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Effects of interactions between various fats and active/passive phases on postprandial inflammation in rats

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The circadian clock controls number of behavioral and physiological processes during daily light/dark cycle including inflammation and vascular injury. However, how reciprocal interaction of dietary fats and light/dark cycle affects postprandial inflammation is currently unknown. To this end, effects of various dietary fats given to rats by gavaging either in light or dark phase on postprandial inflammation were compared. Sunflower oil load activated greater number of inflammatory CD markers in passive phase whereas the butter load in active phase compared to their counter phase. The inflammatory influence of fish oil load appeared to be mostly confined to passive phase. Differences found between the levels of some of the inflammatory markers in active and passive phases of normal fed rats were altered by fat/oil administrations. We conclude that influences of dietary fats/oils on postprandial inflammatory changes might depend not only on their fatty acid compositions but also on their ingestion times.

Keywords: postprandial inflammation; circadian rhythm; inflammation markers; atherosclerosis; dietary fats

Introduction

It is generally accepted that each meal causes an inflammatory response with low intensity and short duration. Chylomicrons, VLDL, and their remnants have been thought to be the major lipoproteins which are increased in the postprandial plasma (Nakajima et al. 2011). These lipoproteins are known to influence vascular inflammation. Postprandial lipemia has been proposed to be one of the common risk factor of cardiovascular diseases.

Endothelial dysfunction is characterised by proinflammatory alterations in the endothelium and results in leukocyte adhesion and transmigration which are early steps in atherogenesis. Studies have demonstrated that the type of fatty acids in meal is a major determinant of the magnitude of postprandial inflammation and related to the incidence of cardiovascular diseases. These effects may be altered by various lipids carried by the remnant particles, including the type of fat and micronutrients (Botham et al. 2005). The percentage of saturated fatty acids and the ratio of n-3 to n-6 polyunsaturated fatty acids in a meal appear to determine the magnitude of postprandial inflammatory response.

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The circadian clock entrains multiple behavioral and physiological processes to daily light/dark cycle including activity, sleeping, feeding, and metabolism. Peripheral tissues comprise food-entrainable circadian oscillators which communicate with SCN in the brain by endocrine and neuronal means (Mistlberger 2011). Multiple aspects of lipid digestion, absorption, as well as lipoprotein metabolism are profoundly affected by circadian clock including absorption of dietary lipids, expression of microsomal transfer proteins, and apo B-48 which are known to be important in chylomicron assembly, plasma levels of postprandial remnant lipoproteins, and triacylglycerol (Pan & Hussain 2007, 2009). The circadian rhythm regulates lipid metabolism and vice versa. The time of the day at which a high-fat meal is digested influences lipid/lipoprotein parameters. Lipid metabolism in mice fed high-fat meal during the end of active phase markedly differed from those of mice fed the same meal at the beginning of the active phase (Bray & Young 2011). High-fat diet disrupts behavioral and molecular circadian rhythms in mice (Kohsaka et al. 2007). Diurnal variation in inflammatory and immune function can be seen in animals. Vascular injury is also known to be affected by circadian clock function (Bass & Takahashi 2010). However, how reciprocal interaction of different dietary fats and light/dark cycle of the day affects postprandial inflammation is currently unknown.

To this end, effects of various dietary fats, fish oil (rich in omega 3 fatty acids), butter (rich in saturated fatty acids), sunflower oil (rich in omega 6 polyunsaturated fatty acids), and olive oil (rich in monounsaturated fatty acids), given in light or dark cycle of the day on postprandial inflammation, vascular and systemic, were compared. Cytokines taking part in inflammatory response including IL-1β, TNF-α, IL-6, and soluble adhesion molecules (VEGF-C, sE-selectin) were analysed in blood samples by ELISA. Monocyte, granulocyte, lymphocyte levels, and the levels of VCAM-1, ICAM-1, and L-selectin on these cells were detected by flow cytometric analysis. The present results implicate that not only the type of fat but also time of day at which they are consumed might be important in postprandial inflammation. Inflammatory effects of dietary fat or oil consumption might be time-of-day dependent.

