

The Effect of Protein and Glycemic Index on Children's Body Composition: The DiOGenes Randomized Study

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KEY WORDS

childhood adiposity, dietary intervention, DiOGenes, glycemic index, protein, randomized controlled trial

ABBREVIATIONS

HP—high protein

GI—glycemic index

LGI—low glycemic index

HGI—high glycemic index

DiOGenes—Diet, Obesity, and Genes

LCD—low-calorie diet

LP—low protein

This trial has been registered at www.clinicaltrials.gov (identifier NCT00390637).

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WHAT'S KNOWN ON THIS SUBJECT: The potential of HP and LGI diets to promote weight loss in adults has resulted in research to investigate the effect of these diets on weight control in children; results have been promising but still conflicting.



WHAT THIS STUDY ADDS: In the DiOGenes study, a European family-based, randomized, controlled, multicenter, 6-month energy ad libitum dietary intervention study, the LP/HGI diet increased body fat, whereas overweight/obesity decreased in those on the HP/LGI diet.

abstract

OBJECTIVE: To investigate the effect of protein and glycemic index (GI) on body composition among European children in the randomized, 6-month dietary intervention DiOGenes (diet, obesity, and genes) family-based study.

PATIENTS AND METHODS: In the study, 827 children (381 boys and 446 girls), aged 5 to 18 years, completed baseline examinations. Families with parents who lost $\geq 8\%$ of their weight during an 8-week run-in low-calorie diet period were randomly assigned to 1 of 5 ad libitum diets: low protein (LP)/low glycemic index (LGI); LP/high GI (HGI); high protein (HP)/LGI; HP/HGI; and control diet. The target difference was 15 GI U between the LGI/HGI groups and 13 protein percentage points between the LP/HP groups. There were 658 children examined after 4 weeks. Advice on food-choice modification was provided at 6 visits during this period. No advice on weight loss was provided because the focus of the study was the ability of the diets to affect outcomes through appetite regulation. Anthropometric measurements and body composition were assessed at baseline, week 4, and week 26.

RESULTS: In the study, 465 children (58.1%) completed all assessments. The achieved differences between the GI and protein groups were 2.3 GI U and 4.9 protein percentage points, respectively. The LP/HGI group increased body fat percentage significantly more than the other groups ($P = .040$; partial $\eta^2 = 0.039$), and the percentage of overweight/obese children in the HP/LGI group decreased significantly during the intervention ($P = .031$).

CONCLUSIONS: Neither GI nor protein had an isolated effect on body composition. However, the LP/HGI combination increased body fat, whereas the HP/LGI combination was protective against obesity in this sample of children. *Pediatrics* 2010;126:e1143–e1152

Adiposity in childhood is associated with increased risk of mortality.¹⁻⁵ Recent increases in energy intake, produced by untoward changes in macronutrient composition^{4,6} and factors such as portion size, availability and cost of food and soft drinks, and reduction in physical activity, have reportedly played a major role in the rise of obesity.^{4,7} With high-protein (HP) diets, weight loss is promoted⁸ and weight regain in adults is prevented,⁹ most probably by increasing satiety.¹⁰ However, this has not been indicated in obese children.^{11,12} Low-glycemic index (LGI) diets are also suggested to promote weight loss in adults, mainly by promoting satiety and reducing hunger.^{13,14} However, the clinical usefulness of GI in weight regulation has been questioned.¹⁵ In children, LGI meals compared with HGI meals significantly reduced subsequent energy intake and hunger in some,^{13,16} but not all,¹⁷ studies.

The effect of HP, LGI diets in children has not been assessed in large-scale, randomized controlled studies. We aimed to investigate the effect of protein and GI on body weight, anthropometric measurements, and body composition among free-living children after a 6-month, family-based dietary intervention. It should be noted that no advice on weight loss was provided to children because the intervention gave less emphasis on energy intake (which was ad libitum), but focused on the ability of the diets to regulate appetite and thus body weight and composition. This study is part of the European integrated project DiOGenes (Diet, Obesity, and Genes), which focused on dietary means of preventing weight gain^{9,18,19} and was performed in 8 European centers.

PATIENTS AND METHODS

Participants

Volunteer families from 8 countries (Netherlands, Denmark, United King-

dom, Greece, Germany, Spain, Bulgaria, and Czech Republic) were invited to participate during the period from November 2005 to April 2007. Families attended a screening examination to determine eligibility. Eligible families were generally healthy, with at least 1 parent overweight (BMI ≥ 27 kg/m²) and younger than 65 years, and at least 1 child between the age of 5 and 18 years.⁹ Recruitment strategies and exclusion criteria for parents are provided in detail elsewhere.⁹ Exclusion criteria for children were special diets, food intolerances, systemic infections/chronic diseases, use of medication that might influence study outcomes, and drug or alcohol abuse. Informed consent was obtained from parents and assent was obtained from the children, according to local legislation. The study was approved by the local medical ethical committees in the respective countries.

Study Design and Procedures

A description of the design and study procedures are provided in an earlier report.⁹ In short, eligible adults underwent an 8-week low-calorie diet (LCD) period after their screening, during which the enrolled children received no intervention. During the seventh week of the LCD, children attended a clinical examination (representing baseline),⁹ when anthropometric pa-

rameters and body composition were assessed and a 3-day weighed dietary record was provided. Families with at least 1 parent who lost $\geq 8\%$ of weight during the LCD were randomly assigned to 1 of 5 ad libitum diets: low protein (LP)/LGI; LP/HGI; HP/LGI; HP/HGI; and control diet (national dietary guidelines, with medium protein content and no specific instructions on GI).¹⁹ Eligible families were allocated to a dietary intervention group by using a simple block randomization procedure with stratification.⁹

Randomization was followed by (1) in Maastricht and Copenhagen, a 6-month supermarket period (free food provided to families by laboratory shops, in addition to dietary instructions),^{20,21} and (2) in remaining centers, a 6-month dietary instruction-only period. Families followed their randomized diet for 6 months. Children attended a second clinical examination 4 weeks into their randomized diet (same measurements as baseline, apart from body composition) and a final examination at the end of the 6-month intervention (week 26, same measurements as baseline) (Fig 1).

