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ORIGINAL ARTICLE

Regulation of abdominal adiposity by probiotics (*Lactobacillus gasseri* SBT2055) in adults with obese tendencies in a randomized controlled trial

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Background/Objectives: In spite of the much evidence for the beneficial effects of probiotics, their anti-obesity effects have not been well examined. We evaluated the effects of the probiotic *Lactobacillus gasseri* SBT2055 (LG2055) on abdominal adiposity, body weight and other body measures in adults with obese tendencies.
Subjects/Methods: We conducted a multicenter, double-blind, randomized, placebo-controlled intervention trial. Subjects ($n=87$) with higher body mass index (BMI) (24.2–30.7 kg/m^2) and abdominal visceral fat area (81.2–178.5 cm^2) were randomly assigned to receive either fermented milk (FM) containing LG2055 (active FM; $n=43$) or FM without LG2055 (control FM; $n=44$), and were asked to consume 200 g/day of FM for 12 weeks. Abdominal fat area was determined by computed tomography.
Results: In the active FM group, abdominal visceral and subcutaneous fat areas significantly ($P<0.01$) decreased from baseline by an average of 4.6% (mean (confidence interval): −5.8 (−10.0, −1.7) cm^2) and 3.3% (−7.4 (−11.6, −3.1) cm^2), respectively. Body weight and other measures also decreased significantly ($P<0.001$) as follows: body weight, 1.4% (−1.1 (−1.5, −0.7) kg); BMI, 1.5% (−0.4 (−0.5, −0.2) kg/m^2); waist, 1.8% (−1.7 (−2.1, −1.4) cm); hip, 1.5% (−1.5 (−1.8, −1.1) cm). In the control group, by contrast, none of these parameters decreased significantly. High-molecular weight adiponectin in serum increased significantly ($P<0.01$) in the active and control groups by 12.7% (0.17 (0.07, 0.26) μg/ml) and 13.6% (0.23 (0.07, 0.38) μg/ml), respectively.
Conclusion: The probiotic LG2055 showed lowering effects on abdominal adiposity, body weight and other measures, suggesting its beneficial influence on metabolic disorders.
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Keywords: abdominal fat; body weight and measures; computed tomography; probiotics; cultured milk products; adiponectin

Introduction

Probiotics, live microorganisms that when administered in adequate amounts confer a health benefit on the host (FAO and WHO, 2001), have been attracting growing interest for their health-promoting effects (Jayaprakasha *et al.*, 2005), and have often been administered in fermented milk (FM) products. Meanwhile, there are a large number of studies on the beneficial effects of consuming more dairy products on metabolic disorders and body weight regulation (Elwood *et al.*, 2004; Teegarden, 2005; Zemel, 2005); these effects are usually attributed to higher calcium intake. However, as far as we know, no human intervention trials have examined the regulatory effects of probiotics on abdominal visceral fat accumulation, an excess of which is considered a crucial factor in the development of a series of metabolic disorders (Fujimoto *et al.*, 1994; Abate and Garg, 1995; Tchernof *et al.*, 1996; Nieves *et al.*, 2003).

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Lactobacillus gasseri SBT2055 (LG2055) is a probiotic that originates from human intestine and has been selected for its ability to improve the intestinal environment (Fujiwara *et al*., 2001; Takahashi *et al*., 2006); it also has other properties as follows: bile tolerance, bile acid deconjugation and binding of cholesterol (Usman and Hosono, 1999); a cholesterol lowering effect in humans with boundary and mild hypercholesterolemia (Kajimoto *et al*., 2002); a preventive effect on dextran sulfate sodium-induced ulcerative colitis in rats (Imai *et al*., 2002); and production of a bacteriocin (Kawai *et al*., 1997, 2000), among others.

Moreover, a further finding regarding probiotics has recently been reported (Sato *et al*., 2008); skim milk fermented with the probiotic LG2055 lowered adipocyte enlargement caused by a high-fat diet in rats. As enlargement of adipocytes is closely related to elevated adipose tissue mass (van Harmelen *et al*., 2003; Cariou *et al*., 2006), this finding raises the possibility that probiotics may have anti-obesity effects, and prompted us to examine such effects in humans.

Thus, in this study, we examined the anti-obesity effects of the probiotic LG2055 in healthy adults with obese tendencies in a randomized controlled trial by measurement of abdominal fat area, body weight and other body measures, and serum adiponectin.

