British Journal of Nutrition (2015), **113**, 479–487
doi:10.1017/S0007114514003845

Metabolic syndrome risk factors are associated with white rice intake in Korean adolescent girls and boys

SuJin Song[1], Hee Young Paik[1], Won O. Song[2] and YoonJu Song[3]*

[1]*Department of Food and Nutrition, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea*
[2]*Department of Food Science and Human Nutrition, Michigan State University, 469 Wilson Road, East Lansing, MI 48824, USA*
[3]*Major of Food and Nutrition, School of Human Ecology, The Catholic University of Korea, 43 Jibong-ro, Wonmi-gu, Bucheon-si, Gyeonggi-do 420-743, Republic of Korea*

(Submitted 13 March 2014 – Final revision received 18 October 2014 – Accepted 23 October 2014 – First published online 9 January 2015)

Abstract

In the present study, we examined the associations of total carbohydrate intake, dietary glycaemic load (DGL) and white rice intake with metabolic syndrome risk factors by sex in Korean adolescents. For the present cross-sectional study, data from the Fourth Korea National Health and Nutrition Examination Survey (2007–9) were used. A total of 2209 adolescents (*n* 1164 boys and *n* 1045 girls) aged 10–18 years with complete anthropometric, biochemical and dietary intake data were included in the study. Dietary intake data were obtained using the 24 h recall method, and total carbohydrate intake, DGL and white rice intake were divided into quartiles by sex. The metabolic syndrome and its risk factors were defined using the International Diabetes Federation criteria for children and adolescents. Fasting insulin levels and insulin resistance were included as the metabolic syndrome risk factors. All statistical analyses considered the complex sampling design effect and appropriate sampling weights. Multivariate linear regression analysis was used to estimate means with their standard errors of the mean for the metabolic syndrome risk factors across the quartiles of total carbohydrate intake, DGL and white rice intake. While high DGL was significantly associated with increased fasting glucose levels in boys, high total carbohydrate intake, DGL and white rice intake were consistently associated with reduced HDL-cholesterol levels in girls. High white rice intake was significantly associated with an increased risk of insulin resistance and the metabolic syndrome in girls but not in boys. Optimising dietary carbohydrate intake with respect to the source or amount is fundamental to preventing and managing metabolic diseases in Asian adolescents.

Key words: **Dietary carbohydrate: White rice: Metabolic syndrome: Insulin resistance: Korean adolescents**

The prevalence of the metabolic syndrome in Asian countries is high and continues to increase[1,2]. The uptrend has also been observed in children and adolescents[3]. Due to the rapid increase of the obesity rate in the paediatric population, the prevalence of the metabolic syndrome is expected to increase continuously[4]. A recent study has compared the prevalence of the metabolic syndrome between American and Korean adolescents using the data from the American and Korean versions of the National Health and Nutrition Examination Survey. The prevalence of the metabolic syndrome in the USA decreased from 7·3 % in 1988–94 to 6·5 % in 2003–6, whereas the prevalence in Korea almost doubled during a 9-year period from 4·0 % in 1998 to 7·8 % in 2007[5].

Dietary factors are probably the most important determinant of the metabolic syndrome. One important dietary component for Asian populations is the type, amount and proportion of carbohydrate intake. Dietary carbohydrates account for 66 % of daily energy intake in the Korean population[6], in contrast to 51 % in the US population[7]. Consequently, dietary glycaemic load (DGL) is high in Asian populations, which is determined by the quantity and quality of dietary carbohydrate intake[8]. A high-DGL diet has been associated with an increased risk of metabolic diseases[9–11]. White rice or polished rice is the predominant type of rice consumed, is a major source of refined grains and is the largest contributor to DGL in Asian populations[12–14]. Previous studies in Asian adult populations have reported that high-DGL diets or high white rice intake increase the risk of the metabolic syndrome and its associated risk factors[13–17].

Few studies on the association between dietary factors and the metabolic syndrome or its associated risk factors have been conducted in adolescent populations. High dietary fibre

Abbreviations: DGL, dietary glycaemic load; GI, glycaemic index; HOMA-IR, homeostasis model assessment of insulin resistance; KNHANES, Korea National Health and Nutrition Examination Survey.

