Fatty Acid Composition of Adipose Tissue Triglycerides in Obese Diabetic Women After Bariatric Surgery: a 2-Year Follow up

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Summary

Bariatric surgery is the most effective method in the treatment of obesity and type 2 diabetes (T2DM). The aim of this study was to evaluate the effects of different types of bariatric procedures on remission of T2DM and on the fatty acid composition in subcutaneous adipose tissue. Patients included obese diabetic women who underwent bariatric surgery: biliopancreatic diversion (BPD), n=8, laparoscopic gastric banding (LAGB), n=9 or laparoscopic greater curvature plication (LGCP), n=12. Anthropometric characteristics and fatty acid composition of adipose tissue (FA AT) were analyzed before surgery, then 6 months and 2 years after surgery. FA AT was analyzed by gas chromatography. Diabetes remission was estimated. BPD was most efficient in inducing a remission of diabetes (p=0.004). Significantly higher increases in lauric (12:0), myristoleic (14:1n-5) and palmitoleic (16:1n-7) acids and delta-9 desaturase were found two years after BPD, suggesting higher lipogenesis in adipose tissue. Docosatetraenoic acid (22:4n-6) increased significantly after BPD, while docosapentaenoic acid (22:5n-3) decreased 6 months after BPD and increased after 2 years. No changes were found after LAGB and LGCP after 2 years. Bariatric surgery led to significant changes in the fatty acid composition of subcutaneous adipose tissue in severely obese diabetic women after six months and two years, and was partly influenced by the type of surgery used.

Key words

Obesity • Adipose tissue • Bariatric surgery • Palmitoleic acid • Fatty acids

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Introduction

Bariatric surgery is the most efficient method for the management of type 2 diabetes mellitus in obese subjects (Buchwald *et al.* 2004, 2009, Scheen *et al.* 2009). Various methods are used for the bariatric management of obese diabetics, with the differences of individual surgical procedures resulting in different weight loss and metabolic changes. Biliopancreatic diversion (BPD) is the most effective metabolic surgical procedure due to its mechanism of action including effects on the incretin production of GLP 1 (Tsoli *et al.* 2013), bile acid secretion (Ferrannini *et al.* 2015), and gut microbiota (Calvani *et al.* 2010, Clemente-Postigo *et al.* 2015). Acute caloric restriction may also be involved (Plourde *et al.* 2014). Laparoscopic adjustable gastric banding (LAGB) is one of the most frequently used restrictive methods, and its effect is mediated mainly by weight loss (Svane and Madsbad 2014). Laparoscopic greater curvature plication (LGCP) was recently introduced as a method of metabolic surgery (Talebpour *et al.* 2012, Fried *et al.* 2012). Subsequent decreases in ghrelin and increases in GIP could make this method effective in treating type 2 diabetes (Bradnova *et al.* 2014).

Obesity and type 2 diabetes are often associated with dyslipidemia and an altered composition of fatty

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acids in serum and adipose tissue lipids. The fatty acid composition of adipose tissue triglycerides (AT TG) reflects not only the composition of fat in food, but also the metabolic processing of fat, such as endogenous lipogenesis and lipid oxidation.

The aim of this study was to compare effect of three bariatric methods – biliopancreatic diversion (BPD), laparoscopic adjustable gastric banding (LAGB) and laparoscopic greater curvature plication (LGCP) on serum lipids and the composition of adipose triglycerides in obese type 2 diabetic women after 6 months and 2 years. The effect on glucose metabolism will be presented elsewhere.

Methods

Subjects

The study included 29 morbidly obese women with T2DM (age: 39-66 years; duration of diabetes: 1-14 years) that underwent BPD (8 subjects), LAGB (9 subjects) or LGCP (12 subjects). The patients were enrolled over time, as they were indicated for the operations. T2DM patients eligible for bariatric surgery were allocated to different bariatric procedures according to the consecutive numbers they received as they entered the process for study enrolment. Antidiabetic treatment for the patients was as follows: diet only in 3 cases, metformin in 26 cases, sulphonylurea in 8 cases and insulin in 3 cases. Exclusion criteria were treatment with either glitazones, DPP-IV inhibitors or GLP1 agonists, active cancer or an acute medical condition requiring hospitalization, evidence or history of clinically significant cardiovascular, pulmonary, endocrine (other than obesity and T2DM), hematological, renal, gastrointestinal, hepatic (other than NAFLD), neurologic, psychiatric, or severe allergic disease, pregnancy, breastfeeding, weight change more than 5 % of body weight over the preceding 12 weeks, or recent changes in exercise intensity or frequency over the preceding 4 weeks. All subjects signed an informed consent approved by the local ethical committee before entering the study.

Study design

One month before entering the study the subjects were put on a hypocaloric diet with 5000 kJ/day. Oral antidiabetic drugs were discontinued 3 days before examinations and long-acting insulin 24 h before examinations.

The following bariatric procedures were performed: laparoscopic adjustable gastric banding, laparoscopic greater curvature plication and biliopancreatic diversion.

Body composition

Anthropometric measurements were performed for all patients. Body weight was measured to the nearest 0.5 kg and height to the nearest 1 cm. BMI was calculated as body weight in kilograms divided by the square of the height in meters. Waist circumference was measured in the standing position, at half of the distance between the lower ribs and the crest of the pelvis. Hip circumference was measured as the widest gluteal circumference. Body composition was assessed by DEXA (GE LUNAR iDXA, GE Healthcare Technology, USA).

Adipose fatty acid analysis

Total lipids were extracted from 3-5 mg of adipose tissue by the method of Folch and coworkers (Folch *et al.* 1957) using dichlormethane instead of chloroform (Carlson 1985). Samples were transmethylated to FAME with 1M sodium methoxide in dry methanol under nitrogen atmosphere in darkness, for 60 min at ambient temperature. The reaction mixture was then neutralized with 1M acetic acid, methyl esters were extracted into hexane and passed through a column (5x20 mm) of anhydrous sodium sulphate. Extracts were dried under nitrogen, dissolved in an appropriate volume of isooctane and stored at –80 °C until analyzed.