Dietary Instruction Period

On the day families were randomly assigned, trained dietitians gave detailed

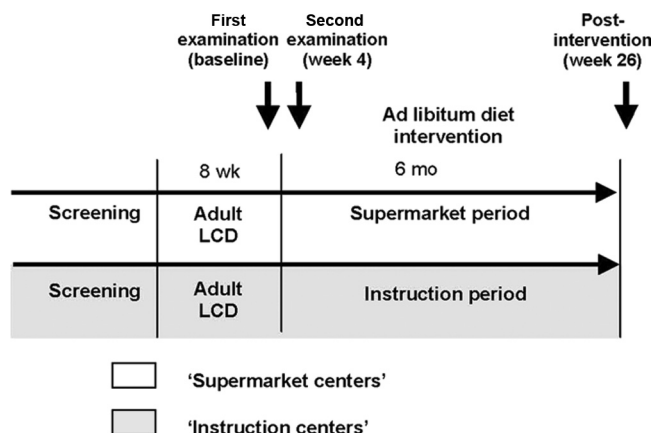


FIGURE 1 Design of the dietary intervention for children at the supermarket and the instruction centers.

instructions on the ad libitum diets. All diets were low in fat (25%–30% of energy). The target was for protein content to comprise 10% to 15% of energy intake in the LP and 23% to 28% in the HP groups, complying with the acceptable range (10%–30%) for children aged 4 to 18 years.²² Children in the LGI groups were advised to consume the LGI foods, and those in the HGI groups to consume the HGI foods within a food group.¹⁹ The aim was to achieve a 15-point GI difference between the HGI and LGI groups. The assignment of GI values to foods is reported separately.²³

Children were encouraged to be present during the randomization visit; otherwise, parents were instructed to aid their children with their randomized diets. During the intervention, children were requested to attend 6 counseling sessions, accompanied by their parents, during which intensive guidance was provided. Dietitians advised on weight control and reinforced the diet composition messages¹⁹ through food-choice and behavior-modification advice. A detailed description of the diets is provided elsewhere.¹⁹

Anthropometric Measurements

Standard operating procedures were produced for all investigations undertaken to ensure standardization across the centers. Moreover, the same measurement devices were used in each center on every occasion a measurement was provided.⁹ Subjects had been fasting for 4 hours before the clinical examinations, and they were measured in their underwear and with an empty bladder.

Weight was measured on calibrated digital scales (Seca 861, Hamburg, Germany) to the nearest 0.1 kg, and height was measured to the nearest millimeter with a wall-mounted stadiometer (Seca 225, Hamburg, Germany), without shoes, on all examinations and di-

etary counseling sessions. BMI was calculated as weight divided by height, squared (kg/m^2), and weight status was determined according to the age- and gender-specific International Obesity Task Force iso-BMI ≥ 25 limits.²⁴ Waist circumference (measured midway between the lower rib and iliac crest) and hip circumference (measured at the widest point between the hips and buttocks) circumference were measured twice, to the nearest 0.5 cm, with a tape in a vertical plane and with the subject standing and gently breathing out. The mean of the 2 measurements was recorded. Waist-to-hip ratio was then calculated.⁹

Body Composition

Body composition was determined by dual-energy radiograph absorption (Lunar Radiation, Madison, WI) or bioelectric impedance analysis (Quad-Scan 4000; Bodystat, Douglas, Isle of Man, United Kingdom). Children who participated in the determination of body composition were fasting (no intake of foods or liquids for at least 4 hours before the investigations except for a water intake of 350–500 mL).⁹

Dietary Records

All families were provided with weighing scales (Soehnle 1208 Actuell Backnang, Germany) and were instructed to record their food and liquid intake for 3 consecutive days (2 weekdays and 1 weekend day). Participants were required to weigh all foods and beverages consumed, as well as leftovers, and to provide cooking methods and recipes for composite meals. When weighing was not possible, participants were instructed to record their intake in household measures. Parents were instructed to aid their children with the recording process when appropriate. Dietary records were checked for completeness on return to clarify any uncertainties. The method

of analysis of dietary records is reported elsewhere.^{9,25}

Statistical Analysis

Primary outcome measures were changes in anthropometric measurements, BMI z score, and body composition during the intervention. Secondary outcomes were changes in the proportion of overweight and obese children and changes in waist-to-hip circumference ratio. Baseline characteristics of participants were compared between the different countries by using the Kruskal Wallis rank test and Pearson's χ^2 test. Changes in dietary intakes during the intervention were calculated for those participants who provided food diaries at baseline, week 4, and week 26, and comparisons between dietary groups were performed by using the Kruskal Wallis test. Comparisons of overall changes in anthropometric measurements during the dietary intervention between dietary groups were performed by using analysis of covariance, with age, gender, family structure (single parent, couple with 1 randomized, and couple with both randomized), and country as covariates. These analyses were performed for "completers only" (all randomized subjects with data from all clinical examinations), as well as on an "intention-to-treat" basis, by using the multiple imputation technique for all randomly assigned subjects.^{25,26} For the completers' analysis, the observed power effect size was 72%. In addition, the differences in effect between the protein groups and the GI groups and potential interaction between GI and protein content were analyzed by analysis of covariance (same covariates as above). A McNemar test was used to examine changes in weight status (overweight and obese children) within the dietary groups. All analyses were performed by using SPSS 17.0 (SPSS Inc, Chicago,

IL), and significance was defined as $P < .05$.

RESULTS

A total of 1140 children were registered to attend screening, and 827 attended the baseline examination. Eight hundred children were randomly assigned, and 465 (201 boys, 264 girls) attended all clinical examinations (baseline, week 4, and week 26) and were included in present analyses. In total, 335 children (41.9% of those randomly assigned) dropped out or were excluded during the dietary intervention because of their parents' withdrawal, noncompliance with study requirements, or because they did not attend at least 1 of the above mentioned clinical examinations (completers only) (Fig 2). Baseline characteristics did not differ between completers and children who did not provide information at all visits or dropped out (data not shown).

Baseline characteristics of children who completed the intervention at the 8 different centers are shown in Table 1. Children differed in various variables between the different centers. There were no baseline differences in anthropometric measurements between the 5 dietary groups (completers' analysis).