* **Corresponding author:** Y. Song, fax +82 2 2164 6583, email yjsong@catholic.ac.kr

intake is inversely associated with the metabolic syndrome in US adolescents[18] and in overweight Latino adolescents[19]; however, high intakes of saturated fat and cholesterol are not related to the metabolic syndrome in US adolescents[18]. A study in Australian adolescents has shown that DGL is positively associated with the metabolic syndrome[20]. However, in Western and Asian adolescents, the association of dietary carbohydrate intake (e.g. DGL or white rice intake) with the metabolic syndrome and its associated risk factors probably differs. Since the presence of the metabolic syndrome in adolescence can predict the risk of the metabolic syndrome in adulthood[21], it is necessary to assess the association of dietary carbohydrate intake with the risk factors of the metabolic syndrome among Asian adolescents.

Thus, the aim of the present study was to examine the associations of total carbohydrate intake, DGL and white rice intake with metabolic syndrome risk factors by sex in Korean adolescents using the data from the Fourth Korea National Health and Nutrition Examination Survey (KNHANES 2007–9).

Methods

Study subjects

The present study was conducted based on the data from the Fourth KNHANES (2007–9). The KNHANES is a cross-sectional and nationally representative survey carried out by the Korea Centers for Disease Control and Prevention. The survey is based on a stratified, multi-stage probability sampling design and consists of three survey sections: health interview; health examination; nutrition survey. Detailed explanations are available elsewhere[6].

Among the 3168 eligible subjects aged 10–18 years, individuals were excluded due to the lack of dietary intake data (n 393), incomplete anthropometric or biochemical data (n 547), implausible energy intake (<2092 or $>20\,920$ kJ/d, n 18), or previous diagnosis of diabetes (n 1). A final sample of 2209 adolescents (n 1164 boys and n 1045 girls) was included in the data analyses. The present study was approved by the Korea Centers for Disease Control and Prevention Institutional Review Board. Written informed consent was obtained from each subject.

Assessment of dietary intake

Dietary intake data were obtained using a single 24 h recall method. Energy and nutrient intake data were calculated for each subject using the Food Composition Table, seventh revision, which was developed by the Korean National Rural Resources Development Institute[22].

The average dietary glycaemic index (GI) and DGL were calculated based on a glucose standard for each subject using a table of GI values for common Korean foods, as reported previously[23]. Briefly, GI values were obtained from published estimates or imputed by matching similar foods based on the energy and carbohydrate content of each food; GI values of foods with low carbohydrate content were assigned a value of zero. Dietary GI was calculated by multiplying the carbohydrate content of food by the corresponding GI and dividing by the total amount of carbohydrate consumed per d; this value was then summed for all food items. DGL was calculated by multiplying the amount of carbohydrates consumed from each food by the GI value of the food, and then this value was summed for all food items (divided by 100)[24].

Measurement of anthropometric and biochemical variables

Height, weight and waist circumference were measured using standardised techniques with calibrated equipment. Height was measured to the nearest 0·1 cm using a portable stadiometer (SECA 225; SECA Deutschland). Weight was measured to the nearest 0·1 kg using an electronic scale (GL-6000-20; CAS). Waist circumference was measured to the nearest 0·1 cm using a measuring tape (SECA 200; SECA Deutschland). BMI was calculated from the measured height and weight (kg/m^2) of the subjects. Weight status was categorised into four groups according to sex-specific BMI-for-age from Korean children-specific growth charts[25]: underweight (BMI percentile $<$ 5th); normal weight (5th $\leq$ BMI percentile $<$85th); overweight (85th $\leq$ BMI percentile $<$ 95th); obese (BMI percentile $\geq$ 95th or BMI $\geq 25\,kg/m^2$). Blood pressure was measured three times using a mercury sphygmomanometer (Baumanometer, WA Baum Co., Inc.) after at least 5 min of rest in the sitting position, and the average of the last two values was used in the analysis.