Gas chromatography was performed with a Trace GC gas chromatograph combined with an AS 2000 autosampler (Thermo Finnigan, USA). The chromatograph was equipped with a capillary split/splitless injector and flame ionization detector (FID).

Analysis of FAME was performed on a fused-silica capillary column coated with 0.25 μm chemically bonded stationary phase Select FAME (100 m, 0.25 mm I.D., Agilent Technologies, The Netherlands). The oven temperature was programmed from 80 °C to 120 °C at 4 °/min, to 270 °C at 2 °/min, then isothermal for 25 min. The injector and detector temperatures were 250 and 270 °C, respectively. Hydrogen carrier gas was maintained at a head pressure of 70 kPa and split flow 10 ml/min, splitless time 0.25 min.

Integration software Clarity (Data Apex Ltd. Prague, Czech Republic) was used for data acquisition and handling.

Plasma samples

Blood samples were collected into chilled EDTA-containing tubes for assessment of glucose, insulin C-peptide levels, hsCRP and blood lipids. All samples were immediately cooled, and plasma was prepared, aliquoted, and stored at –80 °C until assayed. Plasma levels of blood glucose, insulin, C-peptide and HbA1c were measured using the Cobas 6000 analyzer. Plasma concentrations of serum lipids and hsCRP were analyzed using standard laboratory methods.

Statistics

The relationships between individual metric variables and factors were evaluated by ANOVA models followed by least significant difference multiple comparisons. The model consisted of a subject factor (separating inter-individual variability from the remaining factors), the between-subject factors Operation, Age over median, BMI over median, initial value of dependent variable over median, within-subject factor Exam and Operation × Exam interaction. The original data were transformed by power transformations to attain symmetric data distribution and constant variance (Meloun *et al.* 2000). The homogeneity of data was checked using residual analysis as explained elsewhere (Meloun *et al.* 2002, 2004). These analyses were performed in Statgraphics Centurion v. XV (Statpoint Inc., Herndon, Maryland, USA) statistical software.

The statistical software SIMCA-P+ Version 12.0.0.0 from Umetrics AB (Umeå, Sweden) was used for further data analysis. This software enabled us to find the number of the relevant components utilizing the prediction error sum of squares, and also allowed the detection of multivariate non-homogeneities and testing the multivariate normal distribution and homoscedasticity (homogeneity of variance).

The relationships between diabetes remission after individual bariatric procedures was tested using log-linear model (frequency analysis) using statistical software NCSS 2007, Kaysville, Utah, USA.

The results are given as means (lower limit of CI; upper limit of CI at the 95 % level) unless stated otherwise.

Due to significant differences between groups the results were evaluated after adjustment for age, BMI and initial level of the variable.

Diabetes remission was estimated according to Buse *et al.* (2009).

The study was approved by the Ethical Committee of the Institute of Endocrinology in Prague.

Results

Changes of anthropometric parameters and body composition after individual procedures are shown in Table 1. Significant differences in weight and body fat loss among individual types of surgeries were found, with the highest loss observed after BPD as expected due to the mechanism of action of this method.

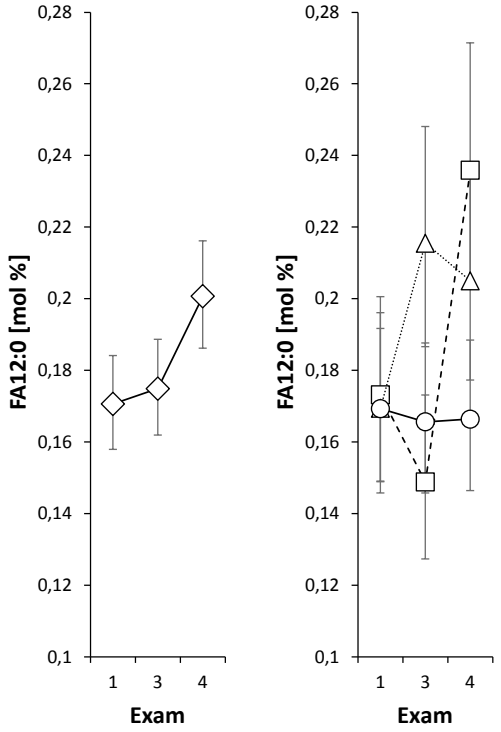

Fig. 1a. Lauric acid (12:0) in adipose tissue before the surgery (1), after 6 months (3) and after 2 years (4). Squares BPD, triangles LAGB, circles LGCP. Exam: F=2.7, p=0.073, Oper x Exam: F=2.7, p=0.037.

Changes in the individual fatty acid composition of adipose tissue triglycerides, blood lipids and hsCRP are given in Tables 2-4. D-6 desaturase activity calculated as a product/precursor ratio did not differ significantly (data not shown). When evaluating differences between individual bariatric procedures we found significant differences in the following saturated and monounsaturated fatty acids: lauric acid (12:0), myristoleic acid (14:1n-5), palmitoleic acid (16:1n-7) and stearic acid (18:0) (Table 2, Fig. 1a and 1b). Concurrently, a significant difference was found in the activity of stearoyl-CoA desaturase-1 (SCD1, delta-9 desaturase) calculated as product/precursor ratio (14:1n-5/14:0, D9-14, p=0.014, 18:1n-9/18:0, D9-18, p=0.021) (Fig. 2). After BPD, there was an increase in the

percentage of lauric, myristoleic and palmitoleic acid after 2 years concurrent with an increase SCD1 activity, suggesting increased lipogenic activity 2 years after the surgery. After LAGB, increased levels were found 6 months after surgery followed mostly by a decrease to the initial levels after 2 years. Gastric plication did not induce significant changes.