Only 113 children (24.3% of those who attended all clinical examinations) recorded their dietary intake at all 3 time points. At all time points, self-reported dietary protein content had increased significantly in the HP groups, resulting in a 4.9-percentage point difference between the HP and LP groups at week 26 ($P < .001$) (Table 2). Between baseline and 26 weeks, the proportion of energy from carbohydrates was reduced more in the HP group than in the LP group (-2.6 vs 4.8% ; $P < .001$). GI was reduced in the 2 LGI groups at week 26, resulting in a 2-point difference between the LGI and HGI groups

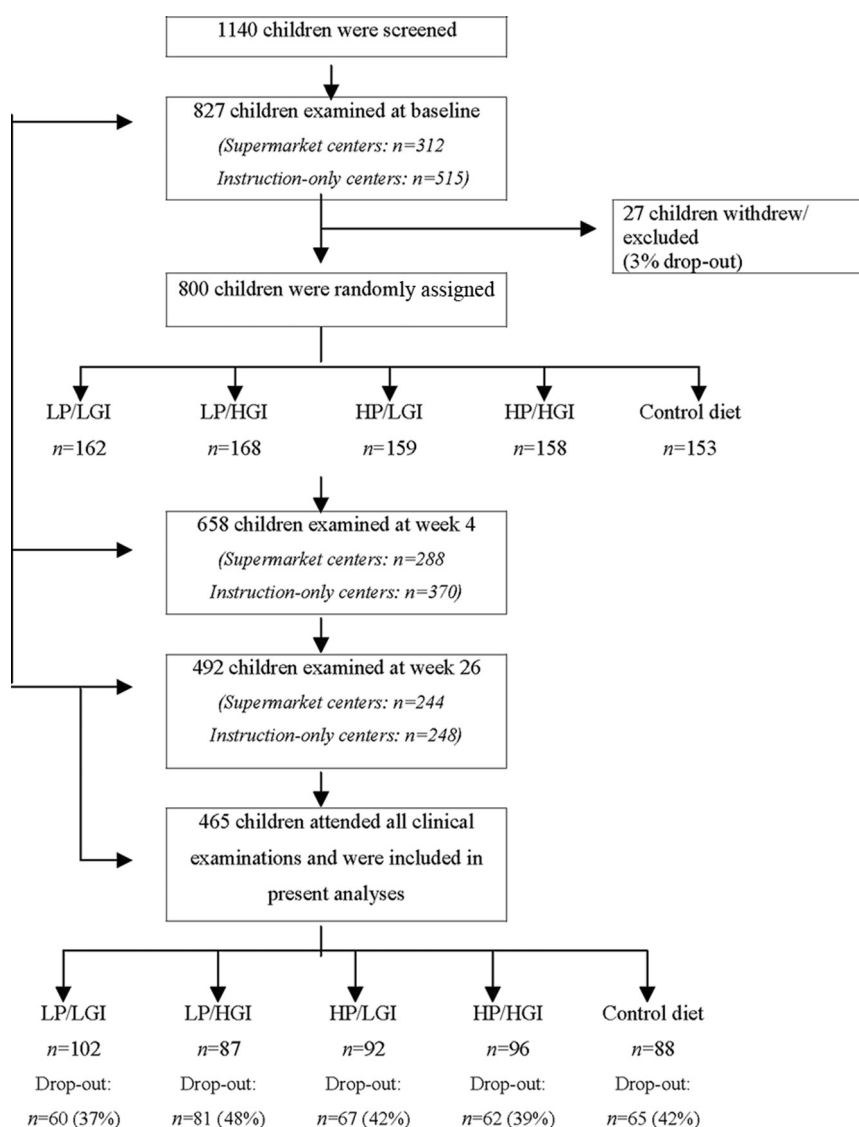


FIGURE 2

Flow diagram in which the progress of the participants from screening to the end of intervention is shown.

($P = .013$). Glycemic load was, as expected, reduced more in the HP group than in the LP group during the intervention (-37.9 vs -12.8 g/day; $P = .006$). The proportion of energy from fat did not differ among groups and was within the recommended levels of 25% to 30% at 4 and 26 weeks.

Between baseline and 26 weeks, there was a significant increase among the overall sample (completers) in body weight (53.2 vs 54.4 kg; $P < .001$), height (1.53 vs 1.55 m; $P < .001$), hip circumference (85.5 vs 85.9 cm; $P =$

$.041$), and fat-free mass (37.7 vs 39.0 kg; $P < .001$), whereas waist-to-hip ratio (0.855 vs 0.846 ; $P < .001$) and waist-to-height ratio (0.477 vs 0.467 ; $P < .001$) were significantly reduced. No statistically significant differences in changes in outcome measures among the dietary groups were observed during the intervention, apart from a statistically significant increase in body fat percentage in the LP/HGI group ($P = .040$; partial $\eta^2 = 0.039$) and a statistically significant reduction in the percentage of overweight/obese chil-

TABLE 1 Baseline (First Examination) Characteristics of Study Participants Who Completed the Intervention (N = 465) at the 8 Centers

