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A Low Glycemic Index Diet Combined with an Aerobic-Resistance Exercise Program Reduces Risk Factors Associated with the Metabolic Syndrome

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Abstract

Background: The purpose of this study was to examine the effects of Low Glycemic Index (LGI) and High Glycemic Index (HGI) versions of a low fat, Moderate Carbohydrate (CHO), moderate protein diet, when combined with an exercise program, on Cardiovascular Disease (CVD) risk factors in people with Metabolic Syndrome (MetS).

Methods: The four groups included *ad libitum* and 30% calorie restricted high and low GI diets. Twenty six individuals completed the 12 week intervention. Data was collected prospectively at weekly counselling sessions.

Results: Calorie restriction was similar between groups (p=0.543), and thus the groups were pooled, leaving only the HGI and LGI groups. The LGI group significantly reduced the GI of their diet (10.5 GI units), significantly reduced the number of subjects classified with MetS (8 people), and had significantly greater improvements in total body weight (7.2 kg), BMI (2.0 kg/m^2), percent body fat (3.3 %) and hip circumference (4.9 cm) compared to the HGI groups, as well as additional improvements in waist circumference (6.3 cm), blood pressure (10.5 mmHg systolic, 5.5 mmHg diastolic), triglycerides (0.6 mmol/L). Both groups had similar improvements in fitness. There were no significant changes in fasting levels of blood glucose, serum insulin, and serum total, HDL, or LDL cholesterol.

Conclusions: The LGI diet and exercise program had a greater ability to reduce the number and severity of CVD risk factors in individuals with MetS, and represents valuable knowledge from which future lifestyle interventions can be developed to reduce the incidence of MetS and the development of CVD.

Keywords: Metabolic syndrome; Low glycemic index; Obesity; Cardiovascular disease

Introduction

Metabolic Syndrome (MetS) is a cluster of metabolic factors that increase Cardiovascular Disease (CVD) and includes abdominal obesity, hypertension, dyslipidemia and impaired fasting glucose [1]. The current definition of MetS was established in 2005 by the International Diabetes Federation (IDF), and is defined as having an elevated Waist Circumference (WC) with ethnic specific cutoffs (europids: ≥ 102 cm in males, ≥ 88 cm in females), plus any two of the following: elevated triglycerides (TG) (>1.7 mmol/L or undergoing treatment), reduced HDL cholesterol (<1.03 mmol/L in males, <1.29 mmol/L in females, or undergoing treatment), raised Blood Pressure (BP) (systolic BP ≥ 130 mmHg, diastolic BP ≥ 85 mmHg, or undergoing treatment), or raised fasting plasma glucose (>5.6 mmol/L, or previously diagnosed Type 2 Diabetes (T2D)) [2]. The main goal in the management of MetS is to reduce the development of CVD by reducing the number and severity of risk factors. The consensus is that a modified lifestyle, including a modified diet and an increase in physical activity, should be the first line of treatment; however the optimal diet for disease prevention has yet to be determined. Many dietary approaches have been successful for weight loss, including low-fat diets [3-5], low carbohydrate (CHO) diets [6-10], and high protein diets [11-14], however, these diets have difficulty addressing the entire MetS profile. There has been limited research on lifestyle interventions using subjects with MetS [15-17], however these studies are too few in number and variety of design to recommend one specific treatment.

Previous work from our lab found that a reduced fat, moderate protein, moderate CHO diet when combined with exercise was easy to maintain and effective in reducing MetS risk factors in overweight women, however it did not modify fasting glucose levels [18]. Low Glycemic Index (LGI) diets can improve insulin sensitivity [19-21] and reduce the risk of T2D [22]. Furthermore, LGI diets have high satiety and may promote spontaneous energy restriction [19,23,24], as well as improve dyslipidemia [19,25-29], promote reductions in body fat mass [30] and BMI [31], and reduce CVD risk [32-34]. The attractiveness of the LGI approach and in particular the Glycemic Load (GL) is that they consider both the quality and quantity of carbohydrates and the potential for interaction between them and with other nutrient and non-nutritive components of foods. The aim of the current study was to address whether the combination of a LGI diet with a low fat, moderate CHO, moderate protein diet, when combined with exercise, could reduce CVD risk factors in people with MetS. The main objectives were to determine if i) the GI would influence how the diet impacts the MetS risk factors, and ii) if calorie restriction is necessary in a LGI diet to reduce energy consumption and reduce disease risk. This study examined the short-term effects of four low fat, moderate CHO, moderate protein diets that differed in mean GI and calorie restriction, combined with exercise in free living adults with MetS. It was hypothesized that the calorie restricted LGI diet would be more beneficial than the HGI or *ad libitum* versions of the diets.

