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Research Article

Six Different Fat Tolerance Tests in Young, Healthy Subjects – Gender Dependent Postprandial Lipemia and Glucose

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Abstract

Background: Exacerbated postprandial lipid responses are associated with an increased cardiovascular risk. Meals with different types of fat may affect postprandial responses differently. The aim of this study was to evaluate the postprandial lipemia in young healthy subjects after six oral fat tolerance test (OFTT) with varying amounts of saturated fat.

Methods: With six different types of butter added in random order to potatoes we measured postprandial lipemia, lipoprotein, glucose, and insulin increments for eight hours in 14 young, lean, healthy students, seven of each gender. The area under the curve (AUC) was determined for the postprandial values.

Results: The meals with six types of butters had similar postprandial response even if the saturated fat content varied with 50%. Gender significantly affected the TG responses, as time to peak was 90 minutes in women and 180 minutes in men. Postprandial AUC was higher with respect to TG ($p<0.001$), LDL-Cholesterol ($p<0.002$), total cholesterol ($p<0.027$), and glucose ($p<0.009$) in men compared to women. HDL-Cholesterol was lowest in men (AUC, $p<0.001$). No association with gender was found with free fatty acids and insulin AUCs.

Conclusion: The six OFTT gave similar metabolic responses and postprandial lipemia was gender-specific. Replacement of saturated fat by mono- or polyunsaturated fat did not alter postprandial lipemia during a single OFTT.

Keywords

Postprandial lipemia; Gender; Butter; Free fatty acids; Lipoprotein; Glucose; Insulin

Introduction

Saturated fat intake constitutes a major risk factor for the development of cardiovascular disease (CVD) by accelerating the atherosclerotic process through alterations in plasma lipoprotein and lipid levels [1-3]. A meta-analysis including 262,000 subjects found a strong positive correlation between ischemic heart disease and postprandial lipemia (PPL), most strongly in triglyceride (TG) levels [4]. The important physiological event appears to occur between two and 12 hours after the ingestion of food high in lipids like TG and TG-rich lipoproteins. The accelerated atherosclerotic process is thought to be effected by reduced lipid efflux from the vascular endothelial intima associated with postprandial TGs and lipoprotein levels [5-8]. Most studies in CVD have applied fasting lipid and lipoprotein levels, which may not give the true picture of lifestyle intervention, and data from the postprandial state are scarce [3,5,6,8].

Patients with CVD have higher non-fasting TG levels compared with normal, and TGs measured 2 to 4 hours postprandial show the strongest association with cardiac events in an 11-year follow-up study [9]. Most individuals are hyperglyceridemic after a moderate- or high-fat meal, which usually peaks four to six hours after the meal [7,10]. In Western countries, TG levels are elevated most of the day due to high-fat diets rich in saturated fat which exposes individuals to large amounts of atherogenic TGs-rich remnants particles and low HDL-C levels, contributing to lipid accumulation in the endothelium. Current recommendations, thus, prescribe a reduction in total fat, saturated fat in particular, which should be replaced by carbohydrate [11]. However, monounsaturated fat may also be used as an alternative to saturated fat. Thus, clinical studies with high-fat diets rich in monounsaturated fatty acids (MUFAs) showed improved lipoprotein composition compared with the recommended high-carbohydrate diet in normal subjects and improved glycemic control in subjects with type 2 diabetes [12,13].

Gender is known to affect the PPL; however, the etiology is uncertain [10,14,15]. A negative association between oestrogens and the postprandial lipoprotein lipase activity is well- described and will result in lower dissociation of TG to free fatty acids (FFA) from the postprandial TG-rich chylomicron and VLDL particles [10,16,17]. This activity lowers FFA flux to target tissues and increases extracellular/vascular levels. Furthermore, BMI, age, and exercise influence PPL significantly but the effect in young, healthy subjects is less investigated [10,15,18,19].