Materials and methods

Animals

Male Wistar rats obtained from Experimental Animal Unit of İnönü University were used throughout the study. They were kept under constant conditions of 12 h light and 12 h dark cycles and temperature (21 °C) and fed a standard pellet diet (containing 2.64% (w/w) linoleic acid, 0.18% (w/w) linolenic acid, 0.28% (w/w) arachidonic acid, and 0.666% (w/w) oleic acid) and given ad libitum access to water. Rats of 300–350 g body weight were used. The present work has been approved by İnönü University Ethical Committee of Experimental Animals.

Study design

Rats were divided into six groups (butter, sunflower oil, olive oil, fish oil, and controls for active and passive phases) each of which contained 5–6 rats. Following 9–10 h of fasting, to each group were given 1.3 ml of different fats or oils, that is, sunflower oil, olive oil, butter or fish oil via gastric gavaging on alternate days for five days starting from Monday either at the beginning of active (at 7 pm) or passive (at 7 am) phases.

Blood and spleen tissue samples were collected 4 h after the final fat/oil gavaging. Control groups received saline. From our previous experiments, we observed a relatively short period of postprandial hypertriacylglycerolemia after gavaging 1 mL of oil. In an effort to increase the duration of postprandial hypertriacylglycerolemia, 1.3 mL of oil, instead of 1 mL, was employed.

Biochemical analysis

Plasma concentrations of IL-6, IL-1β, VEGF-C, and TNF-α were determined by commercial ELISA kits (eBioscience). Quantification of rat soluble E-selectin (sE-selectin) was carried out by commercial ELISA kits from Cusabio Biotech Co., Ltd.

Assessment of leukocyte activation markers

Leukocytes were isolated from spleens by mechanical disruption and straining through nylon mesh. Following that, 10^6 cells per experiment were stained with properly paired monoclonal antibodies labeled either with fluorescein isothiocyanate (FITC) or Phycoerythrin (Pe) (BD Bioscience; USA). Peridinin chlorophyll (PerCp) labeled anti-rat CD3 antibody were used for all T-cell subtype analysis, and FITC labeled anti-rat CD3 was used for T-cell analysis. Anti-rat CD45RA antibody and anti-rat CD11b were used to determine B-lymphocytes and neutrophils, respectively. All data were collected on a FACS Canto flowcytometer and analysed using FACS Diva software (BD Bioscience, USA).

Statistical analysis

Data are presented as median, minimum, maximum, and interquartile range. All parameters were tested by the Shapiro–Wilks normality test, and its distribution was not normal in analyses of receptors and cytokines ($p > 0.05$). Therefore, statistical differences between groups were determined with the nonparametric Kruskal–Wallis analysis and Mann Whitney U Tests. One way ANOVA and post hoc LSD (Least Significant Difference) were used to compare the percentage of the receptor cells. Independent samples t-test was used to compare active vs. passive phase for each oil and control groups. P value less than 0.05 was regarded as significant.

Results

Parameters related to postprandial inflammation were analyzed following various fats oils or saline administration to rats by oral gavage on alternate days for five days ($n = 5$ or 6 per group).

Comparison of inflammation markers between fats and controls

Active phase: As seen in Figure 1, plasma TNF-α, VEGF, and IL-6 levels significantly decreased after sunflower oil load compared to the control. Four hours after the final administration, olive oil load also led to significantly lower plasma level of VEGF. It can be seen from the results that CD8/CD54 expression in leukocytes was enhanced, whereas CD3/CD62L or CD4/CD62L expression was lowered by all the fats or oils tested in comparison with controls, although the increase of CD8/CD54 by sunflower