Methods

Study design

Subjects were recruited from the city of Guelph through

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advertisements in the newspaper and community. The study was approved by the University of Guelph Research Ethics Board, and all subjects gave informed written consent. Inclusion criteria were as follows: 18-60 years of age, BMI ≥ 27 kg/m^2, and meeting the 2005 IDF definition of MetS. Individuals were excluded if they were taking any medications known to affect blood pressure, blood glucose, blood lipids, or weight. While we recognized that a large proportion of the population for whom this dietary strategy may be efficacious, may be on these medications, we wanted to avoid the confounding of medication use in this pilot study. Subjects who previously had stroke, myocardial infarction or other major DVD events were also excluded. The intervention consisted of a 12 week diet and exercise program. Subjects were randomly assigned to one of four diets and all attended three exercise sessions per week. Additional baseline measurements included percent body fat, a 7 day food record and a fitness assessment. Daily food records were kept throughout the intervention and periodically 7 day records were analyzed using The Food Processor for Windows 2000 (version 10.4 ESHA Research, Salem, Oregon). Subjects met once a week with a study coordinator for individual nutrition counselling, and were provided with additional resources such as menu plans, and recipes. All baseline measurements were repeated at the end of the intervention. Subjects did not receive any financial compensation, but did receive a free membership to the University of Guelph Athletic Center.

Dietary component

All subjects were instructed to consume a diet composed of 23% protein, 30% fat, and 47% CHO, which describes a low fat, moderate CHO diet that was previously shown to promote weight loss and improve lipid profiles [18]. Subjects were randomized to one of four experimental diets that differed in Glycemic Index (GI) and energy restriction: 1) High Glycemic Index (HGI), *ad libitum* (HGI-AL); 2) HGI with 30% Calorie Restriction (HGI-CR); 3) LGI, *ad libitum* (LGI-AL) and 4) LGI with 30% Calorie Restriction (LGI-CR). The HGI subjects were instructed to consume as many HGI (GI>65) CHOs as possible (i.e. whole wheat bread, English muffins, shredded wheat cereal, baked potatoes, pineapple, and watermelon). The LGI subjects were instructed to consume as many LGI (GI<50) CHOs as possible (i.e. 100% whole grain bread, unrefined cereals, sweet potatoes, legumes, berries, and pears). The 30% calorie restriction was determined for each individual based on the average caloric intake calculated from the baseline 7 day food record. The *ad libitum* groups did not receive counselling to encourage calorie restriction.

Circuit training and fitness assessment

Strength and cardiovascular fitness was assessed by a personal trainer at the University of Guelph Athletic Center. For the chest and leg press, subjects first completed 10 repetitions at a low level weight, and then the load was increased to a sub-maximal weight. The number of repetitions and load was recorded and the total weight lifted was calculated. For abdominal strength, the subject completed a series of curls and the distance traveled by their finger tips across the gym mat was recorded, as was the number of curls and the time. The number of curls completed per min was calculated. Cardiovascular fitness was assessed using a sub-maximal cycling test. The difficulty level was adjusted to reach 40% maximum Heart Rate (HR) for the 5 min warm-up and 65% maximum HR for the 10 min testing period. HR, difficulty level and the revolutions per minute were recorded at 0, 2.5, 5, 7.5 and 10 min. At week 12, the difficulty level was adjusted to match baseline, and the change in HR was calculated (final HR - baseline HR).

Supervised fitness sessions were prescribed 3 days per week in the morning and evenings. Sessions consisted of a warm-up on a stationary bicycle (5 min), followed by a circuit with alternating resistance machines and cardiovascular stations, which was completed twice (1 min/station; 30 sec/station). Resistance machines included: chest press, leg extension, leg curl, lateral pull-down, posterior deltoid fly, seated row, leg press, and shoulder press. The aerobic stations included exercises using a springboard pad or a step, and abdominal curls. Completion of the circuit was followed by a series of stretches.

Anthropometry and blood collection

Height (cm) and weight (kg) were measured using a stadiometer and digital scale, respectively. WC (cm) was measured using an inelastic plastic measuring tape gently wrapped around the subject's waist an equal distance from the lowest rib and the top of the iliac crest. Hip circumference (cm) was measured similarly around the subject's hips located at the top of the greater trochanter of each leg. Blood Pressure (BP) was measured twice at each study visit using an automatic BP monitor (Omron® IntelliSense™ BP monitor MODELHEM-907XL) after a 5 min rest in the seated position and the measurements averaged. Body composition was measure using Bioelectrical Impedance Analysis (Bodystat® 1500) as we have previously described.