Different types of fatty acids influence PPL and glycaemic responses differently, which is important for planning of diets of patients with higher CVD risk like diabetes, obesity, and hypercholesterolemia [20-22]. Clinical studies of metabolic responses to various foods are important to improve health information strategies and recommendations; in concordance, certain standards for the methodology in studying postprandial lipid metabolism were suggested to enable comparison on the effect of diets [23].

Our aim was to evaluate the influence of fat type in meals by acute metabolic responses and their association with gender in a group of young healthy subjects. Therefore, we used six different mixtures of fats, i.e. saturated, mono-and polyunsaturated fat, and measured PPL and glycaemia. Similarly, most studies are performed on both sexes in variety of ages. We were aware that baseline values between sexes vary; thus, we aimed at narrowing the age and weight range of the investigation to minimize the effect of these variables.

Materials and Methods

Fourteen healthy medical students of both sexes (seven male,

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seven female), all Caucasian age 21-24 years, BMI (19.2-22.5 kg/m^2), consumed six meals in random order over a 3 month period as six OFTT containing 300 g mashed potato (Sava Cultivar) mixed with six different Danish butters. The meals contained in total 82.3 g fat, 55.1 g available carbohydrate, 5.8 g protein, and 4177 kJ in total (Table 1): 1) Lurpak butter, 2) Kjaergaarden blend butter, 3) Blend butter (milk/oil), 4) Blue Gaio butter (fish oil-enriched butter), 5) Blend butter (olive oil-enriched butter), 6) Blend butter (low saturated fat butter). The saturated fat content varied: 52 g, 37.4 g, 23.4 g, 22.6 g, 22.6 g and 14.9 g per 100 g of butter or blend in the six meals respectively, and saturated fat was replaced by MUFA and PUFA, and 0.6 g of ώ-3 fatty acids, eicosapentaenoic acid and docosahexaenoic acid, were present in all meals except for meal 4, which had 9.2 g per 100 g in blend. The potatoes, without skin, boiled in 20 minutes in excess of water with 5 g of salt added, and were then blended in four minutes and served hot. After a 12-hour overnight of fasting, the meals were ingested over 10 minutes with 250 ml tap water. The following eight hours the participants stayed at the clinic to watch TV, read or take a short walk of 10 minutes. The subject's meals, activity level, sleep and caffeine intake were discussed, recorded, and constant within 24-48 h prior to the testing and did not differ between meals. None of the participants smoked.

An intravenous catheter was inserted into a forearm vein for blood sampling. Blood samples were drawn at -15, 0, 30, 60, 90, 120, 180, 240, 300, 360, 420, and 480 minutes after the meals and processed after each drawing. After blood collection, plasma was immediately separated by centrifugation at 3000 rpm for 10 minutes at 4°C. Exclusion criteria were hypercholesterolemia, hypertension, abuse of drugs or alcohol, known kidney, liver, heart and metabolic disease and hormonal therapies. The information was based on the subject's history only and no other screening was done. None of the female participants took oral contraceptives during the study, which was performed randomly according to their cycle. The cycle was grouped in four categories: day 1-7, 1; day 8 to 14, 2; day 15-21, 3; day 22-28, 4.

Blood glucose was analyzed using the glucose oxidase method (CV: 3.8%), serum insulin by a specific radioimmunoassay CV 1.7%) [24]. Triglycerides (TG) and plasma lipoproteins were analyzed by en Enihom Chem analyser (CV triglyceride 4%, CV total cholesterol 1.7%, CV HDL-cholesterol 6%).

The study was approved by the local Scientific Ethical Committee and Danish Data Protection Agency (jr. no.:1-16-02-301-15) and conducted in accordance with the Helsinki Declaration and the guidelines for Good Clinical Practice. Written informed consent was obtained from all subjects. Further, the trial was registered at ClinicalTrials.gov (NCT02506920). The primary outcomes were postprandial cholesterol and FFA.