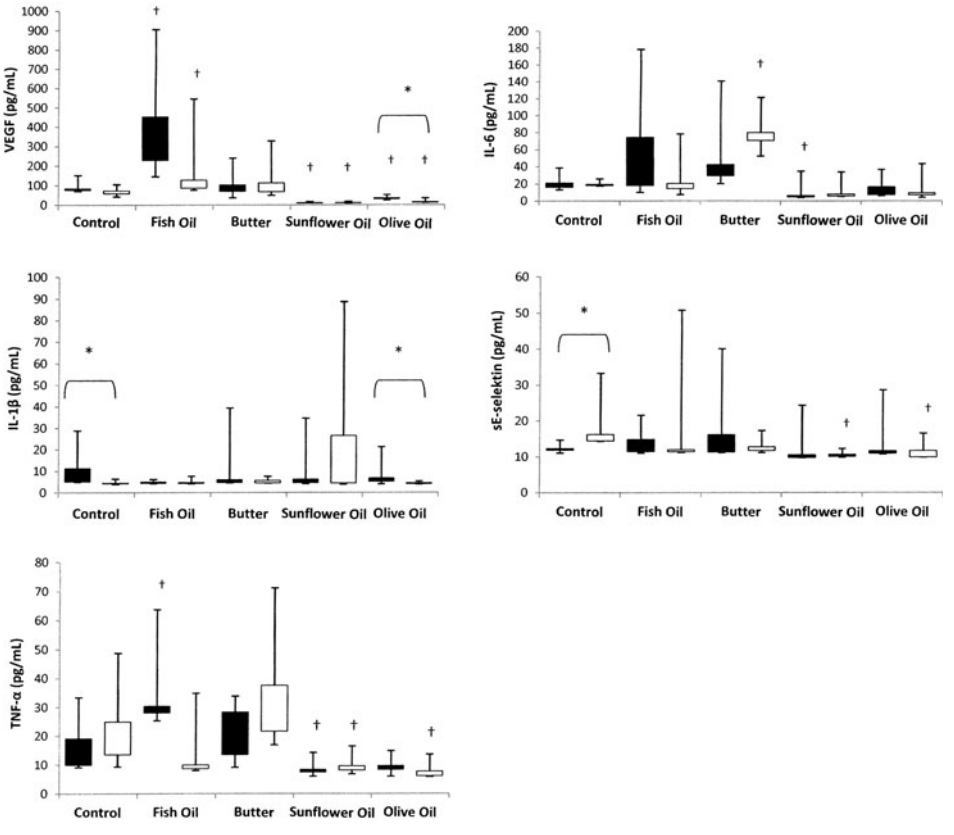

Figure 1. Comparison of inflammatory cytokines and adhesion molecules among active/passive phases and their respective controls after different fat or oil gavaging.
Notes: Data are presented as median, minimum, maximum, and interquartile ranges. Mann–Whitney U analysis was used to compare the percentages of cytokines between active and passive phases after each oil/fat administration, whereas comparison with respective controls were made by Kruskal–Wallis analysis ($n = 5–6$). p values less than 0.05 are regarded as significant. $^{\dagger}p < 0.05$ compared with respective control. $^{*}p < 0.05$ compared between active (■) and passive (□) phases.

oil was not statistically significant (Table 1). In general, fat or oil administration increased the percentage of lymphocytes expressing ICAM-1 (CD54) whereas lowered that expressing L-selectin (CD62L) (Tables 1 and 2).

Passive phase: Plasma TNF-α, VEGF, and sE-selectin levels were diminished after sunflower oil and olive oil administrations, whereas VEGF and IL-6 levels were found to be higher compared to saline load after fish oil and butter gavaging, respectively. Plasma IL-1β levels were not differentially affected by any fat or oil load (Figure 1). Sunflower oil was found to be the least efficient of all the fats or oils in influencing the leukocyte compared to control in passive phase (Tables 1 and 2). After sunflower oil load, only the leukocytes expressing CD4/CD54 and CD8/CD54 increased. As in the active phase, in general, fat or oil administration increased ICAM-1 (CD54) expression on leukocytes whereas lowered L-selectin (CD62L) expression. The neutrophils expressing CD11b/CD54 were increased by all the fats or oils except for sunflower oil

Table 1. Comparison of percentages of rat spleen leukocytes expressing various activation markers among active/passive phases and their respective controls after different fat or oil gavaging.