Venous blood was collected after a 12 h fast and sent to a commercial laboratory (LifeLabs, Kitchener, ON) for analysis of glucose, TG, Total Cholesterol, HDL Cholesterol, and LDL Cholesterol. Fasting serum insulin was analyzed in duplicate using a solid-phase ^{125}I radioimmunoassay (Human Insulin Specific Radioimmunoassay, Millipore, Missouri, United States; Precision: inter-assay 2.9-6.0%, intra-assay 2.2-4.4%).

Statistics

An intention to treat "completers" analysis of the results was performed [35], and included all subjects in the groups to which they were assigned who completed all follow-up measures (n=26). The rest of the subjects are reported as dropouts. All data are presented as means ± Standard Error of the Mean (SEM). Initially, between group comparisons were conducted using the baseline and week 12 data from the four dietary groups (HGI-AL, HGI-CR, LGI-AL, and LGI-CR), and statistical significance was assessed using a univariate ANOVA. After finding no significant difference in the level of calorie restriction between the four groups (data not shown; p=0.543), the groups were pooled leaving only two groups that differed in mean GI (HGI and LGI). Further statistical analysis was conducted using the pooled groups. Between group comparisons were conducted using the baseline and week 12 data, as well as the absolute change in the variables, and was assessed for statistical significance using independent sample t-tests. Within group differences between baseline and final measurements were assessed using paired sample t-tests. The number of subjects meeting each of the MetS criteria and the number classified with MetS at baseline and after the intervention were compared using a Chi-Square test. Differences were considered significant if p<0.05 (SPSS version 17.0, SPSS Inc.).

Results

Subjects

Forty-five individuals met the inclusion criteria and were randomized to an intervention group. Seven subjects withdrew after receiving their diet assignment but did not begin the intervention (HGI-AL n=3; HGI-CR n=3; LGI-AL n=1). An additional 12 subjects

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withdrew before completing the study (HGI-AL n=3; HGI-CR n=3; LGI-AL n=4; LGI-CR n=2). Twenty-six subjects completed the entire study (HGI-AL n=6; HGI-CR n=5; LGI-AL n=6; LGI-CR n=9).

Dietary measures

All dietary groups appeared to restrict their calorie intake, regardless of the dietary counselling advice given and there were no differences in the level of calorie restriction between the four groups (data not shown; p=0.543). There were significant differences in the average GI of the high and low GI diets (data not shown; p<0.05), therefore the division into *ad libitum* and calorie restricted groups was eliminated, leaving two groups differing only in GI; HGI (n=11) and LGI (n=15) (Table 1).

Both groups had significant reductions from baseline in total energy, CHO: protein ratio, Glycemic Load (GL)/day, total CHO, total fat, and sodium (p<0.05). The LGI group also had significant reductions from baseline in the percentage of calories from fat, the GI, total protein, saturated fat, monounsaturated fat, polyunsaturated fat, transfatty acids, omega-6 fatty acids, and caffeine (p<0.05). The HGI group also had a significant reduction in dietary fibre (p<0.05). The GI of the diet was significantly lower in the LGI group during the study compared to the HGI group, and the overall change in the GI of the diet was significantly larger in LGI group (p<0.05).

Anthropometry and blood biochemistry

Table 2 shows that both groups had significant reductions from baseline in total body weight, BMI, WC, HC, SBP, DBP, and fasting serum TG (p<0.05). Of these variables, the absolute change from baseline in total body weight, BMI, and HC was significantly greater in the LGI group (p<0.05). In addition, the LGI group also had a significant reduction in percent body fat from baseline, and this change was significantly larger than that of the HGI group (p<0.05). The HGI group did have significant reductions from baseline in fasting serum total and HDL cholesterol; however these changes did not differ from the LGI group.