Subjects and methods

Subjects

Eighty-seven generally healthy adults (59 men and 28 women) with body mass index (BMI) between 24.2 and 30.7 kg/m^2, abdominal visceral fat area between 81.2 and 178.5 cm^2 and aged 33–63 years were enrolled for the study. Those who had serious disorders, including internal organ diseases, diabetes and hypersensitivity to dairy products, were excluded.

Study design

This study was performed as a multi-center, double-blind, randomized, placebo-controlled intervention trial. The protocol of this study was in accordance with the Declaration of Helsinki, and was approved by the Institutional Review Board of Isogo Central and Neurosurgical Hospital (Yokohama, Kanagawa, Japan) before initiation of the study. Subjects provided written informed consent before the study began. This study was conducted by a contract research organization, Esucal Laboratories Co., Ltd. (Kitamoto, Saitama, Japan) and was performed from August to December 2008 at the following 10 facilities in Japan: Isogo Central and Neurosurgical Hospital, Kodama Central Hospital (Honjo, Saitama), Yuki Clinic (Shibuya-ku, Tokyo), Ishiguro Clinic (Gifu, Gifu), Kameido-minamiguchi Clinic (Koto-ku, Tokyo), Mizuno Internal Medical Clinic (Tokorozawa, Saitama), Prime Clinic (Konosu, Saitama), Dantsuka Clinic (Iruma, Saitama), Megumidai Clinic (Hiki-gun, Saitama) and Samejima Bonding Clinic (Kumagaya, Saitama).

Probiotic FM

Lactobacillus gasseri SBT2055 (LG2055) was provided in FM. Two types of FM were prepared: an active FM containing LG2055 and a control FM lacking LG2055. The active FM was prepared with lactic acid bacteria starter cultures (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus*) commonly used for conventional yogurt production and viable cells of LG2055. A FM mixture consisting of approximately 11% skim milk powder and a small amount of flavoring, agar and sucralose as a zero-calorie artificial sweetener, was inoculated with the yogurt starter cultures and LG2055 cells, and then cultured at 40 °C for 3.5–4 h. The viable cell count of LG2055 was approximately 5×10^{10} cfu/100 g of FM on the initial day. The control FM was prepared in the same way except that the LG2055 cells were not added. The active and control FMs were identical in energy (43 kcal), protein (4.3 g), fat (0.1 g), carbohydrate (6.1 g), sodium (55 mg) and calcium (140 mg) content per 100 g; they were also indistinguishable in taste. The test FMs were kept in cold storage and delivered weekly.

Study schedule and protocol

The study period consisted of a 4-week lead-in period, followed by a 12-week consumption period in which initiation of the test and consumption of either the active or control FM was designated as week 0 (W0). Subjects were carefully matched with regard to age, body weight and BMI within the medical facilities according to information obtained during the lead-in period, and then randomly assigned to the active ($n = 43$; male: 29, female: 14) or control ($n = 44$; male: 30, female: 14) groups. Subjects consumed 200 g, as two portions of 100 g, of the active or control FM every day for 12 weeks, while they maintained their habitual mode of living including diet and exercise.

Measurement of body weight and other body parameters as well as blood pressure, pulse rate, common blood and urinary tests, and an interview with a doctor were performed at each time point in weeks (W0, W4, W8 and W12). Abdominal computed tomography scans for the measurement of abdominal fat area were carried out at W0 and W12. Each subject made a daily record of taking the test FM, habitual diet and exercise, number of steps walked as the amount of physical activity, and physical condition. A detailed dietary record was also made by subjects for three consecutive days before each test point, and was analyzed by an administrative dietician to determine the intake of energy, protein, carbohydrate, fat and calcium. Subjective symptoms, such as headache, nausea and abdominal pain, were checked by an interview with a doctor at each main time point (W0, W4, W8 and W12).

Abdominal fat area
Four-slice abdominal computed tomography scans were taken at the level of the lumbar 4–5 vertebra, with a 120-kVp tube voltage, 240-mAs tube current, 10-mm slice thickness and 450-mm field of view. These computed tomography scan images taken were analyzed using Fat Scan ver.4 software (East Japan Institute of Technology Co., Ltd., Hitachi, Ibaraki, Japan) to obtain abdominal visceral, subcutaneous, and total (the sum of visceral and subcutaneous) fat areas.