For polyunsaturated fatty acids we found significant differences among individual bariatric methods in n-6 and n-3 polyunsaturated fatty acids. Significant differences were found in changes of docosatetraenoic acid (22:4n-6, DTA) and in docosapentaenoic acid (22:5n-3, DPA) (Table 3, Fig. 3). In the BPD group, there was an increase in DTA two years after the surgery, while no change was found in subjects after LAGB and LGCP. Representative of n-3 PUFA, DPA decreased after 6 months in the BPD and LAGB groups, followed by an increase after 2 years. In LGCP group the level of DPA did not change (Table 3, Fig. 3).

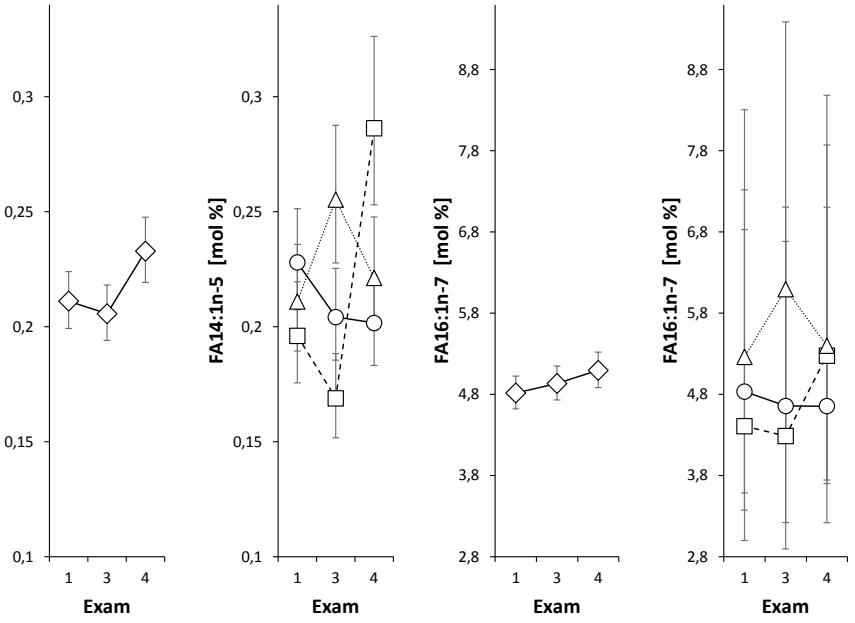

Fig. 1b. Myristoleic (14:1n-5) and palmitoleic (16:1n-7) acid in adipose tissue before the surgery (1), after 6 months (3) and after 2 years (4). Squares BPD, triangles LAGB, circles LGCP. 14:1n-5: Exam: F=2.5, p=0.094, Oper x Exam: F=6.7, p<0.001. 16:1n-7: Exam: F=0.9, p=412, Oper x Exam: F=3.0, p=0.027.

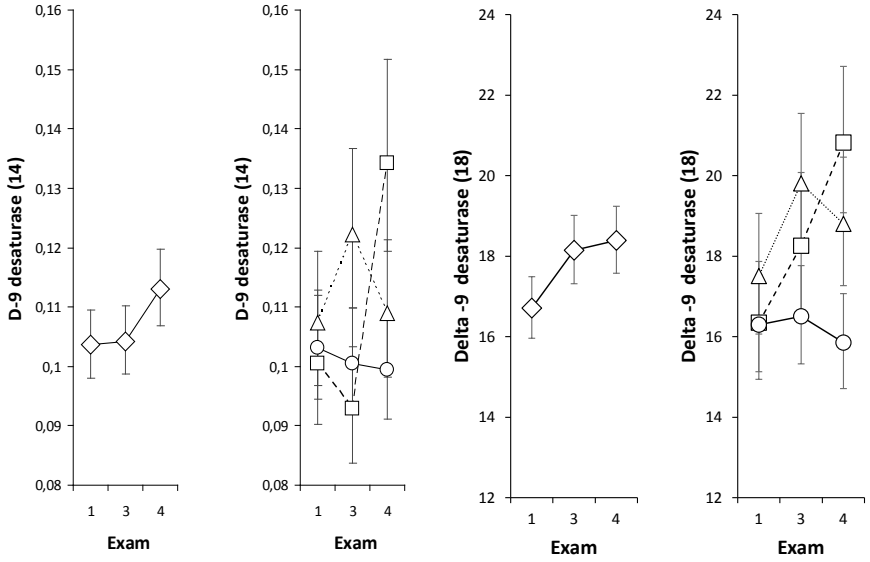

Fig. 2. Delta-9 desaturase 14:1n-5/14:0 and 18:1n-9/18:0 in adipose tissue before the surgery (1), after 6 months (3) and after 2 years (4). Squares BPD, triangles LAGB, circles LGCP. Delta-9 desaturase (14:1n-5/14:0): Exam: F=1.5, p=0.227, Oper x Exam: F=3.4, p=0.014. Delta-9 desaturase (18:1n-9/18:0): Exam: F= F=4.6, p=0.013, Oper x Exam: F=3.1, p=0.021.