	Netherlands	Denmark	United Kingdom	Greece	Germany	Spain	Bulgaria	Czech	Total
Boys									
Age, mean ± SD (n), y	10.8 ± 3.1 (44)	11.5 ± 3.5 (53)	12.3 ± 2.8 (26)	11.9 ± 3.7 (12)	12.6 ± 3.4 (17)	12.4 ± 3.6 (32)	13.9 ± 3.4 (13)	11.7 ± 2.4 (4)	11.9 ± 3.4 (201)
Weight, mean ± SD (n), kg	46.8 ± 20.9 (44)	52.8 ± 25.3 (53)	53.2 ± 20.3 (26)	69.6 ± 29.4 (12)	54.7 ± 20.2 (17)	51.5 ± 18.6 (32)	71.0 ± 25.8 (13)	58.6 ± 18.7 (4)	53.8 ± 23.2 (201) ^a
Height, mean ± SD (n), m	1.48 ± 19 (44)	1.52 ± 22 (53)	1.56 ± 16 (26)	1.86 ± 22 (12)	1.59 ± 19 (17)	1.53 ± 17 (32)	1.64 ± 14 (13)	1.57 ± 19 (4)	1.53 ± 0.19 (201)
BMI, mean ± SD (n)	20.1 ± 4.5 (44)	21.5 ± 5.2 (53)	21.3 ± 4.8 (26)	27.0 ± 5.1 (12)	20.9 ± 5.0 (17)	21.3 ± 4.4 (32)	25.7 ± 5.8 (13)	23.2 ± 2.6 (4)	21.8 ± 5.1 (200) ^b
Weight status, OW/OB, %	13.6/18.2	32.1/17.0	33.3/6.3	25.0/66.7	23.5/11.8	34.5/10.3	36.5/56.5	50.0/25.0	28.1/19.4 ^b
WC, mean ± SD (n), cm	70.8 ± 15.6 (43)	72.9 ± 15.3 (53)	74.9 ± 14.3 (26)	86.8 ± 14.9 (12)	72.3 ± 13.7 (17)	72.2 ± 12.4 (32)	76.3 ± 11.4 (4)	77.6 ± 5.1 (4)	73.6 ± 14.6 (191)
HC, mean ± SD (n), cm	73.8 ± 15.4 (43)	84.3 ± 17.0 (53)	88.1 ± 12.8 (24)	99.9 ± 16.9 (12)	85.2 ± 13.9 (17)	85.7 ± 12.7 (32)	87.3 ± 11.9 (4)	90.8 ± 9.3 (4)	83.9 ± 16.1 (189) ^b
Waist/hip ratio, mean ± SD (n)	0.960 ± 0.053 (43)	0.866 ± 0.047 (53)	0.846 ± 0.065 (24)	0.870 ± 0.064 (12)	0.848 ± 0.053 (17)	0.842 ± 0.053 (32)	0.874 ± 0.064 (4)	0.857 ± 0.036 (4)	0.879 ± 0.069 (189) ^b
Waist/height ratio, mean ± SD (n)	0.478 ± 0.067 (43)	0.480 ± 0.061 (53)	0.479 ± 0.065 (25)	0.567 ± 0.070 (12)	0.456 ± 0.066 (17)	0.473 ± 0.065 (32)	0.499 ± 0.088 (4)	0.497 ± 0.031 (4)	0.482 ± 0.067 (190)
FFM, mean ± SD (n), kg	35.5 ± 16.6 (23)	40.2 ± 17.5 (29)	40.7 ± 11.5 (19)	49.5 ± 20.1 (11)	42.1 ± 16.2 (16)	37.9 ± 13.8 (14)	—	47.2 ± 15.2 (4)	40.5 ± 16.1 (116)
FM, mean ± SD (n), kg	10.8 ± 8.0 (23)	19.9 ± 10.8 (29)	13.4 ± 7.6 (19)	22.9 ± 11.3 (11)	11.2 ± 7.2 (16)	15.5 ± 7.2 (14)	—	11.5 ± 4.0 (4)	15.3 ± 9.6 (116) ^b
Fat, mean ± SD (n), %	20.9 ± 10.0 (42)	29.4 ± 9.5 (26)	37.0 ± 14.1 (12)	31.7 ± 8.0 (11)	19.8 ± 9.2 (16)	28.5 ± 6.4 (14)	—	19.7 ± 3.5 (4)	25.8 ± 11.8 (125) ^b
Total energy intake, mean ± SD (n), kJ/d	7717 ± 2664 (37)	8541 ± 2392 (51)	8450 ± 3095 (19)	8421 ± 2462 (12)	8982 ± 2580 (12)	7499 ± 2471 (23)	—	7223 ± 1317 (4)	8176 ± 2564 (158)
Girls									
Age, mean ± SD (n), y	12.3 ± 3.2 (63)	11.8 ± 3.5 (73)	13.2 ± 3.0 (26)	11.9 ± 3.6 (7)	12.5 ± 3.8 (16)	11.7 ± 3.8 (29)	14.1 ± 3.3 (28)	12.9 ± 3.9 (22)	12.4 ± 3.5 (264)
Weight, mean ± SD (n), kg	51.3 ± 20.0 (63)	50.7 ± 19.4 (73)	51.7 ± 16.9 (26)	61.3 ± 24.4 (7)	53.6 ± 22.9 (16)	49.9 ± 18.9 (29)	59.9 ± 19.2 (28)	57.2 ± 21.1 (22)	52.8 ± 19.8 (264)
Height, mean ± SD (n), m	1.52 ± 15 (62)	1.51 ± 18 (73)	1.56 ± 13 (26)	1.51 ± 15 (7)	1.53 ± 18 (16)	1.49 ± 19 (29)	1.57 ± 14 (28)	1.54 ± 16 (22)	1.52 ± 0.16 (263)
BMI, mean ± SD (n)	21.6 ± 5.2 (62)	21.4 ± 4.5 (73)	20.6 ± 5.7 (24)	25.7 ± 6.5 (7)	21.7 ± 5.6 (16)	21.5 ± 4.1 (29)	23.5 ± 4.7 (28)	23.4 ± 5.4 (22)	21.9 ± 5.0 (261)
Weight status, OW/OB, %	25.4/15.9	38.6/14.3	23.1/7.7	14.3/57.1	18.8/18.8	35.0/5.0	42.9/10.7	68.2/9.1	34.5/13.9
WC, mean ± SD (n), cm	72.3 ± 12.8 (61)	70.5 ± 12.2 (73)	71.3 ± 12.1 (25)	85.0 ± 15.3 (7)	69.4 ± 12.5 (15)	71.1 ± 10.4 (28)	78.9 ± 20.1 (9)	73.8 ± 11.5 (22)	72.1 ± 12.7 (240)
HC, mean ± SD (n), cm	80.8 ± 15.1 (61)	86.3 ± 15.4 (73)	91.4 ± 14.1 (25)	100.2 ± 19.8 (7)	84.7 ± 14.9 (15)	87.9 ± 14.8 (28)	93.9 ± 18.7 (9)	91.5 ± 14.7 (22)	86.7 ± 15.7 (240) ^b
Waist/hip ratio, mean ± SD (n)	0.898 ± 0.055 (61)	0.821 ± 0.070 (73)	0.777 ± 0.050 (24)	0.853 ± 0.069 (7)	0.821 ± 0.056 (15)	0.816 ± 0.076 (28)	0.834 ± 0.071 (9)	0.809 ± 0.048 (22)	0.836 ± 0.073 (239) ^b
Waist/height ratio, mean ± SD (n)	0.477 ± 0.062 (61)	0.468 ± 0.058 (73)	0.451 ± 0.070 (23)	0.559 ± 0.072 (7)	0.457 ± 0.055 (15)	0.477 ± 0.051 (28)	0.497 ± 0.088 (9)	0.480 ± 0.049 (22)	0.474 ± 0.062 (238) ^b
FFM, mean ± SD (n), kg	37.1 ± 12.0 (46)	34.0 ± 9.9 (47)	35.5 ± 10.7 (22)	34.5 ± 11.5 (6)	36.8 ± 13.7 (16)	32.4 ± 14.3 (21)	—	41.0 ± 13.4 (19)	35.8 ± 11.7 (177)
FM, mean ± SD (n), kg	15.2 ± 7.8 (46)	18.6 ± 11.5 (47)	17.0 ± 10.0 (22)	20.5 ± 9.2 (6)	17.1 ± 10.2 (16)	15.7 ± 7.3 (21)	—	17.0 ± 10.1 (19)	16.9 ± 9.6 (477)
Fat, mean ± SD (n), %	26.8 ± 8.6 (61)	32.4 ± 10.1 (48)	32.2 ± 6.9 (19)	36.4 ± 7.1 (6)	29.9 ± 9.1 (16)	31.9 ± 7.5 (21)	—	28.3 ± 7.2 (19)	30.0 ± 8.9 (490) ^b
Total energy intake, mean ± SD (n), kJ/d	7782 ± 1752 (53)	7827 ± 2536 (62)	7939 ± 2167 (18)	9032 ± 661 (7)	7737 ± 2414 (15)	6535 ± 2303 (22)	—	7981 ± 2051 (16)	7727 ± 2208 (193)