Statistical Analyses

From a previous study of ours we performed a sample size calculation with a statistical power of 80 and α of 0.05 and intended to include 14 volunteers in order to detect a difference in AUC of TG of 37 mmol/L*480 min with a SD of 32 [20]. Results are given as mean ± SD if not stated otherwise. Differences between the two genders were tested by Student's *t* test or Mann-Whitney U- test, depending on the presence of a Gaussian distribution. The area under the curve (AUC) was determined by the trapezoid method for TG, HDL-C, LDL-C, total cholesterol, FFA, insulin, and glucose concentrations. Multiple regressions were performed with AUC as dependent variable to adjust for age, gender, meals, and BMI to the variance of postprandial responses. The difference between meals was tested with ANOVA. Adjustment for the fasting levels was performed by dividing AUC with the average fasting levels of -15 and 0 minutes. If $p<0.05$ in ANOVA, post-hoc-testing with Student-Newman-Keul's test was performed to identify which meal was significantly different from the other and to minimize the risk of significance by multiple testing. IBM SPSS Statistics 20 was used as the statistical software and a two-sided p-value<0.05 considered significant.

Results

All participants completed the study and ingested the six test meals within the time limit. No significant association of either gender or meal type with fasting glucose, insulin, and FFA was seen (Table 2). The male subjects had higher total cholesterol, LDL-C, and TG as well lower HDL-C concentrations compared with the female subjects. Men and women had similar fasting insulin and glucose levels. The variance of TG and HDL-C was different with respect to gender during the 480 minutes of the study (Figures 1A and 1B); no difference in variance was detected between the meals across the length of time (Figures 2A and 2B). The order of meals and the days of cycle had no significant association with fasting values or postprandial levels of any of the variables measured.

The six OFTT meals gave similar AUC of insulin, cholesterol, HDL-C, LDL-C, and TG (Figure 3, all ANOVA, $p>0.05$). The AUC of FFA and glucose show different results for the six OFTTs ($p=0.035$ and $p=0.02$, respectively) but no specific meal was different from the other when adjustment for multiple testing was made in the post-hoc

Table 1: Fat composition of the different meals in the study. MUFA: monounsaturated fatty acid, PUFA: polyunsaturated fatty acid. All meals when served contained same amount of total fat and carbohydrate.

Meal no	1	2	3	4	5	6
Contents all per 100 g butter or blend	**Butter 100 % milk fat**	**Blend 70 % milk/ 30% oil**	**Blend 57 % milk/ 43 % oil**	**Blend 57 % milk/43 % oil**	**Blend 51 % milk/49 % oil**	**Blend 53 % milk/ 47 % oil**
Total fat (g)	81.5	80	60	60.6	60.6	40
Saturated (g)	52	37.4	23.7	22.6	22.6	14.9
MUFA (g)	19.1	27.3	23.2	26.9	26.9	16
PUFA (g)	1.6	1.8	7.8	0.7	5.7	5.6
PUFA ώ 6 (g)	1.3	5.3	1.3	1.2	4.1	3.8
PUFA ώ 3 (g)	0.3	2.3	0.6	9.2	1.6	1.9
Sodium (g)	0.48	0.36	0.36	0.36	0.36	0.43
Ingredients	Cream, lactate culture, salt	Butter rapeseed oil, lactate culture, salt	Butter rapeseed oil, lactate culture, salt	Butter rapeseed oil, lactate culture, fish oil, salt	Butter rapeseed oil, olive oil, lactate culture, salt	Butter, lactate culture, salt