	CD3		CD45RA		CD4		CD8		CD11b		CD11b/CD62L		CD11b/CD54		CD3/CD62L		CD3/CD54		CD4/CD54		CD4/CD62L		CD8/CD54		CD8/CD62L	
	P	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**
Butter	53.7	**67.3***	37.8	**22.8***	**31.2***	38.1	18.7	**15.6***	**3.2***	**4.5***	52.7	63.3	**61.8***	71.9	**21.3***	**27.2***	**39.1***	**52.6***	30.6	37.8	**11.1***	**16.2***	25.4	**40.4***	41.9	56.3
	***p* = 0.004**	***p* = 0.010**	***p* = 0.020**	***p* = 0.006**	***p* = 0.010**		***p* = 0.005**	***p* = 0.008**			***p* = 0.004**	***p* = 0.004**	***p* = 0.004**													
Fish oil	68.3	46.5	**25.4***	37.4	**27.6***	37.0	**15.5***	19.4	**5.5***	2.3	32	**26.5***	**52.7***	23.4	**3.30***	3.4	**52.9***	20.2	**40.2***	45.4	**15.2***	**25.1***	**54.2***	**44.5***	53.2	49
	***p* = 0.004**	***p* = 0.037**	***p* = 0.004**	***p* = 0.004**	***p* = 0.004**		***p* = 0.004**		***p* = 0.006**																	
Sunflower oil	43.5	48.1	31.9	35.5	37.6	36.5	20.3	15.8	2.7	1.7	37.5	48.9	28.1	45.6	58.8	**50.0***	28.0	26.7	**43.1***	27.2	49.8	**45.6***	**56.7***	58.7	61.3	61.8
				***p* = 0.016**	***p* = 0.005**	***p* = 0.006**	***p* = 0.004**	***p* = 0.008**		***p* = 0.004**	***p* = 0.004**															
Olive oil	53.3	46.6	41.7	**23.1***	37.4	36.1	20.7	19.4	3.2	2.1	45.8	45.3	**51.9***	38.2	**15.4***	**24.3***	**35.1***	36.1	26.6	40.5	**11.9***	**20.2***	**33.7***	**46.7***	**11.5***	**20.3***
		***p* = 0.006**			***p* = 0.028**			***p* = 0.037**				***p* = 0.025**														
Control	57.1	47.9	40.5	30.9	40.1	38.6	22.3	22.3	2.1	2.0	31.8	50.8	22.3	32.3	57.5	42.1	21.3	24.7	19.9	29.6	49.6	50.9	3.9	30.2	52.9	58.0
	***p* = 0.004**	***p* = 0.025**				***p* = 0.037**	***p* = 0.004**	***p* = 0.004**				***p* = 0.037**														

Notes: Data are presented as mean. One way ANOVA and post hoc LSD (Least Significant Difference) were used to compare the percentages of receptor cells. Independent samples t-test was used to compare active vs. passive phase for each oil and control groups ($n = 5–6$). p values less than 0.05 were regarded as significant.
*$p < 0.05$ compared with respective control. p values were indicated where the difference between active/passive phases is significant. P: passive phase; A: active phase.

Table 2. Comparison of various activation markers of rats 4 h after fat or oil gavaging with that of their respective controls.

	Active phase		Passive phase	
Fats/oils	Increased	Decreased	Increased	Decreased
Butter	CD3	CD45RA	CD11b	CD4
	CD11b	CD8	CD11b/CD54	CD3/CD62L
	CD8/CD54	CD3/CD62L	CD3/CD54	CD4/CD62L
Fish oil	CD8/CD54	CD11b/CD62L	CD11b	CD45RA
		CD4/CD62L	CD11b/CD54	CD4
			CD3/CD54	CD8
			CD4/CD54	CD3/CD62L
			CD8/CD54	CD4/CD62L
Sunflower oil	CD3/CD62L	CD4/CD62L	CD4/CD54	
			CD8/CD54	
Olive oil	CD8/CD54	CD45RA	CD11b/CD54	CD3/CD62L
		CD3/CD62L	CD3/CD54	CD4/CD62L
		CD4/CD62L	CD8/CD54	CD8/CD62L
		CD8/CD62L		

Note: The data were deduced from Table 1.

in passive phase. Additionally, fish oil and butter gavaging also enhanced the levels of CD11b also increased as measured by flow cytometry (Tables 1 and 2).