	HGI (n=11)						LGI (n=15)					
	Baseline		Study		Change		Baseline		Study		Change	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Calorie Restriction (%)	N/A		22.1 [a]	3.3			N/A		26.6 [a]	3.9		
Energy (kcal)	2136[a]	60	1661[b]	77	-475	73	2034[a]	138	1490[b]	156	-544	105
CHO: Protein ratio	3.2 [a]	0.3	2.7[bc]	0.2	-0.6	0.2	2.9 [ac]	0.2	2.4 [b]	0.1	-0.4	0.2
Calories from fat (%)	31.9[ab]	1.5	29.0 [b]	1.4	-2.9	2.0	33.9 [a]	1.5	27.8 [b]	1.4	-6.1	1.5
GI	54.9 [a]	0.8	56.6 [a]	0.5	2.2*	1.2	52.8[a]	0.7	43.1[b]	0.3	-10.5*	1.6*
GL/day	129.1 [a]	9.3	107.1[b]	7.6	-22.0	4.9	113.6 [a]	7.4	72.8[c]	8.0	-40.7	7.1
Protein (g)	87.4[ab]	4.9	81.0[ab]	3.3	-6.4	4.1	87.8 [a]	6.2	77.7 [b]	4.9	-10.1	4.5
Carbohydrates (g)	270.5 [a]	15.3	208.2[bc]	10.6	-62.4	11.5	242.8 [ac]	15.3	186.4[b]	15.4	-56.4	10.2
Dietary Fibre (g)	25.1 [a]	3.1	19.0 [b]	1.4	-6.0	2.3	24.2[ab]	3.6[ab]	24.3[ab]	2.9	0.1	2.3
Soluble Fibre (g)	2.0[ab]	0.4	1.4 [a]	0.1	-0.6	0.5	1.7 [b]	0.3	2.3[b]	0.3	0.6	0.4
Total Sugars (g)	85.7[ab]	7.0	71.0[ab]	6.1	-14.8	6.9	78.1[ab]	8.5	66.2[a]	5.7	-11.8	6.6
Monosaccharides (g)	11.5 [a]	2.4	12.4 [a]	2.9	0.8	2.1	13.6 [a]	2.6	15.8 [a]	1.9	2.2	3.1
Disaccharides (g)	7.3 [a]	1.7	8.2[a]	1.5	0.9	0.9	9.4 [a]	2.6	6.0 [a]	0.9	-3.4	2.8
Fat (g)	75.5[a]	3.4	54.2 [b]	4.4	-21.3	6.1	77.5 [a]	6.6	48.9 [b]	8.9	-28.7	6.0
Saturated Fat (g)	23.5[ab]	2.1	17.5[b]	1.8	-6.0	2.9	24.0 [a]	2.3	15.3 [b]	3.2	-8.7	2.4
Monounsaturated Fat (g)	14.3[ab]	1.8	10.8[b]	0.9	-3.5	1.9	16.1 [a]	1.9	10.7[b]	1.9	-5.4	1.7
Polyunsaturated Fat (g)	7.4[ab]	0.9	5.7[b]	0.4	-1.7	1.1	8.1 [a]	0.9	5.4 [b]	0.9	-2.7	0.7
Trans Fatty Acids (g)	1.2[ab]	0.5	0.8[a]	0.2	-0.4	0.4	1.2 [a]	0.2	0.4 [b]	0.1	-0.8	0.2
Cholesterol (mg)	239.7 [a]	27.6	260.6 [a]	23.9	20.9	28.0	252.6 [a]	29.9	201.8 [a]	20.4	-50.8	28.7
Omega 3 Fatty Acids (g)	0.6 [a]	0.1	0.7 [a]	0.1	0.1	0.1	0.6 [a]	0.1	0.6 [a]	0.2	-0.0	0.2
Omega 6 Fatty Acids (g)	5.0[ab]	0.6	4.4 [a]	0.4	-0.6	0.7	6.1 [b]	0.7	4.1[a]	0.7	-2.0	-0.8
Caffeine (mg)	115[ab]	38	125[ab]	57	10*	25	101[a]	18	50[b]	14	-51*	17
Sodium (mg)	3827[a]	549	2527 [b]	115	-1300	544	3418 [a]	192[a]	2589 [b]	242	-830	214

Abbreviations HGI=high glycemic index; LGI=low glycemic index; GL=glycemic load
[abc]Mean baseline and week 12 values in a row with unlike superscript letters are significantly different (p<0.05).
*Indicates a significant difference in the change in the variable between groups (p<0.05).
All values are presented as mean ± SEM.

Table 1: Dietary analysis of the baseline and study diets for the HGI and LGI groups, and the overall change in the dietary variables.

