associated with eating an HFM, attenuation of endothelial dysfunction appears to be more strongly linked to performing physical exercise than to the type, duration or intensity of exercise session, or other factors, such as study population.

CONCLUSIONS

This review of the literature allows for the conclusion that the acute and subacute effects of physical exercise are capable of attenuating the parameters of risk of CVD development after consumption of an HFM.

The markers of oxidative stress appear to vary according to the type, duration and intensity of the exercise session and the time elapsed before the HFM, the markers chosen for analysis, the composition of the meal and the study population. In contrast, attenuation of endothelial dysfunction after a session of physical exercise takes place irrespective of these variables.

REFERENCES

1. Otani H. Oxidative stress as pathogenesis of cardiovascular risk associated with metabolic syndrome. Antioxid Redox Signal. 2011;15(7):1911-26. http://dx.doi.org/10.1089/ars.2010.3739. PMid:21126197.
2. Gorter PM, Olijhoek JK, van der Graaf Y, Algra A, Rabelink TJ, Visseren FL. Prevalence of the metabolic syndrome in patients with coronary heart disease, cerebrovascular disease, peripheral arterial disease or abdominal aortic aneurysm. Atherosclerosis. 2004;173(2):363-9. http://dx.doi.org/10.1016/j.atherosclerosis.2003.12.033. PMid:15064114.
3. World Health Organization – WHO. *Global Atlas of cardiovascular disease prevention and control*. Gevena. 2011.
4. World Health Organization – WHO. *The top 10 causes of death*. Gevena; 2011.
5. Zilversmit DB. Atherogenesis: a postprandial phenomenon. Circulation. 1979;60(3):473-85. http://dx.doi.org/10.1161/01.CIR.60.3.473. PMid:222498.
6. Tushuizen ME, Nieuwland R, Scheffer PG, Sturk A, Heine RJ, Diamant M. Two consecutive high-fat meals affect endothelial-dependent vasodilation, oxidative stress and cellular microparticles in healthy men. J Thromb Haemost. 2006;4(5):1003-10. PMid:16689751.
7. Wallace JP, Johnson B, Padilla J, Mather K. Postprandial lipaemia, oxidative stress and endothelial function: a review. Int J Clin Pract. 2010;64(3):389-403. http://dx.doi.org/10.1111/j.1742-1241.2009.02146.x. PMid:20456177.
8. Ursini F, Sevanian A. Postprandial oxidative stress. Biol Chem. 2002;383(3-4):599-605. http://dx.doi.org/10.1515/BC.2002.062. PMid:12033449.
9. Correa CS, Teixeira BC, Bittencourt A, Macedo RCO, Reischak-Oliveira A. Postprandial lipemia and cardiovascular diseases: the beneficial role of strength exercise. J Vasc Bras. 2014;13(2):123-30. http://dx.doi.org/10.1590/jvb.2014.057.
10. Barbosa JPAS, Henriques PM, Barros MVG, Wolosker N, Ritti-Dias RM. Physical activity level in individuals with peripheral arterial disease: a systematic review. J Vasc Bras. 2011;11(1)
11. Gill JM, Hardman AE. Postprandial lipemia: effects of exercise and restriction of energy intake compared. Am J Clin Nutr. 2000;71(2):465-71. PMid:10648259.
12. Cox-York KA, Sharp TA, Stotz SA, Bessesen DH, Pagliassotti MJ, Horton TJ. The effects of sex, metabolic syndrome and exercise on postprandial lipemia. Metabolism. 2013;62(2):244-54. http://dx.doi.org/10.1016/j.metabol.2012.08.003. PMid:22974968.
13. Cohn JS. Postprandial lipemia: emerging evidence for atherogenicity of remnant lipoproteins. Can J Cardiol. 1998;14(Supl B):18B-27B. PMid:9627538.
14. Anderson RA, Evans LM, Ellis GR, et al. Prolonged deterioration of endothelial dysfunction in response to postprandial lipaemia is attenuated by vitamin C in Type 2 diabetes. Diabet Med. 2006;23(3):258-64. http://dx.doi.org/10.1111/j.1464-5491.2005.01767.x. PMid:16492208.