Comparison of inflammation markers between active and passive phases of each fat and control

From the comparison of postprandial plasma inflammation marker levels between active and passive phases of rats given various fats or oils, it can be seen that after olive oil gavaging, level of VEGF was found to be significantly higher in active phase compared to passive phase, whereas no significant difference could be found between the VEGF levels of active and passive phases of controls. In terms of plasma IL-1β level, active phases of control and olive oil load were both higher compared to passive phases. No difference between active and passive phases of other fats or oils tested was found. There was no difference between neither the plasma level of TNF-α nor that of IL-6 of active and passive phases of any fat groups or controls. On the other hand, higher plasma sE-selectin level was found in passive phase compared to active phase of controls but not in any of the fat or oil groups (Figure 1).

The leukocyte activation markers from different fats or oils tested were compared between active and passive phases after oral administration of various fats/oils or saline in rats. The number of CDs (cluster of differentiation), showing significant differences between active and passive period was the least after olive oil administration whereas the most after butter load (Table 1). Differences between the percentages of leukocytes expressing CD11b in the active and passive phases were introduced by all the fats or oils tested whereas that of CD8 emerged after all the fat or oil administrations except for olive oil. No such difference was present in that of controls (Tables 1 and 3). However, active/passive phase differences present in the level of neutrophils expressing L-selectin (CD11b/CD62L) of controls disappeared after all the fats or oils administrations except for sunflower oil. The number of CDs, plasma levels of which were found to be significantly higher in active phase compared to that in passive phase, was the

Table 3. Comparison of active/passive phase differences of each fat/oil groups with that of controls.

Fats/oils	CDs of fat/oil groups exhibiting significant differences between active and passive phases but without any difference between the respective controls	CDs of fat/oil groups exhibiting no difference between active and passive phases but with significant differences between the respective controls	CDs of fat/oil groups exhibiting significant active-passive phase differences opposite to that of the respective controls
Butter	CD4 CD8 CD11b CD4/CD62L CD8/CD62L	CD11b/CD62L	CD3 CD3/CD62L
Fish oil	CD4 CD8 CD11b CD3/CD54	CD11b/CD62L CD3/CD62L CD8/CD54	CD45RA CD11b/CD54 CD3/CD62L
Sunflower oil	CD8 CD11b CD4/CD54 CD4/CD62L CD8/CD62L	CD3 CD45RA CD8/CD54	
Olive oil	CD11b	CD3 CD11b/CD62L CD11b /CD54	CD3/CD62L

Note: The data were deduced from Table 1.

highest after butter load (total of six CDs) but the lowest after sunflower oil (total of zero), (after the numbers of corresponding CDs of controls were subtracted from those of fat/oil groups), whereas, the number of CDs, plasma levels of which were significantly higher in passive phase, was the highest after sunflower oil (total of five) but the lowest for butter (total of one) and olive oil (total of one). After the butter administration, percentages of neutrophils and that expressing ICAM-1 were higher in active phase, whereas in the case of fish oil, these percentages were found to be higher in passive phase compared to their counter-phases (Table 1).

After the butter load, the percentage of T lymphocytes (CD3) as well as the lymphocytes with CD62L expression level in the active phase was higher in comparison with that in the passive phase, whereas in the control group, these values were higher in the passive phase. In a similar fashion, the leukocyte percentage expressing CD3/CD62L in the active phase after olive oil load was higher compared to that in the passive phase which was opposite to that in the controls. Following fish oil load, the level of leukocytes with CD11b/CD54 expression in the passive phase was higher than that in the active phase, being contrary to what was found after water load (Tables 1 and 3).

Discussion

The goals of this study were to test whether or not postprandial inflammation is differentially affected by reciprocal interactions of fats with different fatty acid compositions and active/passive phases of rat. For the assessment and comparison of

postprandial inflammation after different fat or oil administrations to rats in active or passive phases, some of the markers of inflammation were analyzed in plasma.