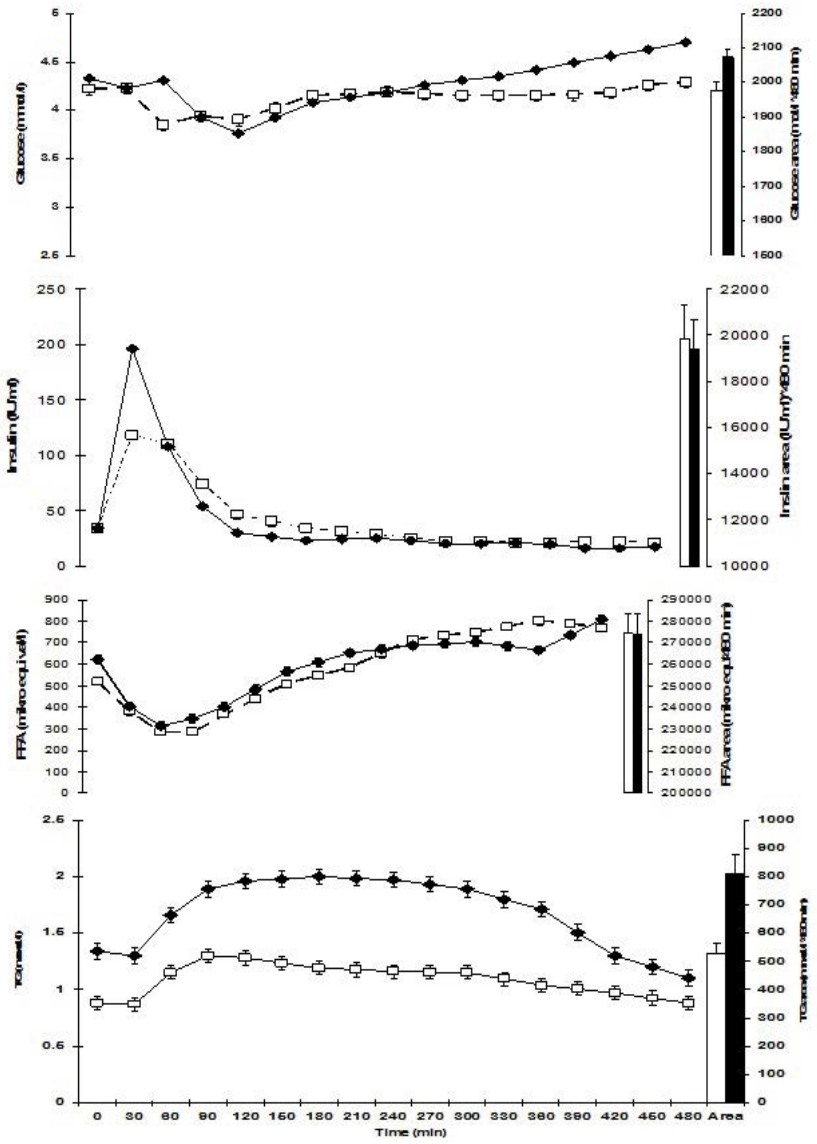

Figure 1A: The mean values and areas under the curves after six OFTT of glucose, insulin, FFA and TG. Postprandial curves: Women shown with open squares and interrupted line; men shown with black diamonds and full line. AUC: Women shown with open bars, men with black bars. Error bars are SEM.

test (Figures 2A, 2B and 3). At regression analysis gender turned out to be the only significant variable for the glucose AUC.

Glucose AUC was higher in men than women (2071 ± 163 vs. 1983 ± 170 mmol/L*480min, p=0.043, Figure 1A). Men and women had similar insulin (p=0.98) and insulinogenic index (insulin AUC/glucose AUC) 9.3 ± 4.0 vs. 10.1 ± 5.0 pmol/mmol (p=0.73).

Men had significantly higher response areas compared with women in TG (819 ± 277 vs. 530 ± 125 mmol/L 480 min, p<0.001), LDL-C (1169 ± 324 vs. 930 ± 329 mmol/L 480 min), and total cholesterol (2051 ± 348 vs. 1848 ± 424 mmol//L· 480 min) (Figures 2A and 2B). HDL-C (508 ± 105 vs. 677 ± 150 mmol/L 480 min) were lowest in men.