15. Gill JM, Al-Mamari A, Ferrell WR, et al. Effects of prior moderate exercise on postprandial metabolism and vascular function in lean and centrally obese men. J Am Coll Cardiol. 2004;44(12):2375-82. http://dx.doi.org/10.1016/j.jacc.2004.09.035. PMid:15607401.
16. Maraki MI, Sidossis LS. The latest on the effect of prior exercise on postprandial lipaemia. Sports Med. 2013;43(6):463-81. http://dx.doi.org/10.1007/s40279-013-0046-9. PMid:23580393.
17. Petitt DS, Cureton KJ. Effects of prior exercise on postprandial lipemia: a quantitative review. Metabolism. 2003;52(4):418-24. http://dx.doi.org/10.1053/meta.2003.50071. PMid:12701052.
18. Hurren NM, Eves FF, Blannin AK. Is the effect of prior exercise on postprandial lipaemia the same for a moderate-fat meal as it is for a high-fat meal? Br J Nutr. 2011;105(4):506-16. http://dx.doi.org/10.1017/S0007114510003995. PMid:21073762.
19. Bae JH, Bassenge E, Kim KB, et al. Postprandial hypertriglyceridemia impairs endothelial function by enhanced oxidant stress. Atherosclerosis. 2001;155(2):517-23. http://dx.doi.org/10.1016/S0021-9150(00)00601-8. PMid:11254924.
20. Gabriel B, Ratkevicius A, Gray P, Frenneaux MP, Gray SR. High-intensity exercise attenuates postprandial lipaemia and markers of oxidative stress. Clin Sci 2012;123(5):313-21. http://dx.doi.org/10.1042/CS20110600. PMid:22435779.
21. Jenkins NT, Landers RQ, Thakkar SR, et al. Prior endurance exercise prevents postprandial lipaemia-induced increases in reactive oxygen species in circulating CD31+ cells. J Physiol. 2011;589(22):5539-53. http://dx.doi.org/10.1113/jphysiol.2011.215277. PMid:21930598.
22. Tyldum GA, Schjerve IE, Tjonna AE, et al. Endothelial dysfunction induced by post-prandial lipemia: complete protection afforded by high-intensity aerobic interval exercise. J Am Coll Cardiol. 2009;53(2):200-6. http://dx.doi.org/10.1016/j.jacc.2008.09.033. PMid:19130989.
23. Mc Clean CM, Mc Laughlin J, Burke G, et al. The effect of acute aerobic exercise on pulse wave velocity and oxidative stress following postprandial hypertriglyceridemia in healthy men. Eur J Appl Physiol. 2007;100(2):225-34. http://dx.doi.org/10.1007/s00421-007-0422-y. PMid:17323071.
24. Clegg M, McClean C, Davison WG, et al. Exercise and postprandial lipaemia: effects on peripheral vascular function, oxidative stress and gastrointestinal transit. Lipids Health Dis. 2007;6(1):30. http://dx.doi.org/10.1186/1476-511X-6-30. PMid:17973988.
25. Silvestre R, Kraemer WJ, Quann EE, et al. Effects of exercise at different times on postprandial lipemia and endothelial function. Med Sci Sports Med. 2008;40(2):264-74. PMid:18202576.
26. Bloomer RJ, Cole B, Fisher-Wellman KH. Racial differences in postprandial oxidative stress with and without acute exercise. Int J Sport Nutr Exerc Metab. 2009;19(5):457-72. PMid:19910649.
27. Melton CE, Tucker PS, Fisher-Wellman KH, Schilling BK, Bloomer RJ. Acute exercise does not attenuate postprandial oxidative stress in prediabetic women. Phys Sportsmed. 2009;37(1):27-36. http://dx.doi.org/10.3810/PSM.2009.04.1680. PMid:20048485.
28. Sedgwick MJ, Morris JG, Nevill ME, Tolfrey K, Nevill A, Barrett LA. Effect of exercise on postprandial endothelial function in adolescent boys. Br J Nutr. 2013;110(2):301-9. http://dx.doi.org/10.1017/S0007114512004977. PMid:23218136.
29. Canale RE, Farney TM, McCarthy CG, Bloomer RJ. Influence of acute exercise of varying intensity and duration on postprandial

oxidative stress. Eur J Appl Physiol. 2014;114(9):1913-24. http://dx.doi.org/10.1007/s00421-014-2912-z. PMid:24907974.