Circadian rhythms in mammals can be entrained by food intake and light. In our experimental design, the rats were starved for 10–11 h before gavaging fat or oil in order to boost the digestion, absorption, and consequently intestinal lipoprotein synthesis so that their effects of fats or oils on postprandial inflammation could be more clearly seen. However, it is well established that shifting food availability to a time different from a standard light–dark schedule causes a phase shift in some peripheral tissues (Bass 2012; Peek et al. 2012). Since animals adjust to the new feeding period within a few days (Froy 2007a; Froy & Miskin 2007b), alternate day fasting was conducted in order to avoid or to minimize any phase shifting effect of changing time of food availability so that any alteration in parameters measured could mostly be attributed to the types of fats/oils and their administration time.

Lipids play a critical role during acute inflammatory process (Cabral 2005). Fatty acids of the diet can modulate immune system (De Pablo & De Cienfuegos 2000). Triglyceride-rich lipoproteins (TRL) in the postprandial phase exert differential actions on the endothelium depending upon their fatty acid composition (Botham & Wheeler-Jones 2013). Recent studies provide evidence of inflammatory responses when cells are exposed to fatty acids or TRL particles (Williams et al. 2004; Dalla-Riva et al. 2010). From our results, it can be seen that butter gavaging increased plasma VEGF, IL-6, and TNF-α levels as well as percentages of neutrophils and their ICAM-1 expressions. Previous works also reported similar data indicating proinflammatory effects of saturated fats on endothelial cells and adhesion molecules (Hall 2009; Magne et al. 2010). In the present work, plasma levels of TNF-α, VEGF, and E-selectin levels and some of the leukocyte activation marker levels (especially in the active phase) were lowered by olive oil administration indicating anti-inflammatory action of olive oil which is in line with previous works. It was reported that olive oil administrations in experimental animals suppressed cytokine production and lymphocyte proliferations (Puertollano et al. 2007). On the other hand, our results indicated that after sunflower oil load, plasma levels of TNF-α, VEGF, IL-6, and E-selectin levels were decreased. Sunflower oil load was also found to be the least efficient in activating leukocyte markers especially in passive period indicating an anti-inflammatory response. However, in general, n-6 PUFA is known to be a proinflammatory factor. But contradictory data were also available. Inhibitory effects of unsaturated fatty acids and linoleic acid on IL-1 or TNF-α mediated VCAM-1 and ICAM-1 expressions in endothelial cells were also shown (Williams et al. 2004). The discrepancy might be attributed to differences in duration, feeding, species of experimental animal, and type and state of activation. Generally, n-3 PUFA is known to ameliorate the effects of postprandial inflammation and reported to suppress proinflammatory cytokine gene expression (NF-kB, IL-1β, IL-6, TNF-α, COX-2) in the immune cells and adhesion molecule productions by vascular endothelial cells (ICAM-1, VCAM-1, E-selectin) (De Caterina et al. 2000; Wu 2004; Hall 2009; Margioris 2009). However, on the contrary to our expectation, VEGF and TNF-α levels showed an increment, and percentages of CD11b and CD11b/CD54 increased compared to controls after fish oil load. Several studies also failed to document any association between n-3 PUFA intake and low inflammatory response. It has been observed that n-3 PUFAs may not have the same effects on inflammation in healthy individuals compared with diseased individuals (Margioris 2009). High content of vitamin A or presence of heavy metals in fish oil might also have contributed to this discrepancy.

Comparison of plasma levels of inflammatory cytokines and adhesion molecules between active and passive phases after gavaging with different fats or oils indicates some disruption in their diurnal oscillations. Following all the fat/oil loads differences present between active and passive phases, IL-1β and sE-selectin levels of controls disappeared with the exception of IL-1β after olive oil load. The number of CDs exhibiting significant differences between active and passive period was the least after olive oil administration whereas being maximum after butter load. Whether or not these can be related to the atherogenic/antiatherogenic properties of these fats/oils remain to be seen.