When adjustment for the fasting levels was performed only the response area for HDL-C and FFA showed significant difference with respect to gender (444 ± 28 vs. 463 ± 26 [480 min], p=0.003 and 535 ± 254 vs. 670 ± 319 [480 min], p=0.035, men vs. women, respectively).

Maximum level of TG was seen at 180 min after all meals in men and after 90 minutes in women (Figure 1A, p<0.001). The meals with higher MUFA peaked earlier (meals 2-5, 90 and 120 minutes) than the meals with lowest MUFA content (meal 1 and 6, 180 and 240 minutes, respectively, Figure 2A). FFA showed similar responses in both gender with an initial decline after one hour, followed by an increase between one and eight hours (Figure 1A). FFA returned to fasting values after 2-3 hours similarly in all six different OFTT.

For comparison with our initial power calculation, this study provided a mean difference between men and women in AUC in TG of 91 ± 25 mmol/L 480 min (95% CI: 140,42) and a SEM of 24. The different test meals showed no significant differences in ANOVA but

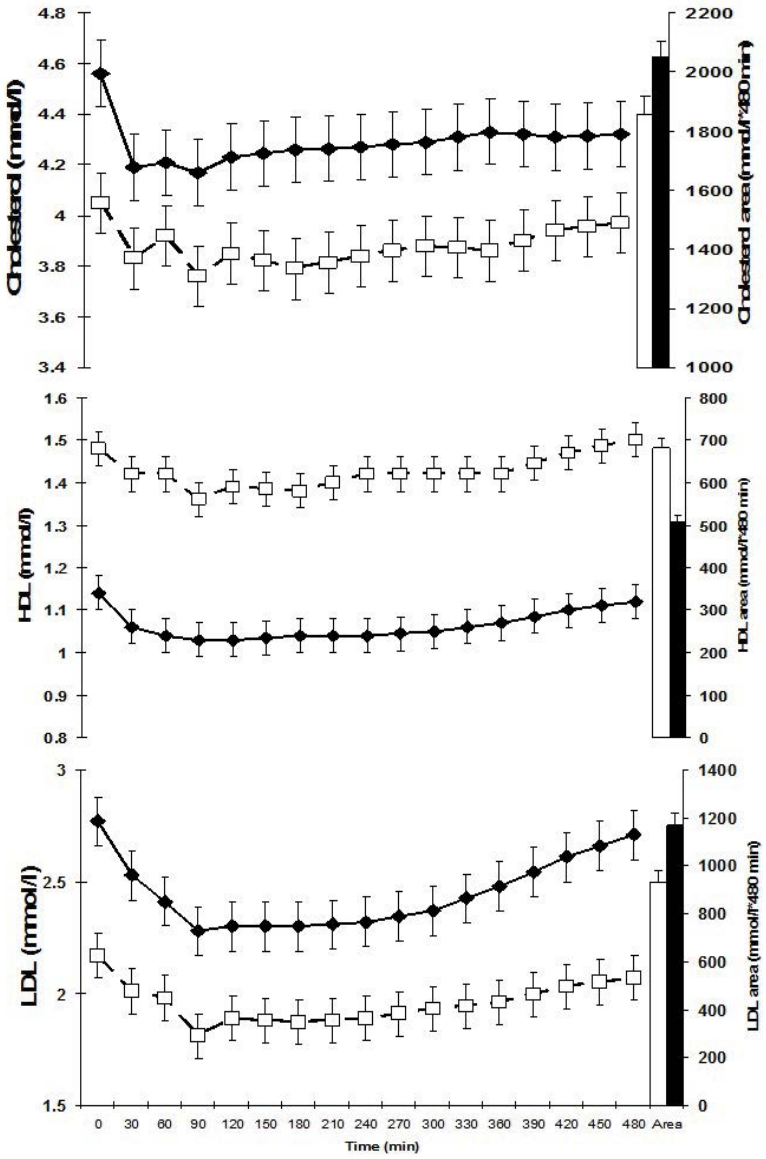

Figure 1B: The mean values and areas under the curves after six OFTT of LDL-C, HDL-C, and total cholesterol. Postprandial curves: Women shown with open squares and interrupted line; men shown with black diamonds and full line. AUC: Women shown with open bars, men with black bars. Error bars are SEM.

the SD ranged from 97 to 164 mmol/L 480 min and the SEM between 13 and 38 mmol/L 480 min. This means that the comparison between the genders proofed more accurate and displayed less variation.