Body weight and other measures, and body fat percentage
Body weight, waist circumference and hip circumference were measured in the usual way. BMI was calculated as body weight (kg)/height (m^2). Body fat percentage was measured by the bioelectrical impedance method using a scale for body composition (Inner Scan 50, TANITA, Tokyo, Japan). Body fat mass and lean body mass were calculated using body fat percentage and body weight.

Serum adiponectin
Total, high-molecular weight (HMW), middle-molecular weight (MMW) and low-molecular weight (LMW) adiponectin levels in serum were determined at W0 and W12. Analysis was carried out by a clinical laboratory testing company, SRL, Inc. (Tokyo, Japan).

Statistical analysis
The interaction between the experimental group and the consumption period of time (group-by-time interaction), and the main effect of the experimental group (group-effect) were analyzed using repeated-measures analysis of variance. Within-group comparisons between W0 and each subsequent time point (W4, W8 and W12) were carried out using repeated-measures analysis of variance followed by Bonferroni multiple comparisons. The between-group comparisons were performed using the amount of change (Δ) from W0 to W4 (ΔW4), from W0 to W8 (ΔW8) and from W0 to W12 (ΔW12) by applying a one-way analysis of variance. We considered a *P*-value of <0.05 to be statistically significant. The primary end-point was the abdominal visceral fat area. The power calculation showed a power of 0.79. The SPSS statistical software package 15.0J for Windows (SPSS Japan Inc., Tokyo, Japan) was used for statistical analyses.

Results

Baseline characteristics of subjects
Subject demographics and physical characteristics at W0 did not differ significantly between the groups. The intake of energy and main nutrients, and the number of steps walked did not show any significant difference between the groups (Table 1); furthermore, none of these parameters showed significant alteration at any time point (W4, W8 and W12). No subject dropped out during the study.

Table 1 Baseline characteristics of subjects

Parameters	*Active*	*Control*
n	43	44
Gender		
Male	29	30
Female	14	14
Age (year)	48.3 ± 9.3	49.2 ± 9.1
Height (cm)	166.9 ± 9.0	168.0 ± 9.1
Body weight (kg)	76.9 ± 9.8	77.1 ± 10.5
BMI (kg/m^2)	27.5 ± 1.7	27.2 ± 1.7
Waist circumference (cm)	93.0 ± 6.1	93.9 ± 5.3
Abdominal visceral fat area (cm^2)	127.3 ± 24.6	119.3 ± 21.4
Nutrient intake		
Energy (kJ/day)	7622.3 ± 1139.1	7613.8 ± 1489.6
(kcal/day)	(1820.9 ± 272.1)	(1818.9 ± 355.9)
Protein (g/day)	67.3 ± 14.3	65.0 ± 13.9
Carbohydrate (g/day)	250.9 ± 43.1	256.2 ± 52.6
Fat (g/day)	54.8 ± 14.7	52.7 ± 15.6
Calcium (mg/day)	320.8 ± 124.0	323.9 ± 161.6
Steps walked (count/day)	8457 ± 3102	7943 ± 2405

Values are means ± s.d.

Abdominal fat areas
Group-by-time interactions were statistically significant for the visceral, subcutaneous and total fat areas. Next, within-group comparisons between W0 and W12 revealed a significant decrease in the visceral, subcutaneous and total fat areas in the active group; by contrast, no significant changes were observed in the control group. Between-group comparisons for ΔW12 showed that the visceral, subcutaneous and total fat areas in the active group decreased significantly compared with those in the control group (Table 2).

Body weight, BMI, waist and hip circumferences, and waist-to-hip ratio
Group-by-time interactions were statistically significant for body weight, BMI, waist and hip circumferences, and waist-to-hip ratio. Next, within-group comparisons between W0 and each subsequent time point (W4, W8 and W12) were carried out. The active group revealed significant decreases from W0 in the following parameters at the stated time points: body weight at W8 and W12, BMI at W8 and W12, waist circumference at W8 and W12, hip circumference at W8 and W12, and waist-to-hip ratio at W8. The control group, by contrast, showed no significant decrease in any parameter of the measured values at any time point. Between-group comparisons were performed for the amount