	HGI (n = 11)						LGI (n=15)					
	Baseline		Week 12		Change		Baseline		Week 12		Change	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Number of Males	4		4				4		4			
Number of Females	7		7				11		11			
Age (years)	45.3^{a}	2.9					47.7^{a}	1.6				
Age (range)	32-58						41-59					
Height (m)	1.7						1.7					
Height range (m)	1.6-1.9						1.6-1.8					
BMI (kg/m²)	35.8^{ac}	1.1	34.8^{b}	1.2	-1.1*	0.3	39.0^{a}	1.0	36.4^{bc}	1.2	-2.0 *	0.5
BMI range (kg/m²)	29.9-41.4		29.2-40.4				32.1-47.8		28.3-45.3			
Total body weight (kg)	105.4^{ac}	5.3	102.1^{bd}	5.4	-3.3*	0.1	110.0^{ad}	3.5	102.8^{bc}	3.6	-7.2 *	1.6
Body Fat (%)	41.4^{ac}	2.9	40.4^{ab}	2.7	-1.1*	0.5	45.9^{a}	1.9	42.6^{bc}	2.2	-3.3 *	0.8
WC (cm)	113.6^{ac}	3.3	109.1^{bd}	3.0	-4.5	1.4	115.9^{ad}	1.9	109.5^{bc}	2.2	-6.3	1.7
HC (cm)	120.9^{ac}	3.5	119.3^{bd}	3.7	-1.6 *	0.7	128.8^{ad}	3.2	123.9^{bc}	3.2	-4.9 *	1.0
SBP (mmHg)	137.6^{ac}	4.0	127.2^{b}	4.3	-10.4	-3.3	138.9^{a}	2.9	128.4^{bc}	2.8	-10.5	3.6
DBP (mmHg)	88.4^{a}	3.4	84.1^{bc}	3.0	-4.3	1.8	86.4^{ac}	1.9	80.8^{b}	2.0	-5.5	1.2
Fasting blood glucose (mmol/L)	5.5^{a}	0.2	5.5^{a}	0.2	0.0	0.2	5.9^{a}	0.3	5.6^{a}	0.2	-0.3	0.3
Fasting serum insulin (µIU/ml) †	20.4^{a}	6.8	17.4^{a}	4.0	-3.0	5.7	14.5^{a}	1.9	12.6^{a}	1.5	-2.0	1.4
HOMA-IR†	5.7^{a}	2.4	4.6^{a}	1.2	-1.1	1.7	4.1^{a}	0.9	3.2^{a}	0.5	-0.8	0.7
Fasting serum total cholesterol (mmol/L)	5.4^{a}	0.3	4.9^{bc}	0.2	-0.4	0.1	5.3^{ac}	0.2	4.9^{ab}	0.4	-0.4	0.3
Fasting serum LDL cholesterol (mmol/L)	3.1^{a}	0.3	3.1^{a}	0.2	-0.0	0.1	3.2^{a}	0.2	3.0^{a}	0.2	-0.2	0.2
Fasting serum HDL cholesterol (mmol/L)	1.2^{a}	0.1	1.1^{b}	0.1	-0.1	0.0	1.2^{ab}	0.1	1.2^{ab}	0.1	-0.1	0.1
Fasting serum TGs (mmol/L)	2.6^{a}	0.3	1.9^{bc}	0.3	-0.7 ± 0.2	-0.7 ± 0.2	2.0^{ac}	0.2	1.5^{b}	0.1	-0.6	0.2

Abbreviations HGI=high glycemic index; LGI=low glycemic index; WC=waist circumferences; HC=hip circumferences; SBP=systolic blood pressure; DBP=diastolic blood pressure; HOMA=homeostatic model assessment; IR=insulin resistance; TG=triglyceride

^{abc} Mean baseline and week 12 values in a row with unlike superscript letters are significantly different (p<0.05).

* Indicates a significant difference in the change in the variable between groups (p<0.05).

† Due to missing samples the insulin analysis was based on HGI n=8 and LGI n=14.

All values are presented as mean ± SEM.

Table 2: Baseline, week 12 and the change in anthropometric measurements and blood biochemistry of the subjects who completed all 12 weeks of the study.

Fitness assessment

Compliance to the fitness program varied from 50 to 100% attendance. The mean attendance of the LGI group (84%) was significantly greater than the attendance of the HGI group (67%) (p<0.01). Both groups had significant increase in strength from baseline on the chest press, leg press and abdominal curl fitness tests (p<0.05), and these changes were similar between the groups (Table 3). For the aerobic cycling test, both groups had reductions in exercising HR at 7.5 min, and the LGI group had reductions at 5 and 10 min. The HR was significantly lower in the LGI group than the HGI group only at 10 min (p<0.05). There were no significant differences in the absolute changes in HR between groups at any time point (p<0.05).