OW indicates overweight; OB, obese; WC, waist circumference; HC, hip circumference; FFM, fat-free mass; FM, fat mass. Age and gender were recorded at screening; the other variables are from baseline. The distributions of weight status at the different centers were compared by using the Pearson χ^2 test. The other variables were compared (between centers) by using the Kruskal Wallis rank test: ^a $P < .05$, ^b $P < .01$.

dren in the HP/LGI group (Table 3; Figs 3 and 4). When the main effect of protein and GI and the interaction between protein and GI were assessed, no significant changes in outcome measures were observed between the groups. Multiple imputation confirmed that the LP/HGI group had the highest increase in body fat percentage: imputation number 4 ($P = .034$) and imputation number 5 ($P = .013$).

DISCUSSION

Excess adiposity is said to be the most serious health problem that affects children in developed countries.⁴ The potential of HP⁸ and LGI¹⁴ diets to promote weight loss in adults has resulted in research that investigates the effect of these diets on weight control in children, with promising but still conflicting results. The DiOGenes study has several strengths compared with earlier studies because it involved a prospective large-scale, randomized controlled design. With the intervention we examined the effectiveness of the diet (application in a real-life setting), and the family-based plan encouraged support between family members that could positively affect treatment in children.^{4,9}

Our most significant finding, that the combination of LP and HGI increased body fat percentage, may suggest that this dietary combination does not affect body composition favorably. LP diets hinder satiety and energy expenditure and inhibit fat oxidation by increasing insulin response.¹⁰ In addition, carbohydrates with HGI are rapidly digested, thereby increasing insulin levels, stimulating hunger, and promoting food intake and the accumulation of body fat.^{14,27–29} These mechanisms may explain the increase in body fat observed in the LP/HGI group. In contrast, the percentage of overweight/obese children in the HP/LGI group decreased significantly during

TABLE 2 Mean Changes in Self-reported Total Energy and Macronutrient Intake, GI, and Glycemic Load in the 5 Dietary Groups, for Children Who Provided Dietary Records at Baseline, Week 4 and Week 26