Table 2 Abdominal fat areas

Parameters	*Values*	*Groups*	*W0*	*W12*			*Group-by-time Group*
Visceral fat (cm^2)	Measured	Active	127.3 (119.7, 134.9)	121.5 (130.2, 112.8)	**		##
		Control	119.3 (112.8, 125.8)	120.7 (114.0, 127.4)			
	Change from W0	Active	—	−5.8 (−10.0, −1.7)		##	
		Control	—	1.4 (−2.2, 5.1)			
Subcutaneous fat (cm^2)	Measured	Active	222.2 (196.9, 247.5)	214.8 (189.4, 240.3)	**		#
		Control	227.8 (204.4, 251.2)	226.5 (204.0, 249.1)			
	Change from W0	Active	—	−7.4 (−11.6, −3.1)		#	
		Control	—	−1.3 (−4.9, 2.4)			
Total fat (cm^2)	Measured	Active	349.5 (322.5, 376.6)	336.3 (309.5, 363.2)	**		##
		Control	347.1 (321.3, 372.9)	347.2 (321.9, 372.6)			
	Change from W0	Active	—	−13.2 (−20.5, −6.0)		##	
		Control	—	0.1 (−5.7, 6.1)			

Values are means (95% confidence interval (CI)). Within-group comparisons between week 0 (W0) and W12: $^{**}P<0.01$. Between-group comparisons: $^{\#}P<0.05$, $^{\#\#}P<0.01$. Group-by-time interaction ('Group-by-time'): $^{\#}P<0.05$, $^{\#\#}P<0.01$. Group-effect ('Group'): not significant.

of change in the case wherein the group-effect was statistically significant. The active group showed significant decreases in body weight, BMI, waist, hip and waist-to-hip ratio for both ΔW8 and ΔW12 as compared with the control group (Table 3).

Body fat percentage, body fat mass and lean body mass
Group-by-time interactions were statistically significant for body fat percentage and body fat mass. Next, within-group comparisons between W0 and each time point (W4, W8 and W12) were carried out. The active group revealed a significant decrease from W0 only in body fat mass at W12. The control group, by contrast, showed no significant decrease in any parameter of the measured values at any time point. Between-group comparisons were performed for the amount of change in the case wherein the group-effect was statistically significant. The active group showed significant decreases in body fat mass for both ΔW8 and ΔW12 as compared with the control group (Table 4).

Serum adiponectin
Group-by-time interactions were statistically significant for the total and MMW adiponectin levels, and the group-effect was significant only for the MMW adiponectin level. The HMW and LMW adiponectin levels showed no group-by-time interactions or group-effect. Between-group comparisons for ΔW12 revealed that the total and MMW adiponectin levels in the control group increased significantly more than those in the active group. These analyses showed that the total and MMW adiponectin levels increased in a different manner between the groups, while the HMW and LMW increased similarly in both groups (Table 5).

Daily life and adverse events
According to the daily record, no irregularity in daily life or adverse events related to consumption of the test FMs were observed throughout the study (data not shown).

Discussion

In this study, intake of the probiotic LG2055 showed significant reductions in abdominal visceral and subcutaneous fat areas, as well as body weight, BMI, waist and hip circumferences, and body fat mass. Of these parameters, the reduction in visceral fat stands out because an excess accumulation of visceral fat is primarily involved in metabolic disorders, and visceral fat is more strongly correlated with most metabolic risk factors than subcutaneous fat (Fox *et al*., 2007). We also think that the reduction in waist circumference is important because waist circumference is involved in a useful measure of fat distribution and is closely correlated with atherogenic lipid profiles (Terry *et al*., 1989). In addition, body fat mass, a calculated variable of body fat percentage measured using the bioelectrical impedance method, which differs from the computed tomography method, was also significantly reduced in the active group. It is likely that the reductions in waist circumference and body fat mass both reflect a decrease in abdominal fat areas, and thus they ensure this result at the same time.

Meanwhile, although the data are not shown here, we noticed neither significant alteration nor physiological abnormality in lipid metabolism-related parameters such as triglycerides, total-, low-density lipoprotein- or high-density lipoprotein-cholesterols; or in fundamental physiological parameters, including blood test, urinary test, blood pressure and pulse rate. Thus, no clinically problematic findings were observed throughout the study in any subject, confirming