30. Sedgwick MJ, Morris JG, Nevill ME, Barrett LA. Effect of repeated sprints on postprandial endothelial function and triacylglycerol concentrations in adolescent boys. J Sports Sci. 2015;33(8):806-16. PMid:25357120.
31. Augustine J, Tarzia B, Kasprowicz A, Heffernan KS. Effect of a single bout of resistance exercise on arterial stiffness following a high-fat meal. Int J Sports Med. 2014;35(11):894-9. http://dx.doi.org/10.1055/s-0033-1363266. PMid:24886920.
32. Karpe F. Postprandial lipoprotein metabolism and atherosclerosis. J Intern Med. 1999;246(4):341-55. http://dx.doi.org/10.1046/j.1365-2796.1999.00548.x. PMid:10583705.
33. Chan DC, Pang J, Romic G, Watts GF. Postprandial Hypertriglyceridemia and Cardiovascular Disease: Current and Future Therapies. Curr Atheroscler Rep. 2013;15(3):309. http://dx.doi.org/10.1007/s11883-013-0309-9. PMid:23345190.
34. Ginsberg HN. Lipoprotein physiology. Endocrinol Metab Clin North Am. 1998;27(3):503-19. http://dx.doi.org/10.1016/S0889-8529(05)70023-2. PMid:9785050.
35. Morel DW, Hessler JR, Chisolm GM. Low density lipoprotein cytotoxicity induced by free radical peroxidation of lipid. J Lipid Res. 1983;24(8):1070-6. PMid:6415194.
36. Stocker R, Keaney JF Jr. Role of oxidative modifications in atherosclerosis. Physiol Rev. 2004;84(4):1381-478. http://dx.doi.org/10.1152/physrev.00047.2003. PMid:15383655.
37. Gerszten RE, Tager AM. The monocyte in atherosclerosis: should I stay or should I go now? N Engl J Med. 2012;366(18):1734-6. http://dx.doi.org/10.1056/NEJMcibr1200164. PMid:22551134.
38. Steinberg D. Lipoproteins and the pathogenesis of atherosclerosis. Circulation. 1987;76(3):508-14. http://dx.doi.org/10.1161/01.CIR.76.3.508. PMid:3621517.
39. Luscher TF. The endothelium and cardiovascular disease--a complex relation. N Engl J Med. 1994;330(15):1081-3. http://dx.doi.org/10.1056/NEJM199404143301511. PMid:8127338.
40. Cerqueira NF, Yoshida WB. Óxido nítico: revisão. Acta Cir Bras. 2002;17(6)
41. Matsuoka H. Endothelial dysfunction associated with oxidative stress in human. Diabetes Res Clin Pract. 2001;54(2, Supl 2):65-72. PMid:11733111.
42. Palmer RM, Ashton DS, Moncada S. Vascular endothelial cells synthesize nitric oxide from L-arginine. Nature. 1988;333(6174):664-6. http://dx.doi.org/10.1038/333664a0. PMid:3131684.
43. Forstermann U, Munzel T. Endothelial nitric oxide synthase in vascular disease: from marvel to menace. Circulation. 2006;113(13):1708-14. http://dx.doi.org/10.1161/CIRCULATIONAHA.105.602532. PMid:16585403.
44. Teixeira BC, Lopes AL, Macedo RCO, et al. Marcadores inflamatórios, função endotelial e riscos cardiovasculares. J Vasc Bras. 2014;13(2):108-15. http://dx.doi.org/10.1590/jvb.2014.054.
45. Corretti MC, Anderson TJ, Benjamin EJ, et al. Guidelines for the ultrasound assessment of endothelial-dependent flow-mediated vasodilation of the brachial artery: a report of the International Brachial Artery Reactivity Task Force. J Am Coll Cardiol. 2002;39(2):257-65. http://dx.doi.org/10.1016/S0735-1097(01)01746-6. PMid:11788217.
46. Carocho M, Ferreira IC. A review on antioxidants, prooxidants and related controversy: natural and synthetic compounds, screening and analysis methodologies and future perspectives. Food Chem Toxicol. 2013;51:15-25. http://dx.doi.org/10.1016/j.fct.2012.09.021. PMid:23017782.
47. Finaud J, Lac G, Filaire E. Oxidative stress: relationship with exercise and training. Sports Med. 2006;36(4):327-58. http://dx.doi.org/10.2165/00007256-200636040-00004. PMid:16573358.