Increase in plasma VEGF and IL-6 levels appeared to be confined to fish oil and butter load in passive phase compared to that of control. In terms of fish oil gavaging, the percentage of CD11 (neutrophils) as well as that expressing CD11b/CD54 were increased compared to control in passive phase. In addition, the level of leukocytes with CD11b/CD54 expression in passive phase was higher than in that of active phase. Taken together, these data suggest that fish oil administration causes inflammatory response via increased CD11b integrin expression on monocytes as well as proinflammatory cytokines in the passive phase. Stimulation cell surface expression of CD11b on neutrophils is known to promote their adherence to human endothelial cells where they interact with their counters receptors, ICAM-1 on endothelial cell surface. Postprandial recruitment of neutrophils may thus contribute to intravascular inflammatory changes and pathogenesis of atherosclerosis. The data imply that proinflammatory effects of dietary fats might depend on their ingestion time (active or passive phases). Time-of-day dependent dietary fat consumption has also been reported to influence cardiometabolic parameters in mice. Consumption of high-fat meal at the end of the active phase leads to adiposity, glucose intolerance, hyperinsulinemia, and hypertriglyceridemia but not at the end of the passive phase (Bray et al. 2010).

We found that higher percentages of T lymphocytes with CD62L expression found following butter or olive oil loads in active phase compared to active phase were contrary to what was found after saline load, i.e. the percentages being higher in passive phase compared to active phase. The same also applies to higher expression level of CD11b/CD54 determined after fish oil load in passive phase. On the other hand, high-fat feeding has been reported to disrupt oscillation patterns of some metabolites and transcripts some of which are involved in lipid metabolism, circadian rhythm, and antigen presenting and presentation (Kohsaka et al. 2007; Eckel-Mahan et al. 2013). After 10 weeks of high fat or normal chow diet, 43% of the metabolites oscillated in both feeding conditions, whereas 30% oscillated in normal feeding mice and 38% of metabolites oscillated only in mice fed high fat diet. They also found that high-fat feeding can induce or block oscillations of metabolites or transcripts or cause phase shift or reduction in amplitude of the phase. Irregular patterns in oscillations can also be seen (Eckel-Mahan et al. 2013). Besides, the role of circadian gene, Per2, in controlling fatty acid metabolism and inflammation has been reported (Bonney et al. 2013). Circadian gene Bmal1 is known to regulate diurnal oscillations of inflammatory monocytes (Nguyen et al. 2013), increasing in number during the mouse's passive phase and decreasing in the active phase (Druzd & Scheiermann 2013). Whether or not the alterations in differences detected between the levels of some of the inflammatory markers of active and passive phases following fat or oil loads could be attributed to the phase changes and to variations in atherogenicity among different dietary fats or oils await further research.

We conclude that influences of dietary fats/oils on postprandial inflammatory changes might depend not only on their fatty acid compositions but also on their

ingestion times and that these time-of-day dependent variations might provide additional information in the prevention of coronary heart disease and other metabolic disorders influenced by low grade inflammation.

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Disclosure statement

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References

Bass J. 2012. Circadian topology of metabolism. Nature. 491:348–356.

Bass J, Takahashi JS. 2010. Circadian integration of metabolism and energetics. Science. 330:1349–1354.

Bonney S, Kominsky D, Brodsky K, Eltzschig H, Walker L, Eckle T. 2013. Cardiac Per2 functions as novel link between fatty acid metabolism and myocardial inflammation during ischemia and reperfusion injury of the heart. PLoS ONE. 8:e71493.

Botham KM, Bravo E, Elliott J, Wheeler-Jones CP. 2005. Direct interaction of dietary lipids carried in chylomicron remnants with cells of the artery wall: implications for atherosclerosis development. Curr Pharm Des. 11:3681–3695.

Botham KM, Wheeler-Jones CPD. 2013. Postprandial lipoproteins and the molecular regulation of vascular homeostasis. Prog Lipid Res. 52:446–464.

Bray MS, Tsai JY, Villegas-Montoya C, Boland BB, Blasier Z, Egbejimi O, Kueht M, Young ME. 2010. Time-of-day-dependent dietary fat consumption influences multiple cardiometabolic syndrome parameters in mice. Int J Obesity. 34:1589–1598.