Table 3 Body weight, BMI, waist and hip circumferences, and waist-to-hip ratio

Parameters	*Values*	*Groups*	*W0*	*W4*	*W8*		*W12*		*Group-by-time Group*
Body weight (kg)	Measured	Active	76.9 (73.8, 79.9)	76.7 (73.7, 79.7)	76.1 (73.1, 79.1)	***	75.8 (72.8, 78.8)	***	###
		Control	77.1 (73.9, 80.2)	77.0 (73.8, 80.2)	77.3 (74.0, 80.5)		77.4 (74.2, 80.7)		
	Change from W0	Active	—	−0.2 (−0.4, 0.0)	−0.8 (−1.0, −0.4)	*** ###	−1.1 (−1.5, −0.7)	*** ###	###
		Control	—	−0.1 (−0.3, 0.2)	0.2 (−0.1, 0.5)		0.3 (0.0, 0.7)	*	†††
BMI (kg/m^2)	Measured	Active	27.5 (27.0, 28.0)	27.5 (26.9, 28.0)	27.2 (26.7, 27.8)	***	27.1 (26.6, 27.6)	***	###
		Control	27.2 (26.7, 27.7)	27.2 (26.7, 27.7)	27.3 (26.7, 27.8)		27.3 (26.8, 27.9)		
	Change from W0	Active	—	0.0 (−0.1, 0.0)	−0.3 (−0.4, −0.2)	*** ###	−0.4 (−0.5, −0.2)	*** ###	###
		Control	—	0.0 (−0.1, 0.1)	0.1 (−0.0, 0.2)		0.1 (0.0, 0.3)	*	†††
Waist (cm)	Measured	Active	93.0 (91.1, 94.8)	92.6 (90.8, 94.4)	91.8 (90.0, 93.6)	***	91.3 (89.4, 93.1)	*** #	###
		Control	93.9 (92.3, 95.5)	93.8 (92.1, 95.5)	94.0 (92.4, 95.7)		93.9 (92.2, 95.6)		
	Change from W0	Active	—	−0.4 (−0.7, −0.1)	−1.2 (−1.5, −0.9)	*** ###	−1.7 (−2.1, −1.4)	*** ###	###
		Control	—	−0.1 (−0.4, 0.2)	0.1 (−0.2, 0.4)		0.0 (−0.4, 0.4)		†††
Hip (cm)	Measured	Active	101.1 (99.2, 102.9)	100.9 (99.1, 102.7)	100.3 (98.5, 102.0)	***	99.6 (97.8, 101.4)	***	###
		Control	100.9 (99.2, 102.6)	100.9 (99.2, 102.7)	100.6 (99.0, 102.3)		100.6 (98.9, 102.3)		
	Change from W0	Active	—	−0.2 (−0.5, 0.1)	−0.8 (−1.1, −0.5)	*** #	−1.5 (−1.8, −1.1)	*** ###	###
		Control	—	0.0 (−0.4, 0.4)	−0.3 (−0.7, 0.2)		−0.3 (−0.8, 0.1)		†
Waist-to-hip ratio	Measured	Active	0.920 (0.910, 0.931)	0.918 (0.907, 0.929)	0.916 (0.905, 0.927)	#	0.916 (0.905, 0.928)	#	##
		Control	0.931 (0.920, 0.942)	0.930 (0.919, 0.941)	0.935 (0.924, 0.946)		0.934 (0.923, 0.945)		
	Change from W0	Active	—	−0.002 (−0.006, 0.001)	−0.004 (−0.008, −0.002)	##	−0.004 (−0.007, −0.001)	##	#
		Control	—	−0.001 (−0.005, 0.003)	0.004 (−0.001, 0.007)		0.003 (−0.001, 0.007)		†

Abbreviations: BMI, body mass index; CI, confidence interval; W0, week 0.
Values are means (95% CI). Within-group comparisons between W0 and each time point (W4, W8, W12): *$P<0.05$, ***$P<0.001$. Between-group comparisons: $^{\#}P<0.05$, $^{\#\#}P<0.01$, $^{\#\#\#}P<0.001$. Group-by-time interaction ('Group-by-time'): $^{\#}P<0.05$, $^{\#\#}P<0.01$, $^{\#\#\#}P<0.001$. Group-effect ('Group'): $^{\dagger}P<0.05$, $^{\dagger\dagger\dagger}P<0.001$.