Venous blood samples were collected from each subject after they fasted for at least 8 h and were analysed in a certified clinical laboratory. Fasting glucose, TAG and HDL-cholesterol levels were measured by the enzymatic method using an ADVIA 1650 automatic analyser (Siemens) in 2007 and a Hitachi automatic analyser 7600 in 2008 and 2009. Fasting insulin level was measured by the RIA method using the 1470 WIZARD Gamma Counter (PerkinElmer). Homeostasis model assessment of insulin resistance (HOMA-IR), a surrogate measure of insulin resistance, was calculated according to the formula[26]:

$$\text{Fasting glucose (mmol/l)} \times \text{fasting insulin (}\mu\text{U/ml)}/22{\cdot}5.$$

Definition of the metabolic syndrome

The presence or absence of the metabolic syndrome was determined using the International Diabetes Federation criteria published in 2007, which was based on abdominal obesity plus two or more of the following present components[27]: (1) abdominal obesity as defined by a waist circumference $\geq$90th percentile for age and sex with reference to the 2007 Korean National Growth Charts[25] for $\leq$16 years of age, and $\geq$90 cm in boys and $\geq$80 cm in girls aged $>$16 years; (2) elevated TAG level $\geq 1{\cdot}7$ mmol/l; (3) low HDL-cholesterol level $<1{\cdot}04$ mmol/l for $\leq$16 years of age, and $<1{\cdot}04$ mmol/l in boys and $<1{\cdot}3$ mmol/l in girls aged $>$16 years; (4) elevated fasting glucose level $\geq 5{\cdot}55$ mmol/l; (5) elevated systolic blood pressure $\geq$130 mmHg or diastolic blood pressure $\geq$85 mmHg.

Table 1. Characteristics of the Korean adolescent subjects by sex*
(Mean values with their standard errors; *n* 2209)

	Boys (*n* 1164)		Girls (*n* 1045)		
Characteristics	Mean	SEM	Mean	SEM	*P*†
Age (years)	13·5	0·1	13·5	0·1	0·453
Living area (%)					
Urban	70·9		70·5		0·857
Rural	29·1		29·5		
Household income (%)					
Lowest	11·4		10·8		0·035
Lower middle	21·4		26·5		
Upper middle	32·7		32·8		
Highest	34·5		29·9		
Vigorous physical activity‡ (%)					
Never or rarely	32·0		58·2		<0·001
1–2 d	32·4		26·6		
3–4 d	20·3		10·0		
5 d or more	15·3		5·1		
Weight status§ (%)					
Underweight	6·9		6·9		0·007
Normal weight	74·1		76·0		
Overweight	6·0		8·9		
Obese	13·0		8·3		
Metabolic syndrome risk factors					
Waist circumference‖ (cm)	72·6	0·4	68·7	0·5	<0·001
TAG¶ (mmol/l)	0·98	0·03	0·98	0·03	0·857
HDL-cholesterol¶ (mmol/l)	1·24	0·01	1·31	0·01	<0·001
Fasting glucose¶ (mmol/l)	4·97	0·02	4·90	0·02	0·001
Fasting insulin¶ (μIU/ml)	13·1	0·2	13·8	0·3	0·023
HOMA-IR¶**	2·9	0·1	3·0	0·1	0·087
Systolic blood pressure¶ (mmHg)	108	0·4	102	0·5	<0·001
Diastolic blood pressure¶ (mmHg)	66·8	0·4	64·9	0·5	<0·001
Prevalence of the metabolic syndrome and its components†† (%)					
Abdominal obesity	6·9		8·4		0·250
Elevated TAG	9·7		10·3		0·639
Low HDL-cholesterol	19·9		24·2		0·046
Elevated fasting glucose	5·8		4·8		0·333
Elevated blood pressure	4·1		1·1		0·004
Metabolic syndrome	1·5		2·0		0·400
Energy and nutrient intake‡‡					
Total energy (kJ)	8966	141	7340	151	<0·001
Energy from carbohydrate (%)	64·3	0·4	63·8	0·5	0·406
Energy from fat (%)	21·4	0·4	22·0	0·4	0·256
Energy from protein (%)	14·3	0·1	14·2	0·2	0·731
Carbohydrate (g)	313	2·2	309	2·7	0·262
Fat (g)	47·7	0·8	49·6	1·0	0·108
Protein (g)	70·3	0·8	69·2	1·1	0·405
Vitamin A (μg RE)	735	51·6	713	42·0	0·668
Thiamin (mg)	1·4	0·1	1·3	0·1	0·076
Riboflavin (mg)	1·3	0·1	1·2	0·04	0·342
Niacin (mg)	15·0	0·2	14·5	0·3	0·181
Vitamin C (mg)	82·9	4·1	91·3	4·2	0·115
Ca (mg)	482	13·0	482	13·6	0·985
P (mg)	1145	12·7	1112	15·2	0·052
Na (mg)	4282	77·7	4031	110·6	0·034
K (mg)	2519	37·6	2520	44·9	0·985
Fe (mg)	12·2	0·4	11·5	0·3	0·134
Dietary glycaemic index §§	61·9	0·3	60·6	0·4	0·004
Dietary glycaemic load §§	194	1·7	187	2·2	0·016