Metabolic syndrome criteria

At baseline, 100% of the subjects met the IDF definition for MetS. There was a significant reduction in the number of subjects who met the definition of MetS in the LGI group (p<0.01), with only 47% of the LGI group still being diagnosed with MetS at the end of the intervention; in contrast 73% of the HGI group still met the definition for MetS (Table 4). Additionally, in the LGI group, there was a significant reduction from baseline in the number of subjects meeting the MetS cut off for TG (p<0.02), while there was only a trend towards a reduction in the number is subjects meeting the MetS cut off for TG in the HGI group (p=0.056).

Discussion

The present study was designed to assess the efficacy of combining a LGI diet with a low fat, moderate CHO, moderate protein diet with regular exercise on risk factors in individuals with MetS. These findings provide evidence that in adults with MetS, a hypocaloric low-fat, moderate CHO, LGI diet combined with a resistance and aerobic training program for 12 weeks can: 1) reduce the number of individuals who meet the IDF definition of MetS; 2) reduce the severity and/or the number of MetS risk factors for adiposity, hypertension, dyslipidemia and insulin resistance; 3) improve fitness. The hypothesis was partially supported; the LGI diet was more beneficial than the HGI diet at improving MetS risk factors, however the hypothesis that a calorie restricted LGI diet would be more beneficial than *ad libitum* version of the diet was not investigated due to similarities in calorie intake and pooling of the study groups. The LGI group had a greater reduction in the number of subjects classified with MetS, and greater changes

	HGI (n=6)						LGI (n=10)					
	Baseline		Week 12		Change		Baseline		Week 12		Change	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Chest Press (lbs)†	953^{a}	107	1447^{bc}	221			1004^{ac}	141	1498^{b}	168	494	112
Leg Press (lbs)†	3353^{ac}	759	5460^{bd}	1094	2107	756	3360^{ad}	508	5396^{bc}	701	2036	302
Curls (rep/min)‡	19^{a}	2	22^{bc}	2	3	1	23^{ac}	2	26^{b}	1	3	1
HR 2.5min (bpm)	104^{a}	5	102^{a}	4	-2	4	100^{a}	4	99^{a}	4	-1	2
HR 5 min (bpm)	113^{ab}	7	112^{ab}	5	-0.5	- 3	115^{a}	5	107^{b}	4	-8	4
HR 7.5 min (bpm)	134^{a}	6	127^{bc}	5	-8	3	131^{ac}	5	115^{b}	4	-15	3
HR 10 min (bpm)	145^{a}	3	139^{ac}	4	-6	4	139^{ac}	4	123^{b}	3	-15	3

Abbreviations HGI=high glycemic index; LGI=low glycemic index; HR=heart rate
^{abc} Mean baseline and week 12 values in a row with unlike superscript letters are significantly different ($p<0.05$).
* Indicates a significant difference in the change in the variable between groups ($p<0.05$).
† Total weight lifted (lbs)=load (lbs) X # repetitions.
‡ The number of curls completed per minute.
All values are presented as mean ± SEM.

Table 3: Baseline, week 12 and the change in the total load lifted, the number of abdominal curls completed, and exercising heart rate for the subjects who completed the fitness tests.

	BMI (n (%))	WC (n (%))	BP (n (%))	Glucose (n (%))	TG (n (%))	HDL (n (%))	MetS (n (%))
HGI Baseline	11 (100)	11 (100)	9 (82)	5 (45)	10 (91)	5 (45)	11 (100)
HGI Post	11 (100)	10 (91)	6 (54)	3 (27)	6 (54)	6 (54)	8 (73)
LGI baseline	15 (100)	15 (100)	12 (80)	9 (60)	11 (73)	8 (53)	15 (100)
LGI post	15 (100)	14 (93)	8 (53)	6 (40)	4 (27)*	8 (53)	7 (47)*

Abbreviations: HGI=high glycemic index; LGI=low glycemic index; BMI=body mass index; WC=waist circumference; BP=blood pressure; TG=triglyceride; HDL=high density lipoprotein cholesterol; MetS=Metabolic Syndrome
* Indicates a significant change from baseline ($p<0.05$).