Table 4 Body fat percentage, body fat mass and lean body mass

Parameters	*Values*	*Groups*	*W0*	*W4*	*W8*		*W12*			*Group-by-time Group*
Body fat percentage (%)	Measured	Active	30.6 (28.6, 32.6)	30.6 (28.7, 32.6)	30.3 (28.4, 32.2)		30.1 (28.2, 32.0)			##
		Control	30.0 (28.1, 31.9)	30.0 (28.0, 31.9)	30.3 (28.4, 32.3)		30.2 (28.4, 32.1)			
	Change from W0	Active	—	0.0 (−0.4, 0.4)	−0.3 (−0.8, 0.1)	#	−0.5 (−1.0, 0.0)	*	#	##
		Control	—	0.0 (−0.3, 0.4)	0.3 (0.0, 0.8)		0.2 (−0.2, 0.7)			
Body fat mass (kg)	Measured	Active	23.5 (21.7, 25.2)	23.4 (21.8, 25.1)	23.0 (21.3, 24.6)		22.7 (21.1, 24.3)	*		###
		Control	22.9 (21.4, 24.4)	22.9 (21.4, 24.5)	23.3 (21.7, 24.9)		23.2 (21.8, 24.6)			
	Change from W0	Active	—	−0.1 (−0.4, 0.3)	−0.5 (−0.9, −0.1)	** ##	−0.8 (−1.2, −0.3)	**	##	###
		Control	—	0.0 (−0.3, 0.3)	0.4 (0.0, 0.7)	*	0.3 (−0.1, 0.7)			††
Lean body mass (kg)	Measured	Active	53.4 (50.7, 56.1)	53.3 (50.6, 56.0)	53.2 (50.5, 55.8)		53.1 (50.4, 55.8)			
		Control	54.2 (51.2, 57.1)	54.1 (51.1, 57.0)	54.0 (51.0, 57.0)		54.2 (51.2, 57.3)			
	Change from W0	Active	—	−0.1 (−0.4, 0.2)	−0.2 (−0.6, 0.1)		−0.3 (−0.7, 0.0)			
		Control	—	−0.1 (−0.3, 0.2)	−0.2 (−0.4, 0.1)		0.0 (−0.3, 0.5)			

Values are means (95% confidence interval (CI)). Within-group comparisons between week 0 (W0) and each time point (W4, W8, W12): $^{*}P<0.05$, $^{**}P<0.01$. Between-group comparisons: $^{\#}P<0.05$, $^{\#\#}P<0.01$. Group-by-time interaction ('Group-by-time'): $^{\#\#}P<0.01$, $^{\#\#\#}P<0.001$. Group-effect ('Group'): $^{\dagger\dagger}P<0.01$.

the safety of the probiotic and FM tested. (Supplementary information regarding the blood test and the blood biochemical test is available at the *European Journal of Clinical Nutrition's* website.).

Energy intake and the number of steps in terms of the amount of physical activity were also normal, as shown in Table 1. However, the subjects had a tendency to be overweight. We speculate that factors other than energy intake and physical activity have been involved in inducing these obese tendencies. For example, some reports have indicated that aspects of a modern lifestyle such as staying up late at night and various kinds of stress, affect the autonomic nervous system, which in turn leads to the occurrence of obesity (Buijs and Kreier, 2006; Kyrou *et al*., 2006).

We believe that the effects observed in this study were because of the LG2055 cells and/or their metabolites. In this study, we used two tests for FMs whose base was a yogurt prepared using conventional yogurt cultures: one was a control FM, which was yogurt without LG2055 cells; the other was an active FM, which was yogurt to which LG2055 cells were added. Although yogurt cultures themselves can be considered probiotics (Guarner *et al*., 2005; Mater *et al*., 2005; Elli *et al*., 2006), we can exclude their influence here because the yogurt cultures used were common to both of the test FMs; in fact, the control FM group showed no significant reduction in any parameter. Moreover, the control and active FMs were identical in nutrient content. Thus, the effects observed in this study cannot be attributed to the conventional yogurt cultures or such components as calcium, conjugated linoleic acid or amino acids, which are widely known factors that provide the beneficial effects of dairy products (Teegarden, 2005).

We consider that the inhibition of lipid absorption is a possible mechanism underlying the observed effects. After the observation of the regulatory effect of FM with LG2055 on the size of adipocytes in rats (Sato *et al*., 2008), Hamad *et al*. (2009) further studied lipid content in the lymph in rats with permanent cannulation of the thoracic duct. They showed that rats fed a diet containing fermented skim milk with LG2055 showed a lower rate of maximum lymphatic lipid absorption than rats fed a diet containing nonfermented skim milk; reduced absorption was also supported by the observation of increased fatty acid excretion in the feces. It may be necessary to examine further whether inhibition of lipid absorption occurs in humans.