Discussion

The six different fat rich meals, with up 50% variation in saturated fat content, gave surprisingly similar postprandial metabolic responses in our study, which is in conflict with previous studies of saturated and unsaturated fats [20-22]. This may be due to the fact that pure olive oil were applied in most other studies while we compared butter and blends with varying amounts of saturated and unsaturated fats. We chose available butter and blends, which contribute to a significant part of the fat content in the Western diets.

The limitations of this study were mainly in the responses on the different fat types in the test meals. We powered the study according to a similar study on butter and olive oil and found similar variation in means with respect to gender but a higher variation with respect to test meals [20]. This underlines the necessity to stratify for gender and caution on conclusion on the test meals. Although the study was planned to evaluate the effect of gender on responses its real strength lies in the testing of all six meals in 14 subjects. It allowed for within subject evaluation at the suggested standardization levels in methodology of postprandial tests suggested by Lairon et al. [23]. The subjects were homogenous for age and BMI. To allow for further evaluation other subjects need to be studied to assess the effect of age, weight, medical treatment like estrogens, and co-morbidity like diabetes. In contrast, Ryan et al. showed that the within-person variability in PPL is low in most healthy adults when an OFTT is performed repeatedly; even when the range of subjects' phenotype is wide with respect to age (18-60 yrs.), BMI (19-50 kg/m^2) and comprises both genders [25]. Identifying these reproducible and

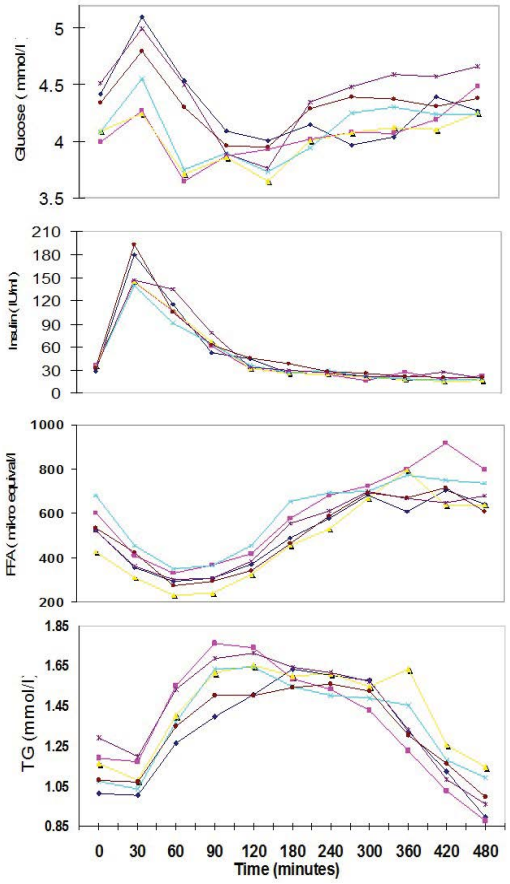

Figure 2A: Glucose, insulin, FFA and TG after six different OFTTs. Meal no. 1: Blue line, filled diamond (♦); 2: pink line, filled square (■); 3: yellow line, filled triangle (▲); 4, cyan line, hatch cross (x); 5: dark purple, line circle and hatch cross (¤); 6: brown line filled diamond (♦).