Measurement	N	Diet	First Examination (Baseline)		Week 4, Mean (SE)	Δ Change (Week 4 From Baseline)	Week 26 (After Intervention), Mean (SE)	Δ Change (Week 26 From Baseline)	Δ Change (Week 26 From Week 4)
			N	Mean (SE)					
Total Energy intake, kJ/d	113	LP/LGI	20	8361 (515)	6213 (440)	-2148	7081 (490)	-1280	868
		LP/HGI	19	6893 (528)	5758 (452)	-1135	5785 (502)	-1108	27
		HP/LGI	24	7307 (470)	5478 (402)	-1830	6253 (447)	-1054	775
		HP/HGI	29	8479 (427)	6151 (366)	-2328	6878 (407)	-1601	727
		Control diet	21	8676 (502)	6482 (430)	-2194	6879 (478)	-1797	397
<i>P</i>						.446		.845	.851
Carbohydrates, % energy	113	LP/LGI	20	52.5 (1.5)	61.3 (1.5)	8.8	60.2 (1.7)	7.7	-1.1
		LP/HGI	19	52.6 (1.5)	58.1 (1.5)	5.5	58.0 (1.8)	5.3	-0.2
		HP/LGI	24	52.5 (1.3)	52.5 (1.4)	0.0	50.6 (1.6)	-2.0	-2.0
		HP/HGI	29	54.1 (1.2)	51.7 (1.2)	-2.4	49.9 (1.4)	-4.2	-1.9
		Control diet	21	51.9 (1.4)	54.3 (1.5)	2.4	54.6 (1.7)	2.7	0.3
<i>P</i>						<.001		<.001	.826
Total fat, % energy	113	LP/LGI	20	31.9 (1.3)	22.3 (1.3)	-9.6	24.0 (1.7)	-7.9	1.7
		LP/HGI	19	32.1 (1.3)	25.9 (1.4)	-6.2	25.9 (1.7)	-6.3	0.0
		HP/LGI	24	33.5 (1.2)	25.7 (1.2)	-7.8	28.1 (1.5)	-5.5	2.3
		HP/HGI	29	31.0 (1.1)	26.9 (1.1)	-4.2	27.6 (1.4)	-3.5	0.7
		Control diet	21	33.2 (1.3)	28.2 (1.3)	-5.0	28.5 (1.6)	-4.7	0.3
<i>P</i>						.173		.527	.938
Protein, % energy	113	LP/LGI	20	15.2 (0.7)	16.0 (0.9)	0.8	15.9 (0.9)	0.6	-0.1
		LP/HGI	19	15.2 (0.7)	16.0 (0.9)	0.8	16.2 (1.0)	1.0	0.2
		HP/LGI	24	13.9 (0.6)	21.6 (0.8)	7.7	21.4 (0.9)	7.5	-0.2
		HP/HGI	29	14.5 (0.6)	21.4 (0.7)	6.9	22.6 (0.8)	8.1	1.2
		Control diet	21	14.9 (0.7)	17.5 (0.9)	2.6	16.9 (0.9)	1.9	-0.7
<i>P</i>						<.001		<.001	.759
GI, %	113	LP/LGI	20	62.7 (0.9)	58.9 (1.1)	-3.8	60.8 (1.2)	-1.9	2.0
		LP/HGI	19	62.5 (1.0)	62.6 (1.1)	0.1	62.9 (1.3)	0.4	0.3
		HP/LGI	24	61.9 (0.9)	57.0 (1.0)	-4.9	56.9 (1.1)	-5.0	-0.1
		HP/HGI	29	63.7 (0.8)	64.2 (0.9)	0.6	63.9 (1.0)	0.2	-0.4
		Control diet	21	60.6 (0.9)	61.4 (1.0)	0.8	61.8 (1.2)	1.2	0.5
<i>P</i>						<.001		.001	.607
Glycemic load, g/d	113	LP/LGI	20	161.9 (10.2)	133.6 (9.2)	-28.3	153.4 (11.3)	-8.6	19.8
		LP/HGI	19	129.6 (10.5)	120.6 (9.4)	-8.9	123.9 (11.6)	-5.7	3.2
		HP/LGI	24	139.0 (9.3)	94.4 (8.4)	-44.6	105.0 (10.3)	-34.0	10.6
		HP/HGI	29	169.6 (8.5)	120.5 (7.6)	-49.2	128.0 (9.4)	-41.6	7.6
		Control diet	21	161.7 (10.0)	126.4 (9.0)	-35.3	139.0 (11.0)	-22.7	12.6
<i>P</i>						.041		.062	.587

Comparisons of overall changes between dietary groups were performed by using the Kruskal-Wallis rank test.

the intervention, which is in line with the purported beneficial impact of HP and LGI diets on satiety, weight loss, and fat oxidation.^{9,10,13,14} Considering the lack of isolated effect of protein and GI in the present study, it might be that the combination of protein and GI is a more important factor that affects insulin response and thus also hunger and fat accumulation.

Bioelectric impedance analysis has been suggested to generally underestimate body fat in comparison with dual-energy x-ray absorption.³⁰ However, the 2 methods were not used interchangeably in this study. Thus, each

child was measured by using the same method each time body composition was determined. In addition, although there are some differences in outcome between the 2 methods, the main interest of our study was the Δ -change in body composition. Although body fat percentage measurements were only available for 262 participants, there were no differences in age, gender, baseline BMI, or dietary group between those who provided this measurement and those who did not.

Advice on dietary protein (LP versus HP) did not influence body weight and other anthropometric measurements in this

sample of European children. However, the HP group's protein intake comprised ~20% of energy, which was lower than the 23% to 28% recommended in this group. The LP group's protein intake comprised ~16% of energy at week 26, slightly above the recommended 10% to 15%. Consistent with 2 earlier reports in which the effect of HP compared with normal-protein diets, on body weight, and body composition in obese children and adolescents were examined, the lack of protein effect in our study might have been the result of the HP groups not reaching their recommended protein intake levels and the subsequent smaller-

TABLE 3 Mean Changes of Outcome Measures Over the 6-Month Dietary Intervention Period