Table 4: The number of subjects who met each MetS criteria and who would have been classified with MetS at baseline and at the end of the intervention in the HGI (n=11) and LGI (n=15) groups.

in total body weight, BMI, percent body fat and HC, with additional improvements in WC, BP, TGs, and fitness. Furthermore, subjects were more satisfied with the LGI diet, which suggests improved compliance outside of the clinical setting and that this intervention could be successful in treating individuals with MetS.

Of the 38 subjects who began the intervention, only 26 successfully completed the study, giving a retention rate of 68%. A high attrition rate is not commonly found in the literature on high and low GI diets, with reports of 80% and 90% subject retention in 12 and 3 month studies, respectively [29,36]; however these studies did not include an exercise component and required a smaller overall time commitment. The subjects allocated to the HGI or the *ad libitum* diets expressed more dissatisfaction with their diet assignment, which may have contributed to the greater number of withdrawals from these groups. The relatively small number of subjects completing the study is certainly a limitation of the study and may have led to the lack of statistical significance for several of the parameters.

Despite only counselling two groups to reduce their energy intake, there was no difference in the calorie restriction between the original four groups. It is possible that some subjects in the calorie restricted groups had difficulties reaching their calorie goals because they were not satiated by their diet, particularly the HGI-CR group, as the consumption of HGI meals can increase ratings of hunger and voluntary food intake [23]. However, it was particularly surprising that the HGI-AL and LGI-AL groups had similar levels of calorie restriction, as this contradicts evidence that LGI *ad libitum* diets are more satiating and may cause spontaneous energy restriction [19,24]. This suggests that LGI foods will not always result in energy restriction when a diet is consumed *ad libitum* over a longer time. It is also possible that some subjects were purposely underreporting their calorie intake, as underreporting of energy intake is often a problem in weight loss interventions, and overweight women often underreport their energy intake [37]. The failure of the HGI group to significantly increase their mean GI over the course of the study is not uncommon in the literature [31], and suggests that individuals at risk for disease are making fewer healthy dietary choices to begin with, including the consumption of HGI foods.

Both groups were successful in reducing their total energy intake, CHO to protein ratio, GL, total fat, total CHO and sodium from baseline; however the LGI diet group had additional benefits, including significant reductions in the percentage of calories from fat, the GI, saturated fat, and transfatty acid. In addition, while both groups reduced their CHO consumption, the LGI group did so without altering their dietary fibre intake, while the HGI group had a significant reduction of 6 g of dietary fibre per day.

Both groups had significant reductions in total body weight, BMI, WC and HC, however, the change from baseline in these improvements (except WC) were significantly greater in the LGI group. In addition, the LGI group had a significant reduction in percent body fat, which was not experienced by the HGI group. Overall, this indicates that assignment to the LGI diet was more successful in reducing body weight and body fat compared to assignment to the HGI diet. There was discordance in the reported and expected weight losses in both groups. The reported mean energy restriction in the HGI group of 474 kcal per day should have resulted in a minimum weight loss of 5.2 kg mean weight loss over the 12 weeks. This is minimum, because one would expect extra energy to have been expended during the exercise periods, which would result in an even greater energy deficit. Instead the HGI group lost an average of 3.3 kg suggesting that this group was underreporting their calories. Underreporting of calories occurs frequently in obese populations and is often given as the reason why these subjects fail to lose weight despite a reported reduced calorie intake [38]. In contrast, the LGI group lost more weight (7.16 kg) than expected (5.94 kg) based on the mean energy restriction of 544 kcal per day, which may have been due to increased energy expenditure from their higher gym attendance, and possibly more accurate recording of their energy intake.

The reductions in SBP and DBP were similar between the groups, indicating that both interventions were effective at reducing BP in individuals with MetS. This suggests that the GI of the diet did not play a significant role in altering BP, which is consistent with previous work [28,36,39]. Given that sodium intake was reduced in both groups, it is possible that this was more important in reducing BP than the GI.

There were no changes in fasting blood glucose, fasting serum insulin or HOMA-IR in either group, although, by the end of the intervention, an additional two and three subjects in the HGI and LGI groups no longer met the fasting glucose cut-off for MetS. These results are contrary to what was expected, as previous reports have indicated a reduced risk of T2D in subjects following LGI diets [40-42]. These surprising results, however, may have been due to the relatively normal blood glucose levels at baseline, as it has been proposed that the GI may affect healthy individuals differently than those with metabolic disturbances [42], and perhaps the protective effects of a LGI diet are only evident in those with greater potential for improvement. Nonetheless, there are reports that a LGI diet does not alter fasting glucose homeostasis over the short-term [26,27,30,31], and perhaps more time is needed to observe beneficial changes from a LGI diet.