In addition, there are other possible mechanisms. It has recently emerged that intestinal microbes have an important role in body weight regulation by influencing energy metabolism (Ley *et al*., 2006; Turnbaugh *et al*., 2006; DiBaise *et al*., 2008; Sanz *et al*., 2008; Tennyson and Friedman, 2008). For a decrease in body weight, there must be a shift in the balance between available energy utilization and food intake, leading to a net energy deficit. Although the possible effect of a reduction in food intake in diabetic mice has been reported for other species of *Lactobacillus gasseri* (Yun *et al*., 2009), this possibility cannot account for our results because

Table 5 Serum adiponectin

Parameter	*Values*	*Groups*	*W0*	*W12*			*Group-by-time Group*
Total adiponectin (μg/ml)	Measured	Active	3.63 (3.20, 4.06)	4.07 (3.55, 4.59)	***	#	#
		Control	4.14 (3.64, 4.65)	4.88 (4.28, 5.48)	***		
	Change from W0	Active	—	0.44 (0.28, 0.59)		#	
		Control	—	0.74 (0.49, 0.98)			
HMW adiponectin (μg/ml)	Measured	Active	1.34 (1.08, 1.61)	1.51 (1.20, 1.83)	**		
		Control	1.69 (1.35, 2.04)	1.92 (1.53, 2.31)	**		
	Change from W0	Active	—	0.17 (0.07, 0.26)			
		Control	—	0.23 (0.07, 0.38)			
MMW adiponectin (μg/ml)	Measured	Active	0.87 (0.76, 1.00)	0.95 (0.83, 1.07)		#	#
		Control	0.98 (0.87, 1.08)	1.21 (1.05, 1.36)	***		†
	Change from W0	Active	—	0.08 (−0.01, 0.17)		#	
		Control	—	0.23 (0.12, 0.35)			
LMW adiponectin (μg/ml)	Measured	Active	1.42 (1.31, 1.52)	1.61 (1.43, 1.78)	**		
		Control	1.48 (1.35, 1.60)	1.75 (1.59, 1.91)	**		
	Change from W0	Active	—	0.19 (0.07, 0.31)			
		Control	—	0.27 (0.13, 0.42)			

Abbreviations:CI, confidence interval; HMW, high-molecular weight; LMW, low-molecular weight; MMW, middle-molecular weight; W0, week 0.
Values are means (95% CI). Within-group comparisons between W0 and W12: $^{**}P<0.01$, $^{***}P<0.001$. Between-group comparisons: $^{\#}P<0.05$. Group-by-time interaction ('Group-by-time'): $^{\#}P<0.05$. Group-effect ('Group'): $^{\dagger}P<0.05$.

the level of energy intake did not differ between the groups. It is also likely that the inflammatory status of the body, on which components of intestinal microbes have an effect, has been involved in these obese tendencies (Cani *et al*., 2007). We consider that LG2055 used in this study may have an influence on energy metabolism and inflammatory status of the body through intestinal microbes, because this probiotic has the ability to become established in the intestine of humans and to improve the intestinal environment. Such properties of LG2055, in concert with its ability to decrease lipid absorption, may lead to decreases in abdominal fat and other body measures. Additional research is needed to clarify further the mechanisms underlying the effects observed in our study.

Adiponectin is an adipocyte-derived serum protein that has important roles in the regulation of lipid and glucose metabolism (Matsuzawa *et al*., 2004), and is present in the blood as three multimers: LMW (trimer), MMW (hexamer) and HMW (12- to 18-mers) multimers (Waki *et al*., 2003). Of these multimers, the HMW multimer is more responsible than the LMW and MMW multimers for the favorable activities of adiponectin, including its insulin-sensitizing effects (Kobayashi *et al*., 2004; Hara *et al*., 2006; Nakashima *et al*., 2006); these findings suggest the importance of considering multimer distribution as well as total levels when interpreting serum adiponectin. In our study, the HMW adiponectin level increased significantly in both groups, indicating no specific influence of LG2055 on HMW adiponectin, but instead the favorable effect of FM itself. By contrast, the MMW adiponectin level increased significantly only in the control group, which might have led to the increased level of total adiponectin in the control group as compared with the active group. More examination is required to consider why these differences in adiponectin levels occurred.

In summary, the probiotic LG2055 showed lowering effects on abdominal adiposity, body weight and other measures of subjects with obese tendencies, suggesting its beneficial influence on metabolic disorders.

Conflict of interest

The authors declare no conflict of interest.

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