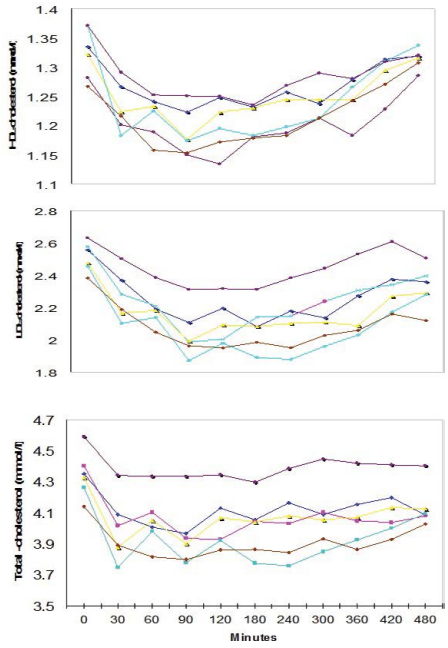

Figure 2B: HDL-C, LDL-C, and total cholesterol after six different OFTTs. Meal no. 1: Blue line, filled diamond (♦); 2: pink line, filled square (■); 3: yellow line, filled triangle with shadow (▲); 4, cyan line, filled diamond (♦); 5: dark purple, line filled circle (●); 6: brown line filled diamond (♦).

Table 2: Mean fasting values of serum lipids, lipoproteins, insulin and glucose in seven men and seven women. HDL-C: High Density Lipoproteins-cholesterol, LDL-C: Low Density Lipoproteins-cholesterol, TG: Triglyceride and FFA: Free fatty acids.

	Gender	Mean	Number of subjects	No of samples	SD	SEM	p-value ♀ vs. ♂
Cholesterol (mM)	Female	4.03	7	42	0.93	0.14	0.01
	Male	4.56	7	42	0.81	0.13	
HDL-C (mM)	Female	1.47	7	42	0.33	0.05	0.001
	Male	1.14	7	42	0.22	0.04	
LDL-C (mM)	Female	2.16	7	42	0.72	0.10	0.001
	Male	2.78	7	42	0.78	0.2	
TG (mM)	Female	0.88	7	42	0.19	0.03	0.001
	Male	1.35	7	42	0.50	0.08	
FFA (µeqval./l)	Female	502	7	42	262	40	0.1
	Male	611	7	42	316	48	
Insulin (pmol/l)	Female	33.8	7	42	15.6	2.4	0.8
	Male	33.6	7	42	17	2.6	
Glucose (mM)	Female	4.19	7	42	0.56	0.9	0.2
	Male	4.32	7	42	0.56	0.9	

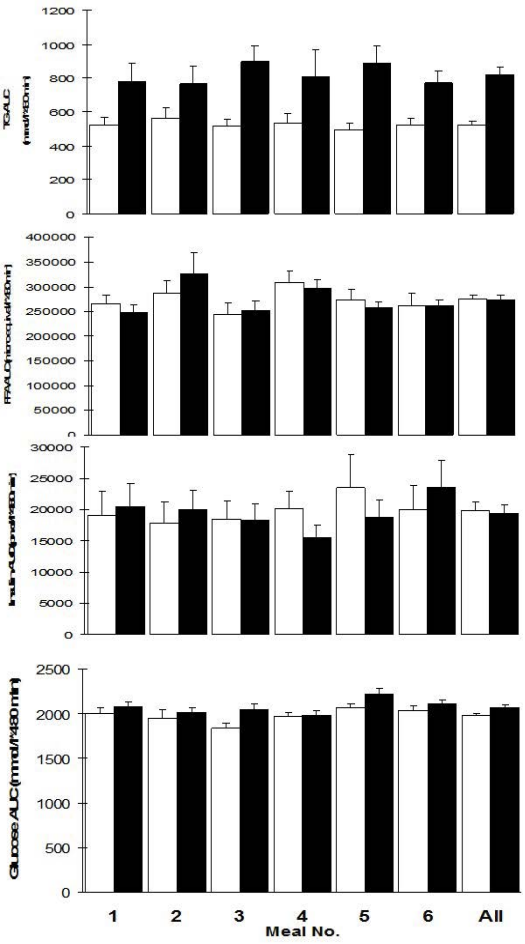

Figure 3: Mean responses of AUC of TG, FFA, insulin and glucose to the six meals in men and women. Women shown with open bars, men with black bars. Error bars are SEM.

measurable phenotypes in healthy individuals has the potential to predict lipid-related disease patterns [3].