Measurement	N	Diet	N	First Examination (Baseline), Mean (SE)	Week 4, Mean (SE)	Δ Change (Week 4 From Baseline)	Week 26 (After Intervention), Mean (SE)	Δ Change (Week 26 From baseline)	Δ Change (Week 26 From Week 4)
Weight, kg	465	LP/LGI	102	52.9 (1.3)	52.7 (1.3)	-0.16	54.0 (1.2)	1.17	1.33
		LP/HGI	87	52.3 (1.4)	52.4 (1.4)	0.05	53.6 (1.4)	1.25	1.21
		HP/LGI	92	53.5 (1.4)	53.4 (1.3)	-0.14	54.5 (1.3)	0.95	1.08
		HP/HGI	96	53.7 (1.3)	53.5 (1.3)	-0.28	54.5 (1.3)	0.76	1.04
		Control diet	88	53.7 (1.4)	53.8 (1.4)	0.08	55.4 (1.3)	1.66	1.58
<i>P</i>						.689		.621	.747
Height, m	464	LP/LGI	103	1.54 (0.008)	1.54 (0.008)	0.01	1.56 (0.008)	0.02	0.02
		LP/HGI	85	1.52 (0.008)	1.53 (0.008)	0.01	1.54 (0.009)	0.02	0.02
		HP/LGI	92	1.52 (0.008)	1.52 (0.008)	0.01	1.54 (0.008)	0.03	0.02
		HP/HGI	96	1.54 (0.008)	1.55 (0.008)	0.01	1.57 (0.008)	0.03	0.02
		Control diet	88	1.52 (0.008)	1.53 (0.008)	0.01	1.55 (0.009)	0.02	0.02
<i>P</i>						.565		.938	.738
BMI	460	LP/LGI	101	21.14 (0.42)	20.95 (0.41)	-0.18	21.12 (0.40)	-0.01	0.17
		LP/HGI	85	21.86 (0.46)	21.72 (0.44)	-0.14	21.80 (0.44)	-0.07	0.08
		HP/LGI	91	22.14 (0.44)	21.92 (0.43)	-0.21	21.81 (0.43)	-0.33	-0.11
		HP/HGI	95	21.89 (0.45)	21.68 (0.42)	-0.21	21.70 (0.42)	-0.19	0.02
		Control diet	88	22.28 (0.43)	22.11 (0.44)	-0.16	22.35 (0.43)	0.07	0.23
<i>P</i>						.966		.445	.375
BMI z score	460	LP/LGI	101	-0.140 (0.083)	-0.144 (0.083)	-0.004	-0.130 (0.085)	0.009	0.013
		LP/HGI	85	0.004 (0.091)	0.013 (0.091)	0.008	0.011 (0.093)	0.007	-0.001
		HP/LGI	91	0.058 (0.088)	0.054 (0.088)	-0.005	0.014 (0.089)	-0.045	-0.040
		HP/HGI	95	0.011 (0.086)	0.005 (0.086)	-0.005	-0.009 (0.088)	-0.020	-0.014
		Healthy diet	88	0.087 (0.089)	0.094 (0.089)	0.007	0.128 (0.091)	0.041	-0.034
<i>P</i>						.952		.439	.379
WC, cm	428	LP/LGI	96	71.2 (1.1)	70.5 (1.1)	-0.68	70.9 (1.1)	-0.26	0.43
		LP/HGI	75	42.3 (1.3)	71.9 (1.2)	-0.80	72.6 (1.2)	-0.08	0.72
		HP/LGI	87	72.7 (1.2)	72.5 (1.2)	-0.24	72.3 (1.2)	-0.45	-0.21
		HP/HGI	88	74.0 (1.2)	73.2 (1.2)	-0.88	72.9 (1.2)	-1.11	-0.28
		Control diet	82	73.5 (1.2)	73.4 (1.2)	0.02	73.4 (1.2)	0.05	0.03
<i>P</i>						.517		.538	.454
HC, cm	426	LP/LGI	95	83.7 (1.1)	83.7 (1.0)	-0.06	84.5 (1.0)	0.79	0.85
		LP/HGI	75	83.9 (1.2)	84.0 (1.1)	0.21	84.9 (1.2)	0.99	0.78
		HP/LGI	88	85.7 (1.1)	85.4 (1.1)	-0.31	85.8 (1.2)	0.15	0.47
		HP/HGI	87	87.5 (1.1)	86.4 (1.1)	-1.04	87.3 (1.1)	-0.21	0.83
		Control diet	81	86.6 (1.1)	86.5 (1.1)	-0.05	87.1 (1.1)	0.51	0.56
<i>P</i>						.140		.402	.958
Waist/hip ratio	424	LP/LGI	95	0.855 (0.007)	0.848 (0.007)	-0.007	0.844 (0.007)	-0.012	-0.005
		LP/HGI	75	0.870 (0.008)	0.858 (0.008)	-0.012	0.859 (0.007)	-0.011	0.001
		HP/LGI	86	0.852 (0.007)	0.853 (0.007)	0.001	0.845 (0.007)	-0.007	-0.008
		HP/HGI	87	0.850 (0.007)	0.851 (0.007)	0.000	0.839 (0.007)	-0.011	-0.011
		Control diet	81	0.850 (0.007)	0.850 (0.007)	0.000	0.845 (0.007)	-0.005	-0.005
<i>P</i>						.277		.832	.532
Waist/height ratio	425	LP/LGI	95	0.465 (0.007)	0.457 (0.007)	-0.006	0.454 (0.007)	-0.009	-0.005
		LP/HGI	75	0.478 (0.007)	0.471 (0.007)	-0.007	0.471 (0.007)	-0.008	0.000
		HP/LGI	86	0.481 (0.007)	0.477 (0.007)	-0.004	0.470 (0.007)	-0.011	-0.007
		HP/HGI	87	0.483 (0.007)	0.477 (0.007)	-0.006	0.470 (0.007)	-0.013	-0.007
		Control diet	82	0.484 (0.007)	0.481 (0.007)	-0.003	0.477 (0.007)	-0.008	-0.007
<i>P</i>						.761		.689	.489
FFM, kg	295	LP/LGI	57	39.7 (0.9)	—	—	41.5 (1.0)	1.80	—
		LP/HGI	55	37.5 (1.0)	—	—	38.8 (1.0)	1.02	—
		HP/LGI	68	37.2 (0.9)	—	—	38.4 (0.9)	1.39	—
		HP/HGI	56	38.1 (1.0)	—	—	39.3 (1.0)	1.27	—
		Control diet	59	36.1 (1.0)	—	—	37.1 (0.9)	0.99	—
<i>P</i>						.233		—	
FM, kg	295	LP/LGI	57	15.2 (1.1)	—	—	14.7 (1.1)	-0.53	—
		LP/HGI	55	14.9 (1.2)	—	—	15.2 (1.1)	0.12	—
		HP/LGI	68	16.6 (1.1)	—	—	16.3 (0.9)	0.12	—
		HP/HGI	56	17.1 (1.1)	—	—	16.3 (1.1)	-0.44	—
		Control diet	59	16.5 (1.1)	—	—	16.6 (1.0)	-0.25	—
<i>P</i>						.531		—	
Fat, %	262	LP/LGI	60	25.2 (1.2)	—	—	24.4 (1.3)	-0.84	—
		LP/HGI	41	26.7 (1.5)	—	—	28.2 (1.5)	1.53	—
		HP/LGI	57	28.2 (1.3)	—	—	28.9 (1.3)	0.73	—
		HP/HGI	56	28.9 (1.3)	—	—	29.4 (1.3)	0.44	—
		Control diet	48	28.4 (1.4)	—	—	27.8 (1.4)	-0.63	—
<i>P</i>						.040 ^a		—	

Comparisons of overall changes between dietary groups were performed by using analysis of covariance, with age, gender, family structure, and country as covariates. Effect-size estimates for analysis of covariance were determined with partial η^2 ($\eta^2 = 0.01$ is a small effect size, 0.06 is a medium effect size, and 0.14 is large effect size). WC indicates waist circumference; HC, hip circumference; FFM, fat free mass; FM, fat mass.

^a Partial $\eta^2 = 0.039$.