Bray MS, Young ME. 2011. Regulation of fatty acid metabolism by cell autonomous circadian clocks: time to fatten up on information? J Biol Chem. 286:11883–11889.

Cabral GA. 2005. Lipids as bioeffectors in the immune system. Life Sci. 77:1699–1710.

Dalla-Riva J, Garonna E, Elliott J, Botham KM, Wheeler-Jones CP. 2010. Endothelial cells as targets for chylomicron remnants. Atherosclerosis Suppl. 11:31–37.

De Caterina R, Liao JK, Libby P. 2000. Fatty acid modulation of endothelial activation. Am J Clin Nutr. 71:213S–23S.

De Pablo MA, De Cienfuegos GA. 2000. Modulatory effects of dietary lipids on immune system functions. Immunol Cell Biol. 78:31–39.

Druzd D, Scheiermann C. 2013. Some monocytes got rhythm. Science. 341:1462–1488.

Eckel-Mahan KL, Patel VR, de Mateo S, Orozco-Solis R, Ceglia NJ, Sahar S, Dilag-Penilla SA, Dyar KA, Baldi P, Sassone-Corsi P. 2013. Reprogramming of the circadian clock by nutritional challenge. Cell. 155:1464–1478.

Froy O. 2007a. The relationship between nutrition and circadian rhythms in mammals. Front Neuroendocrinol. 28:61–71.

Froy O, Miskin R. 2007b. The interrelations among feeding; circadian rhythms and ageing. Prog Neurobiol. 82:142–150.

Hall WL. 2009. Dietary saturated and unsaturated fats as determinants of blood pressure and vascular function. Nutr Res Rev. 22:18–38.

Kohsaka A, Laposky AD, Ramsey KM, Estrada C, Joshu C, Kobayashi Y, Turek FW, Bass J. 2007. High-fat diet disrupts behavioral and molecular circadian rhythms in mice. Cell Metab. 6:414–421.

Magne J, Mariotti F, Fischer R, Mathe V, Tome D, Huneau JF. 2010. Early postprandial low-grade inflammation after high-fat meal in healthy rats: possible involvement of visceral adipose tissue. J Nutr Biochem. 21:550–555.

Margioris AN. 2009. Fatty acids and postprandial inflammation. Curr Opin Clin Nutr Metab Care. 12:129–137.

Mistlberger RE. 2011. Neurobiology of food anticipatory circadian rhythms. Physiol Behav. 104:535–545.

Nakajima K, Nakano T, Tokita Y, Nagamine T, Inazu A, Kobayashi J, Mabuchi H, Stanhope KL, Havel PJ, Okazaki M, et al. 2011. Postprandial lipid metabolism; VLDL vs chylomicrons. Clin Chim Acta. 412:15–16.

Nguyen KD, Fentress SJ, Qiu Y, Yun K, Cox JS, Chawla A. 2013. Circadian gene Bmal1 regulates diurnal oscillations of Ly6C(hi) inflammatory monocytes. Science. 341:1483–1488.

Pan X, Hussain MM. 2007. Diurnal regulation of microsomal triglyceride transfer protein and plasma lipid levels. J Biol Chem. 282:24707–24719.

Pan X, Hussain MM. 2009. Clock is important for food and circadian regulation of macronutrient absorption in mice. J Lipid Res. 50:1800–1813.

Peek CB, Ramsey KM, Marcheva B, Bass J. 2012. Nutrient sensing and the circadian clock. Trends Endocrinol Metab. 23:312–318.

Puertollano MA, Puertollano E, Cienfuegos GA, De Pablo MA. 2007. Significance of olive oil in the host immune resistance to infection. Br J Nutr. 98:54–58.

Williams CM, Maitin V, Jackson KG. 2004. Triacylglycerol-rich lipoprotein-gene interactions in endothelial cells. Biochem Soc Trans. 32:994–998.

Wu D. 2004. Modulation of immune and inflammatory responses by dietary lipids. Curr Opin Lipidol. 15:43–47.