The second part of the study showed that gender affected fasting levels and PPL. Men were characterized by higher fasting TG, total and LDL-cholesterol as well as lower HDL-C cholesterol compared with women. This may be due to prolonged PPL responses in men with the important implication that this phenomenon was shown to enhance the risk of CVD [3,5,6,8]. Higher postprandial glucose responses were demonstrated in men without similar insulin differences and suggested a reduced insulin action in males which may account for some of the gender differences in PPL, too.

In the present study, the different postprandial TG responses with respect to gender were in accordance with previous studies in middle-aged subjects [14,26-28]. The postprandial peak of TG mainly reflected the dietary TG absorption after a fat rich meal and the return to fasting level (from four to eight hours postprandial) reflected TG clearance from the plasma [29,30]. Our results showed a delayed postprandial TG peak in men suggesting an impaired postprandial clearance of TG compared with women [31]. Increased FFA levels were observed in both genders in our study after one hour, indicating similar insulin effect by the two genders on the lipoprotein lipase. The recent DISRUPT study included several hundred subjects with postprandial data but those of so-called younger age were 41 years at an average and no specific data in subjects below 30 years are given [25]. However, in a sub-study middle-aged men were found with exaggerated postprandial lipemia compared with younger men with similar age and BMI as in our study. These changes may hint at an association of age with lipid clearance and lower lipoprotein lipase activity irrespective of insulin [18].

As the half-life is 3-5 days in the small lipoproteins LDL-C and HDL-C one can barely judge the acute effects in these substances. On the other hand, FFA and TG were measured for eight hours postprandial in order to visualize the overshoot or spillover, reflecting the balance between intracellular and extracellular lipolysis in adipose tissue (Figures 1 and 2). The enzyme lipoprotein lipase is a key modulator of fatty acid flux in adipose tissue and its rate of action is severely diminished in obesity, which was not the case in our young, lean subjects [31].

Duez et al. [32] indicate that visceral fat accumulation played a major role in the gender difference in postprandial lipemia. While Xiao et al. found that under insulin-resistant conditions, the anti-lipolytic effect of insulin on adipose tissue was very weak [30]. Visceral obesity is associated with metabolic abnormalities such as fasting hypertriglyceridemia, hyperinsulinemia, and increased

Apo lipoprotein-B concentrations as well as lower HDL-C levels; however, in our study the subjects were lean and without signs of metabolic syndrome [14]. They should have had different visceral fat accumulation and BMI if other than gender should explain the observed effects.

Oestrogens may affect TG clearance and in part supportive of the lower PPL found in women [32]. Variation in lipoprotein lipase activity was gender-dependent [33,34]; similarly, oestrogen and LDL-C is inversely correlated [10,16,17]. These mechanisms alone, however, cannot explain the observed difference in PPL. Postprandial fat oxidation is different in women compared with men and was lower in the fasting state reflected in our study in Table 2 [35,36]. Oestrogen and fat oxidation may account for the greater accumulation of subcutaneous and lesser intra-abdominal fat in women in the clearance of TG after a dietary fat challenge [25,26]. The fact that isocaloric meals were ingested, strengthen the argument of the faster clearance in young women; the women had a larger calorie intake per body weight, albeit not per BMI.

Conclusion

Six different OFTT gave similar metabolic responses irrespective of type of fat content. The postprandial lipemia was gender-specific. Replacement of saturated fat by MUFA or PUFA did not alter postprandial lipemia during a single OFTT. A significant association between gender and postprandial TGs and lipoprotein responses in young healthy subjects was demonstrated.

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