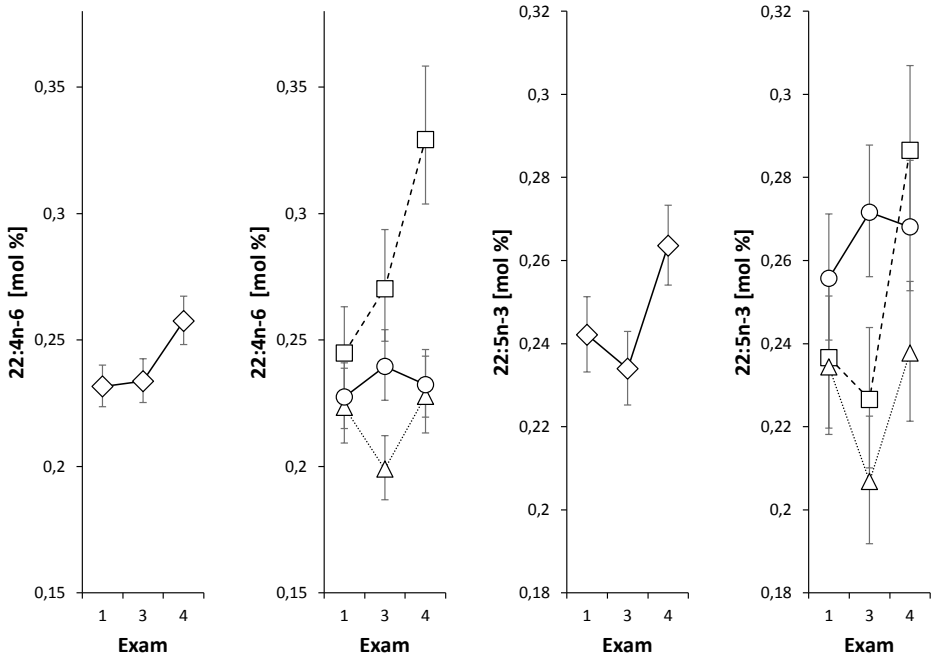

Fig. 3. Docosatetreaenoic (22:4n-6) and docosapentaenoic (22:5n-3) acid in adipose tissue before the surgery (1), after 6 months (3) and after 2 years (4). Squares BPD, triangles LAGB, circles LGCP. 22:4n-6: Exam: F=5.3, p=0.008, Oper x Exam: F=4.0, p=0.006. 22:5n-3: Exam: F=5.6, p<0.006, Oper x Exam: F=2.8, p<0.034.

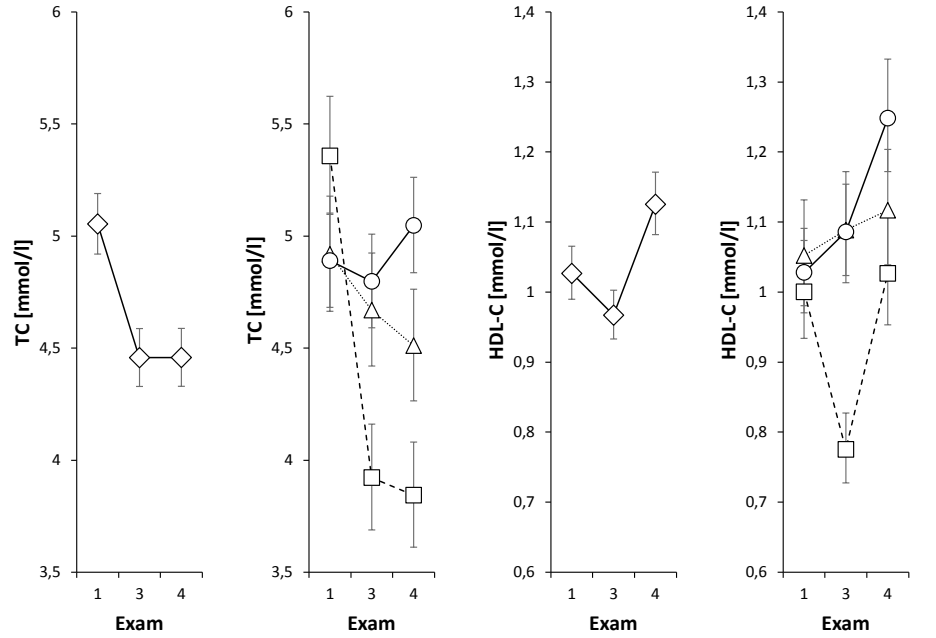

Fig. 4. Total cholesterol and HDL-cholesterol in serum before the surgery (1), after 6 months (3) and after 2 years (4). Squares BPD, triangles LAGB, circles LGCP. TC: Exam: F=13.8, p<0.001, Oper x Exam: F=8.8, p<0.001. HDL-C: Exam: F=8.3, p<0.001, Oper x Exam: F=4.7, p=0.002.

For serum lipids, a significant decrease in total cholesterol was found in the BPD group only, while HDL cholesterol increased significantly after LGCP (Table 4, Fig. 4). The inflammatory marker hsCRP decreased significantly in the BPD group, but only an insignificant decrease was found in the LAGB and LGCP groups (Table 4, Fig. 5).

A significantly higher remission of type 2 diabetes was found after biliopancreatic diversion (in 7 of 8 subjects) in comparison with lapascopic gastric banding (6 of 9 subjects) and laparoscopic greater curvature plication (0/12), P=0.0004. Most of the subjects in the gastric plication group were treated by metformin only (7 of 12 subjects).

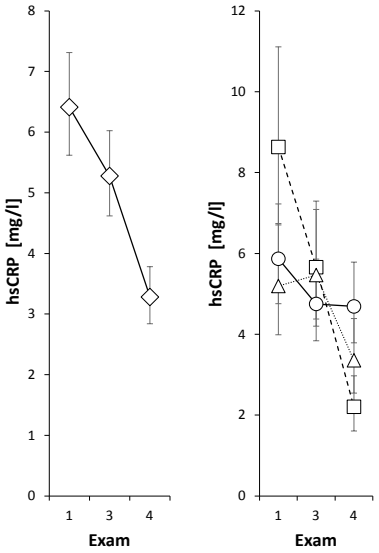

Fig. 5. Hs C-reactive protein in serum before the surgery (1), after 6 months (3) and after 2 years (4). Squares BPD, triangles LAGB, circles LGCP. Exam: F=12.8, p<0.001, Oper x Exam: F=3.7, p=0.01.

Table 1. Characteristic of the subjects and effect of bariatric procedures.