48. Di Meo S, Venditti P. Mitochondria in exercise-induced oxidative stress. Biol Signals Recept. 2001;10(1-2):125-40. http://dx.doi.org/10.1159/000046880. PMid:11223645.
49. Jenkins RR, Goldfarb A. Introduction: oxidant stress, aging, and exercise. Med Sci Sports Exerc. 1993;25(2):210-2. PMid:8450723.
50. Schneider CDO, Oliveira AR. Radicais livres de oxigênio e exercício: mecanismos de formação e adaptação ao treinamento físico. Rev Bras Med Esporte. 2004;10(4):308-13. http://dx.doi.org/10.1590/S1517-86922004000400008.
51. Farrell AJ, Blake DR. Nitric oxide. Ann Rheum Dis.. 1996;55(1):7-20. PMid:8572740.
52. Niess AM, Simon P. Response and adaptation of skeletal muscle to exercise: the role of reactive oxygen species. Front Biosci. 2007;12(12):4826-38. http://dx.doi.org/10.2741/2431. PMid:17569613.
53. Favier AE, Cadet J, Kalyanareman B, Fontecave M, Pierre JL. *Analysis of free radicals in biological systems*. Basel: Birkhäuser Basel; 1995.</bok>.
54. Halliwell B, Gutteridge JMC. *Free radicals in biology and medicine*. Oxford: Clarendon Press; 1988.
55. Shan XQ, Aw TY, Jones DP. Glutathione-dependent protection against oxidative injury. Pharmacol Ther. 1990;47(1):61-71. PMid:2195557.
56. Goldberg IJ, Eckel RH, Abumrad NA. Regulation of fatty acid uptake into tissues: lipoprotein lipase- and CD36-mediated pathways. J Lipid Res. 2008;50(Supl):86-90. http://dx.doi.org/10.1194/jlr.R800085-JLR200. PMid:19033209.
57. Libby P, Lichtman AH, Hansson GK. Immune effector mechanisms implicated in atherosclerosis: from mice to humans. Immunity. 2013;38(6):1092-104. http://dx.doi.org/10.1016/j.immuni.2013.06.009. PMid:23809160.
58. Lakatos S, Furesz J, Pallinger E, Rischak K, Schweitzer K, Szollar L. Noncovalent interactions in maintaining the native structure of low density lipoprotein. Biochem Biophys Res Commun. 1995;216(1):414-21. http://dx.doi.org/10.1006/bbrc.1995.2639. PMid:7488120.
59. Prassl R, Laggner P. Molecular structure of low density lipoprotein: current status and future challenges. EBJ. 2009;38(2):145-58. http://dx.doi.org/10.1007/s00249-008-0368-y. PMid:18797861.
60. Itabe H, Obama T, Kato R. The dynamics of oxidized ldl during atherogenesis. J Lipids. 2011;2011:418313. http://dx.doi.org/10.1155/2011/418313. PMid:21660303.
61. Muñoz A, Costa M. Nutritionally mediated oxidative stress and inflammation. Oxid Med Cell Longev. 2013;2013:610950. http://dx.doi.org/10.1155/2013/610950. PMid:23844276.
62. Fukai T, Folz RJ, Landmesser U, Harrison DG. Extracellular superoxide dismutase and cardiovascular disease. Cardiovasc Res. 2002;55(2):239-49. http://dx.doi.org/10.1016/S0008-6363(02)00328-0. PMid:12123763.
63. Fisher-Wellman K, Bloomer RJ. Macronutrient specific postprandial oxidative stress: relevance to the development of insulin resistance. Curr Diabetes Rev. 2009;5(4):228-38. http://dx.doi.org/10.2174/157339909789804369. PMid:19604133.

64. Zhang JQ, Thomas TR, Ball SD. Effect of exercise timing on postprandial lipemia and HDL cholesterol subfractions. J Appl Physiol. 1998;85(4):1516-22. PMid:9760349.

65. Berzosa C, Cebrian I, Fuentes-Broto L, et al. Acute exercise increases plasma total antioxidant status and antioxidant enzyme activities in untrained men. J Biomed Biotechnol. 2011;2011:540458. http://dx.doi.org/10.1155/2011/540458. PMid:21436993.

66. van Oostrom AJ, Sijmonsma TP, Verseyden C, et al. Postprandial recruitment of neutrophils may contribute to endothelial dysfunction. J Lipid Res. 2003;44(3):576-83. http://dx.doi.org/10.1194/jlr.M200419-JLR200. PMid:12562833.

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