Overall, the intervention had little impact on the dyslipidemia of the subjects, which may have been due to the large degree of variation in the baseline lipid values of the subjects and small number of subjects who completed all twelve weeks. Both groups had significant reductions in fasting serum TG from baseline, but there was no difference in the absolute change in TG between the groups. Again this is inconsistent with previous studies that suggested greater reductions in TG following short-term LGI diets compared to HGI diets [19,25]. The one major difference between our study and these others is the addition of the exercise component, which may have contributed to the TG reductions in both groups. Nonetheless, there was a significant reduction in the number of LGI subjects meeting the MetS criteria for TG, with only a trend being observed in the HGI group. Of interest was that in the HGI group, there was a reduction in fasting HDL cholesterol and one additional subject met the MetS cut-off for HDL cholesterol by the end of the intervention, while the LGI group had no change in HDL cholesterol. Although the LGI diet did not improve HDL cholesterol levels, it did not further impair them, as was the case with the HGI diet. Although previous reports have suggested greater improvements in cholesterol levels with a LGI diet compared to a HGI diet [26-29,31,39], the modest changes in HDL levels in the current study indicate a slight advantage of the LGI diet at maintaining healthy cholesterol levels in subjects with MetS.

The low attendance to the fitness program was unexpected, as this program was modelled after a similar program with a high attendance rate [18]. This study ran through the summer which may have influenced gym attendance, as some subjects expressed difficulties in attending sessions during this time. It was also unexpected that the attendance rates would differ significantly between the groups, which may have been related to their satisfaction with their diet assignment. Based on anecdotal responses from an exit survey, it is clear that the LGI group was happier with their diet assignment, which may have impacted their willingness to commit to three gym sessions per week. There were no significant differences in the change in strength and cardiovascular fitness between the groups, indicating that the exercise program improved overall fitness but that the GI of the diet had no impact on these fitness improvements.

One of the greatest strengths of this intervention was the use of subjects with MetS, allowing us to measure the effects of the treatment on each MetS risk factor within a MetS population rather than studying a healthier population. Previous investigation into the treatment for MetS relied on overweight or obese subjects [8,9,43], or subjects at risk for MetS [13,44], however little work has targeted at MetS population [15,16]. It is important that individuals with MetS are studied directly as they may react differently to interventions due to the presence of multiple metabolic abnormalities. Another advantage was the use of one-on-one nutrition counselling and supervised gym sessions to increase compliance to the diets and fitness program, and so that reliance on activity logs was not necessary. The combined diet and exercise approach is also advantageous, as previous work focused solely on diet or exercise alone. Furthermore, this macronutrient composition allowed for the moderate consumption of a wide variety of foods and could easily be incorporated into a healthy lifestyle.

One limitation was the similar level of calorie restriction reported and the small number of subjects in the original four groups which prohibited the investigation into whether the LGI version of this diet would be sufficient to reduce energy intake and promote weight loss. Additionally, the study was limited by the high attrition rate, and the subjects who completed the intervention represent a highly motivated subset of the population and therefore the results may not be applicable to the general population. Furthermore, the diet information relies on self-reporting and underreporting is common in the overweight and obese population [37,38], however, the study was completed in a free-living environment and thus it was necessary for subjects to record their own intake. Finally, there is limited GI information available in the public domain, and many foods do not have reported GI values or there are large differences in the values ascribed to similar or the same foods. This may make it difficult for an individual to apply the GI concept to their own diet [42]. Without more widely available information on the GI and better education on the subject, it is possible that only highly dedicated individuals will be willing to incorporate the GI into their lifestyle.

Conclusions

This study demonstrated the beneficial effects of a low fat, moderate CHO, LGI diet and exercise program, on individuals with MetS, and supports the use of a lifestyle intervention in the reduction of CVD risk factors in adults with MetS. The LGI version of the diet had a greater ability to decrease the number and severity of MetS risk factors, and increased subject satisfaction and compliance. This research provides valuable knowledge from which future work can be conducted and from which therapeutic approaches can be developed to reduce the incidence of MetS and the development of CVD.

Authors Contributions

Kendra Brett was the lead student researcher on this project and completed the trial as part of her MSc thesis research. Kelly Meckling is the principle investigator and graduate advisor for Ms. Brett. Both authors contributed equally to the design of the trial, the writing of the human participant's protocol, and the development of methods, interpretation of results and writing of the manuscript. Both authors have read and approved the final version.

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