Parameter	Surgery	Exam			ANOVA **	
		1*	3	4	F-ratio	p-value
Age	BPD	52 (48.8, 54.8)	-----	-----		
(years)	LAGB	61.5 (59.4, 63.5)	-----	-----	9.8	<0.001
	GP	53.6 (51.2, 55.8)	-----	-----		
Height	BPD	166 (163, 169)	-----	-----		
(cm)	LAGB	164 (161, 167)	-----	-----	0.5	0.603
	GP	166 (164, 168)	-----	-----		
BMI	BPD	46.4 (44.9, 47.9)	38.5 (37.5, 39.6)	36 (35, 37)		
(kg/m^2)	LAGB	44.8 (43.5, 46.1)	39.6 (38.6, 40.7)	38.4 (37.5, 39.4)	5.5**	0.001
	GP	38.7 (37.8, 39.7)	34.7 (34.1, 35.4)	35.9 (35.2, 36.7)		
Weight	BPD	127 (124, 131)	106 (103, 109)	99.1 (96.5, 102)		
(kg)	LAGB	120 (117, 123)	107 (104, 109)	104 (101, 106)	6.5	<0.001
	GP	107 (104, 109)	95.7 (93.8, 97.6)	99 (97.1, 101)		
Waist	BPD	124 (121, 127)	112 (109, 115)	108 (105, 111)		
(cm)	LAGB	125 (122, 128)	117 (115, 120)	114 (112, 117)	2.6	0.049
	GP	111 (109, 113)	103 (101, 105)	106 (104, 108)		
Hip	BPD	141 (138, 144)	128 (125, 131)	122 (119, 125)		
(cm)	LAGB	138 (136, 141)	133 (130, 135)	130 (127, 132)	4.3	0.005
	GP	129 (127, 131)	120 (118, 123)	124 (122, 127)		
Body fat	BPD	53 (51.8, 54.2)	45.6 (44.3, 46.9)	43.7 (42.2, 45.2)		
(%)	LAGB	51.9 (50.8, 53)	48.9 (47.7, 50)	48.3 (47.2, 49.5)	6.9	<0.001
	GP	50.8 (49.8, 51.7)	47.7 (46.6, 48.7)	47.7 (46.6, 48.7)		
SBP	BPD	128 (121, 135)	115 (109, 122)	117 (110, 124)		
(mm Hg)	LAGB	130 (123, 138)	120 (113, 127)	117 (110, 124)	1.3	0.285
	GP	131 (125, 137)	118 (112, 124)	118 (112, 124)		
DBP	BPD	80.1 (76, 84.4)	71.4 (67.6, 75.3)	68 (64.4, 71.8)		
(mm Hg)	LAGB	81.9 (77.8, 86.3)	82.6 (78.4, 87)	75.1 (70.9, 79.6)	2.9	0.065
	GP	79.5 (76.2, 83)	73 (69.9, 76.3)	73 (69.9, 76.3)		
HR	BPD	82.3 (78.4, 86.3)	75 (71.4, 78.7)	70.8 (67.5, 74.4)		
(/min)	LAGB	78.5 (74.7, 82.5)	72.9 (69.4, 76.7)	71.6 (68.1, 75.3)	0.7	0.512
	GP	75.7 (72.5, 78.9)	71 (68, 74.2)	71 (68, 74.2)		

*mean (lower limit of CI, upper limit of CI at 95 % level); ** ANOVA model Oper x Exam; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate.

Table 2. Changes in adipose tissue saturated and monounsaturated fatty acids.

Variable	Oper	Exam			ANOVA model					
					Oper		Exam		Oper × Exam	
		1	3	4	F-ratio	p-value	F-ratio	p-value	F-ratio	p-value
12:0	BPD	0.17 (0.15, 0.2)	0.15 (0.13, 0.17)	0.24 (0.2, 0.27)						
	LAGB	0.17 (0.15, 0.2)	0.22 (0.19, 0.25)	0.2 (0.18, 0.24)	1.3	0.278	2.7	0.073	2.7	0.037
	LGCP	0.17 (0.15, 0.19)	0.17 (0.15, 0.19)	0.17 (0.15, 0.19)						
14:0	BPD	2.1 (1.99, 2.21)	1.95 (1.85, 2.05)	2.28 (2.17, 2.41)						
	LAGB	1.96 (1.86, 2.06)	2.1 (2, 2.21)	2.03 (1.93, 2.14)	0.6	0.557	2	0.142	2.5	0.054
	LGCP	2.11 (2.02, 2.2)	2.07 (1.98, 2.16)	2.07 (1.98, 2.16)						
14:1n-5	BPD	0.2 (0.18, 0.22)	0.17 (0.15, 0.19)	0.29 (0.25, 0.33)						
	LAGB	0.21 (0.19, 0.24)	0.26 (0.23, 0.29)	0.22 (0.2, 0.25)	0.7	0.52	2.5	0.094	6.7	<0.001
	LGCP	0.23 (0.21, 0.25)	0.2 (0.19, 0.23)	0.2 (0.19, 0.23)						
16:0	BPD	22.8 (22.2, 23.4)	21.8 (21.1, 22.5)	21.5 (20.8, 22.1)						
	LAGB	21.8 (21.1, 22.4)	21.7 (21.1, 22.3)	21.3 (20.6, 21.9)	12.8	<0.001	1.6	0.206	1.2	0.323
	LGCP	23.1 (22.7, 23.6)	23.4 (22.9, 23.8)	23.4 (22.9, 23.8)						
16:1n-9	BPD	0.82 (0.78, 0.86)	0.89 (0.84, 0.93)	0.98 (0.94, 1)						
	LAGB	0.77 (0.74, 0.81)	0.78 (0.74, 0.82)	0.87 (0.83, 0.92)	7.9	<0.001	12.1	<0.001	1.5	0.21
	LGCP	0.79 (0.76, 0.82)	0.82 (0.79, 0.85)	0.82 (0.79, 0.85)						
16:1n-7	BPD	4.41 (3.0, 6.83)	4.29 (2.89, 6.68)	5.28 (3.74, 7.87)						
	LAGB	5.26 (3.58, 8.3)	6.09 (4.27, 9.39)	5.4 (3.7, 8.48)	5.8	0.005	0.9	0.412	3	0.027
	LGCP	4.83 (3.37, 7.32)	4.66 (3.22, 7.11)	4.66 (3.22, 7.11)						
18:0	BPD	16.3 (15.3, 17.5)	18.3 (17, 19.6)	20.8 (19.5, 22.2)						
	LAGB	17.5 (16.4, 18.7)	19.8 (18.6, 21.1)	18.8 (17.6, 20)	8.4	<0.001	4.6	0.013	3.1	0.021
	LGCP	16.3 (15.4, 17.2)	16.5 (15.6, 17.4)	16.5 (15.6, 17.4)						
18:1t	BPD	0.54 (0.51, 0.58)	0.46 (0.44, 0.49)	0.43 (0.41, 0.46)						
	LAGB	0.49 (0.46, 0.51)	0.46 (0.43, 0.48)	0.44 (0.41, 0.46)	12.7	<0.001	11.8	<0.001	1	0.408
	LGCP	0.57 (0.54, 0.6)	0.56 (0.53, 0.59)	0.56 (0.53, 0.59)						
18:1n-9	BPD	46.5 (45.8, 47.1)	47.6 (47, 48.3)	47.3 (46.7, 47.9)						
	LAGB	46.3 (45.7, 46.9)	46 (45.3, 46.6)	47.4 (46.8, 48.1)	0.9	0.414	1.8	0.174	2.2	0.079
	LGCP	46.8 (46.3, 47.4)	46.9 (46.4, 47.5)	46.9 (46.4, 47.5)						
18:1n-7	BPD	2.72 (2.61, 2.84)	2.71 (2.6, 2.83)	2.97 (2.85, 3.09)						
	LAGB	2.8 (2.69, 2.91)	2.84 (2.73, 2.96)	2.75 (2.64, 2.87)	13.1	<0.001	0.3	<0.754	1.9	<0.117
	LGCP	2.54 (2.44, 2.63)	2.55 (2.46, 2.64)	2.55 (2.46, 2.64)						
20:0	BPD	0.068 (0.062, 0.074)	0.064 (0.058, 0.07)	0.057 (0.053, 0.063)						
	LAGB	0.072 (0.066, 0.078)	0.064 (0.059, 0.07)	0.07 (0.064, 0.076)	1	0.382	2.3	0.108	1	0.417
	LGCP	0.066 (0.062, 0.071)	0.066 (0.061, 0.071)	0.066 (0.061, 0.071)						
20:1n-9	BPD	0.69 (0.65, 0.74)	0.71 (0.67, 0.76)	0.76 (0.72, 0.8)						
	LAGB	0.69 (0.65, 0.73)	0.66 (0.62, 0.71)	0.73 (0.69, 0.78)	6.1	0.004	1.4	0.257	1.1	0.391
	LGCP	0.65 (0.62, 0.69)	0.65 (0.61, 0.68)	0.65 (0.61, 0.68)						