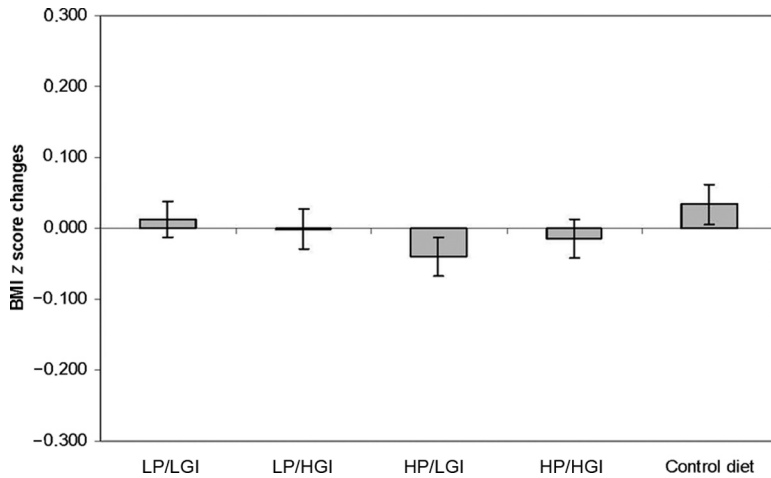


FIGURE 3

Mean changes in BMI z scores over the 6-month dietary intervention. Bars indicate SE. Levels of significance were assessed by using analysis of covariance (age, gender, family structure, and country as covariates).

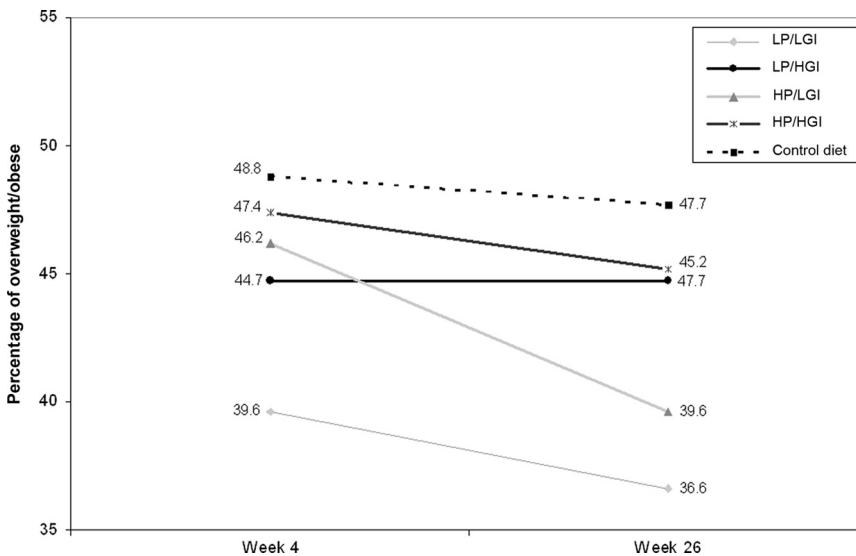


FIGURE 4

Changes in the proportion of overweight and obese children over the 6-month dietary intervention. Levels of significance were assessed by using McNemar test.^a $P = .031$ for the HP/LGI group.

than-intended protein intake difference between the HP and LP groups.^{11,12}

It has been suggested that LGI diets are inversely associated with overweight when compared with HGI diets.^{13,14,16,29,31} The majority of earlier studies have demonstrated this protective effect of LGI diets in children by assessing the short-term effects of LGI meals.^{13,16,32} Although our intervention was not focused on weight loss, making comparisons with earlier studies

problematic, the present study showed that GI did not affect body weight in children, thereby calling into question the long-term potential of such diets on weight control. However, our intervention was not successful in achieving the recommended 15-point GI difference between the LGI and HGI groups because the self-reported difference was 2.3GI U. LGI diets, when compared with HGI diets, have also been found to decrease fat mass and

increase lean body mass in adults.³³ The present study did not show any beneficial impact of the LGI diet compared with the HGI diet on children's body composition. The outcome in the LGI and HGI groups was within the normal range of variation, contradicting an earlier study in which the impact of LGI and HGI meals on body weight among children was compared.³⁴

Results from the current study are not directly comparable to earlier reports. In contrast with earlier studies,^{11,12,35} the current intervention did not give emphasis on weight loss, but examined how appetite regulation would affect body weight. In addition, the inclusion of normal-weight children in our sample did not allow for advice on weight loss to be provided to children. Nevertheless, it is promising that this intervention produced favorable changes in some anthropometric measurements in the overall sample of children. The DiOGenes study is also the first dietary study in which the effect of both protein and GI content in children from different countries is examined.⁹

Although children were not always present at the randomization visit when their prescribed diet would be explained to them, research has indicated that parents are able to lower the GI of their child's diet after a description of the LGI diet.³⁶ However, the high dropout rate limits the external validity of our findings. This level of attrition approximates an earlier intervention study³⁵ but is higher compared with studies in which diets with varying protein content in children were examined.^{11,12} Because both of these earlier studies were conducted in controlled settings, the high dropout rate in our sample may reflect the difficulties participants confront when trying to change their diet in real-life settings. Perhaps the high dropout rate also resulted in the lower-than-expected observed effect size of 72%.

However, children's participation was completely dependent on their parents; thus, a child would withdraw if their parents withdrew their participation. Indeed, the fact that children randomly assigned to the LP/HGI group were more likely to withdraw from the study or not attend all examinations is consistent with what was reported in the LP/HGI adult participants of the DiOGenes study, who also gained the highest amount of body weight and had the lowest decrease of fat mass during the intervention compared with the other dietary groups.⁹ Also, children might have enrolled at the insistence of their parents, which may have resulted in varying degrees of motivation to comply with study requirements. This might have led to the low compliance with the dietary record completion. Future intervention studies should address the need for active involvement of children to increase their effectiveness.

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CONCLUSIONS

The results of this study show that neither GI nor protein had an isolated effect on body composition

among this sample of children after an ad libitum diet, with emphasis on appetite regulation rather than weight loss. However, the LP/HGI combination increased body fat, whereas the HP/LGI combination was protective against obesity. The limitations of the study should be considered before effective dietary macronutrient composition to reduce childhood adiposity are established.

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The Effect of Protein and Glycemic Index on Children's Body Composition: The DiOGenes Randomized Study

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