*mean (lower limit of CI, upper limit of CI at 95 % level).

Discussion

The main result of the study was the significant difference among bariatric procedures in changes of saturated and monounsaturated fatty acids as well as stearoyl CoA desaturase (SCD1) activity evaluated as the product/precursor ratio. The increases in lauric (12:0), myristoleic (14:1n-5) and palmitoleic (16:1n-7) acid concurrently with the increased activity of SCD1 in the biliopacreatic diversion group suggests lasting enhanced lipogenic activity 2 years after the surgery, in contrast to the LAGB and LGCP subjects. A strong association between the SCD1 product/precursor ratio and mRNA expression has been found in abdominal subcutaneous adipose tissue (Pinnick *et al* 2012).

Table 3. Changes in adipose tissue polyunsaturated fatty acids and sums of saturated, monounsaturated and polyunsaturated fatty acids.

Variable	Oper	Exam			ANOVA model					
					Oper		Exam		Oper × Exam	
		1	3	4	F-ratio	p-value	F-ratio	p-value	F-ratio	p-value
18:2n-6	BPD	13 (12.4, 13.5)	12.8 (12.3, 13.4)	12.5 (12, 13)						
	LAGB	13.3 (12.8, 13.8)	13.1 (12.6, 13.6)	12.5 (12.1, 13)	0.4	0.658	1.9	0.164	0.4	0.793
	LGCP	12.9 (12.5, 13.4)	12.4 (12, 12.9)	12.4 (12, 12.9)						
18:3n-6	BPD	0.03 (0.025, 0.036)	0.025 (0.021, 0.03)	0.036 (0.03, 0.043)						
	LAGB	0.041 (0.034, 0.049)	0.041 (0.035, 0.049)	0.038 (0.032, 0.046)	3.1	0.053	0.5	0.632	0.9	0.445
	LGCP	0.037 (0.032, 0.043)	0.036 (0.031, 0.042)	0.036 (0.031, 0.042)						
18:3n-3	BPD	0.81 (0.76, 0.85)	0.69 (0.65, 0.73)	0.71 (0.67, 0.75)						
	LAGB	0.8 (0.76, 0.84)	0.8 (0.76, 0.84)	0.76 (0.72, 0.8)	1.7	0.185	4.7	0.013	1.7	0.16
	LGCP	0.78 (0.74, 0.82)	0.72 (0.69, 0.75)	0.72 (0.69, 0.75)						
20:2n-6	BPD	0.25 (0.24, 0.27)	0.26 (0.25, 0.28)	0.27 (0.26, 0.29)						
	LAGB	0.26 (0.25, 0.27)	0.25 (0.24, 0.27)	0.24 (0.23, 0.26)	12.6	<0.001	0	0.961	1.1	0.371
	LGCP	0.23 (0.22, 0.24)	0.23 (0.22, 0.24)	0.23 (0.22, 0.24)						
20:3n-6	BPD	0.38 (0.36, 0.41)	0.38 (0.35, 0.41)	0.46 (0.42, 0.5)						
	LAGB	0.35 (0.33, 0.38)	0.32 (0.3, 0.34)	0.36 (0.33, 0.38)	9.6	<0.001	3.3	0.044	2	0.111
	LGCP	0.35 (0.33, 0.37)	0.35 (0.33, 0.37)	0.35 (0.33, 0.37)						
20:4n-6	BPD	0.57 (0.55, 0.6)	0.56 (0.53, 0.59)	0.61 (0.58, 0.64)						
	LAGB	0.59 (0.56, 0.62)	0.58 (0.55, 0.61)	0.6 (0.57, 0.62)	2.1	0.128	1.5	0.235	0.5	0.731
	LGCP	0.57 (0.54, 0.59)	0.55 (0.53, 0.57)	0.55 (0.53, 0.57)						
20:5n-3	BPD	0.054 (0.048, 0.06)	0.045 (0.04, 0.051)	0.053 (0.047, 0.06)						
	LAGB	0.057 (0.05, 0.064)	0.051 (0.046, 0.057)	0.051 (0.045, 0.057)	14.7	<0.001	3.2	0.047	0.6	0.674
	LGCP	0.071 (0.065, 0.077)	0.062 (0.057, 0.068)	0.062 (0.057, 0.068)						
22:4n-6	BPD	0.24 (0.23, 0.26)	0.27 (0.25, 0.29)	0.33 (0.3, 0.36)						
	LAGB	0.22 (0.21, 0.24)	0.2 (0.19, 0.21)	0.23 (0.21, 0.24)	15.3	<0.001	5.3	0.008	4	0.006
	LGCP	0.23 (0.22, 0.24)	0.24 (0.23, 0.25)	0.24 (0.23, 0.25)						
22:5n-6	BPD	0.037 (0.033, 0.042)	0.037 (0.033, 0.043)	0.043 (0.037, 0.05)						
	LAGB	0.034 (0.03, 0.038)	0.031 (0.028, 0.035)	0.033 (0.03, 0.038)	7.1	0.002	0.8	0.45	0.5	0.762
	LGCP	0.029 (0.026, 0.031)	0.031 (0.028, 0.034)	0.031 (0.028, 0.034)						
22:5n-3	BPD	0.24 (0.22, 0.25)	0.23 (0.21, 0.24)	0.29 (0.27, 0.31)						
	LAGB	0.23 (0.22, 0.25)	0.21 (0.19, 0.22)	0.24 (0.22, 0.25)	5.8	0.005	5.6	0.006	2.8	0.034
	LGCP	0.26 (0.24, 0.27)	0.27 (0.26, 0.29)	0.27 (0.26, 0.29)						
22:6n-3	BPD	0.14 (0.13, 0.15)	0.12 (0.11, 0.13)	0.14 (0.12, 0.15)						
	LAGB	0.13 (0.12, 0.14)	0.12 (0.11, 0.13)	0.12 (0.11, 0.13)	14.2	<0.001	0.4	0.669	0.9	0.467
	LGCP	0.15 (0.14, 0.17)	0.16 (0.15, 0.18)	0.16 (0.15, 0.18)						
SFA	BPD	27.5 (26.7, 28.3)	26 (25, 26.9)	25.7 (24.8, 26.6)						
	LAGB	26.9 (26.1, 27.7)	26.6 (25.8, 27.4)	26.3 (25.5, 27.1)	24.1	<0.001	1.5	0.236	1.1	0.359
	LGCP	29 (28.4, 29.6)	29.2 (28.6, 29.8)	29.2 (28.6, 29.8)						
MFA	BPD	56.3 (55.5, 57.1)	57.3 (56.5, 58.2)	58.3 (57.5, 59.2)						
	LAGB	56.6 (55.8, 57.4)	57.1 (56.3, 57.9)	58 (57.2, 58.9)	9.4	<0.001	4	0.024	1	0.431
	LGCP	55.5 (54.9, 56.2)	55.5 (54.8, 56.2)	55.5 (54.8, 56.2)						
PUFAn-6	BPD	14.6 (13.9, 15.2)	14.5 (13.8, 15.2)	14.3 (13.7, 15)						
	LAGB	14.5 (13.9, 15.1)	14.2 (13.6, 14.8)	13.7 (13.2, 14.3)	0.5	0.586	0.4	0.664	0.5	0.771
	LGCP	14.6 (14, 15.1)	14.4 (13.9, 15)	14.4 (13.9, 15)						
PUFAn-3	BPD	1.24 (1.19, 1.29)	1.09 (1.05, 1.13)	1.19 (1.15, 1.24)						
	LAGB	1.24 (1.19, 1.29)	1.17 (1.13, 1.21)	1.16 (1.12, 1.21)	3.7	0.032	7.2	0.002	1.5	0.204
	LGCP	1.27 (1.22, 1.31)	1.22 (1.19, 1.27)	1.22 (1.19, 1.27)						

*mean (lower limit of CI, upper limit of CI at 95 % level).

Table 4. Changes in blood lipids and hsCRP.

Variable	Oper	Exam			ANOVA model					
					Oper		Exam		Oper × Exam	
		1	3	4	F-ratio	p-value	F-ratio	p-value	F-ratio	p-value
TC	BPD	5.36 (5.1, 5.62)	3.92 (3.69, 4.16)	3.84 (3.61, 4.08)						
	LAGB	4.92 (4.66, 5.18)	4.67 (4.42, 4.92)	4.51 (4.26, 4.76)	8.7	<0.001	13.8	<0.001	8.8	<0.001
	LGCP	4.89 (4.68, 5.1)	4.8 (4.59, 5.01)	4.8 (4.59, 5.01)						
HDL	BPD	1 (0.934, 1.07)	0.775 (0.728, 0.827)	1.03 (0.953, 1.11)						
	LAGB	1.05 (0.981, 1.13)	1.09 (1.01, 1.17)	1.12 (1.04, 1.2)	12.7	<0.001	8.3	<0.001	4.7	0.002
	LGCP	1.03 (0.97, 1.09)	1.09 (1.02, 1.15)	1.09 (1.02, 1.15)						
TG	BPD	1.24 (1.07, 1.44)	1.42 (1.22, 1.66)	1.01 (0.876, 1.17)						
	LAGB	1.68 (1.44, 1.99)	1.31 (1.11, 1.54)	1.4 (1.2, 1.64)	2.2	0.123	3.5	0.038	1.8	0.143
	LGCP	1.38 (1.22, 1.57)	1.08 (0.957, 1.21)	1.08 (0.957, 1.21)						
hsCRP	BPD	8.63 (6.7, 11.1)	5.66 (4.38, 7.29)	2.21 (1.61, 2.97)						
	LAGB	5.19 (3.99, 6.74)	5.47 (4.2, 7.09)	3.36 (2.54, 4.39)	0.2	0.819	12.8	<0.001	3.7	0.01
	LGCP	5.87 (4.76, 7.22)	4.75 (3.84, 5.86)	4.75 (3.84, 5.86)						

*mean (lower limit of CI, upper limit of CI at 95 % level); TC, total cholesterol; HDL, HDL cholesterol; TG, triglycerides; hsCRP, high sensitivity C-reactive protein.

The relationship of circulating palmitoleate to insulin sensitivity has been broadly discussed in animals as well as in humans, but with unequivocal conclusions. A large study in Finnish men using proton magnetic spectroscopy for analysis of serum FA profiles showed that an increased percentage of saturated but also n-7 and n-9 monounsaturated FA in serum were biomarkers for an increased risk of the development of hyperglycemia and type 2 diabetes (Mahendran *et al.* 2013). On the other hand, Stefan *et al.* (2010) showed a positive correlation of serum palmitoleate (16:1n-7) with insulin sensitivity measured by oGTT and euglycemic hyperinsulinemic clamp in subjects with increased risk for type 2 diabetes. Additionally, no influence of palmitoleate availability on insulin sensitivity assessed by euglycemic hyperinsulinemic clamp was reported in obese insulin sensitive and insulin resistant subjects (Fabbrini *et al.* 2011).

We found the highest lipogenesis in subjects with the highest weight loss after 2 years, i.e. in the BPD group. This corresponds to the results of the pan-European Diogenes study, where obese subjects were treated by a low calorie diet for two months followed by a six-month weight maintenance regimen (Larsen *et al.* 2010). Significant higher weight loss after 8 months was found in subjects with lower baseline monounsaturated fatty acids (14:1n-5, 16:1n-7 and trans 16:1n-7) in adipose tissue triglycerides (Kunešová *et al.* 2012). When evaluating the relationship of fatty acid composition with mRNA expression from the same biopsy of adipose tissue in the Diogenes study, the central role of myristoleic acid after LCD was associated with the down-regulation of genes involved in fatty acid biosynthesis (SCD, FADS1 and FADS2). After the weight maintenance period, there was a significant positive relationship of 14:1n-5 with genes involved in *de novo* lipogenesis (AACS, FASN, SCD, FADS1, FADS2 and ELOVL5) only in subjects with continuing weight loss in contrast to subjects who regained weight (Monastier *et al.* 2015), suggesting enhanced lipogenesis in subjects with continuing weight loss.

The role of palmitoleate as a possible lipokine has been widely discussed in the past few years. The recent review of Hodson and Karpe (2013) summarized the current knowledge on palmitoleate and emphasized the different roles of palmitoleate in blood and adipose tissue. The localization of adipose tissue was shown to play a major role in the release of palmitoleic acid, with a higher contribution from gluteofemoral subcutaneous fat in comparison with abdominal subcutaneous fat. This difference may be the result of enhanced SCD1 mRNA expression in gluteal adipose tissue (Pinnick *et al.* 2012). In this context, the increase of myristoleic and palmitoleic acids in abdominal subcutaneous fat found in our study could reflect a positive metabolic effect of BPD. A similar result was found in a study comparing overweight and obese subjects in which lower monounsaturated FAs and palmitoleic acid content were found in subcutaneous and visceral adipose tissue, respectively, with increasing adiposity (Garaulet *et al.* 2011).

Polyunsaturated fatty acids are a minor FA component of triglycerides in adipose tissue. An enhanced percentage of docosatetraenoic acid (22:4n-6) in AT was shown in the BPD group after 2 years, in contrast to the LAGB and LGCP groups. This could be the result of a better supply of this FA in food. Better resorption is less probable due to the malabsorptive character of the surgery. Enhanced elongation of arachidonic acid (20:4n-6) or reduced oxidation of n-6 PUFA could be other contributing factors.

The decreased percentage of docosapentaenoic acid (22:5n-3) in the BPD and LAGB groups 6 months after surgery could reflect the increased oxidation of n-3 PUFA or their lower supply from circulation due to decreased intake or absorption. After 2 years, the levels returned to baseline.

Type 2 DM remission

We found significant differences in type 2 diabetes mellitus remission (T2DMR) after individual bariatric procedures. BPD resulted in the highest remission followed by LAGB, while in the LGCP group most subjects were treated by metformin two years after the surgery. Robert *et al.* (2013) did not find differences in T2DMR when comparing Roux-en-Y gastric bypass, sleeve gastrectomy and LAGB. They showed rather that preoperative BMI ≤50 kg/m^2, duration of type 2 diabetes ≤4 years, glycated hemoglobin ≤7.1 %, fasting glucose <1.14 g/l and absence of insulin therapy were positive predictors of diabetes remission. Concurrently, a short duration of diabetes and good preoperative glycemic control increased the rates of T2DM remission. Their results suggest that preoperative metabolic data could be of greater importance than the choice of bariatric procedure. Steven *et al.* (2015) did not distinguish between individual bariatric procedures, but patients in that study mostly (63 %) underwent Roux-en-Y gastric bypass. Significant predictors were maximum percentage of weight loss and baseline HbA1c. Preoperative BMI, diabetes duration and age were not significant predictors. This result was also supported by a meta-analysis that found that diabetes remission is unrelated to basal BMI (Panunzi *et al.* 2015).

Conclusion

Significant differences in the fatty acid composition of adipose tissue triglycerides were found among three methods of bariatric surgery. Biliopancreatic diversion lead to an increase of saturated (12:0, 18:0) and monounsaturated (14:1n-5 and 16:1n-7) fatty acids and stearoyl CoA desaturase 1 after 2 years, suggesting enhanced lipogenesis. The highest type 2 diabetes mellitus remission was found after BPD. In contrast, minor changes were found after laparoscopic gastric banding and laparoscopic greater curvature plication.

Conflict of Interest

There is no conflict of interest.

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