HOMA-IR, homeostasis model assessment of insulin resistance; RE, retinol equivalents.
* All analyses accounted for the complex sampling design effect and appropriate sampling weights of the national survey.
† *P* value was obtained from the multivariate linear regression analysis for continuous variables and the χ^2 test for categorical variables.
‡ Vigorous physical activity was examined based on the frequency of high-intensity exercise for 10 min or more during the previous week.
§ Weight status was categorised into four groups according to sex-specific BMI-for-age from Korean children-specific growth charts: underweight (BMI percentile < 5th); normal weight (5th ≤ BMI percentile < 85th); overweight (85th ≤ BMI percentile < 95th); obese (BMI percentile ≥ 95th or BMI ≥ 25 kg/m^2).
‖ Multivariate linear regression analysis was performed after adjustment for age, living area, household income and physical activity.
¶ Multivariate linear regression analysis was performed after adjustment for age, living area, household income, physical activity and BMI.
** HOMA-IR, a surrogate measure of insulin resistance, was calculated according to the formula: fasting glucose (mmol/l) × fasting insulin (μU/ml)/22·5.
†† The metabolic syndrome was diagnosed based on the International Diabetes Federation criteria published in 2007, which was based on abdominal obesity plus two or more of the following present components: (1) abdominal obesity as defined by a waist circumference ≥ 90th percentile for age and sex with reference to the 2007 Korean National Growth Charts for ≤16 years of age, and ≥90 cm in boys and ≥80 cm in girls aged >16 years; (2) elevated TAG level ≥1·7 mmol/l; (3) low HDL-cholesterol level <1·04 mmol/l for ≤16 years of age, and <1·04 mmol/l in boys and <1·3 mmol/l in girls aged >16 years; (4) elevated fasting glucose level ≥5·55 mmol/l; (5) elevated systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg.
‡‡ Multivariate linear regression analysis was performed after adjustment for age, living area, household income, physical activity and total energy intake.
§§ Dietary glycaemic index and load were calculated based on a glucose standard.

Assessment of sociodemographic and lifestyle variables

Sociodemographic (e.g. age, living area and household income) and lifestyle (e.g. physical activity and medical history) data were obtained from a health interview survey using a questionnaire. Household income was categorised into lowest, lower-middle, upper-middle and highest groups. To assess the amount of vigorous physical activity, subjects were asked for how many days they engaged in high-intensity exercise for 10 min or more during the previous week.

Statistical analyses

All statistical analyses were conducted using the Statistical Analysis Systems (SAS) software package, version 9.3 (SAS Institute). All analyses accounted for the complex sampling design effect and appropriate sampling weights of the national survey using PROC SURVEY in SAS.

Continuous variables, such as age, metabolic syndrome risk factors, and total energy and nutrient intakes, were expressed as means with their standard errors of the mean by sex. Categorical variables, such as sociodemographic and lifestyle variables, weight status, and prevalence of the metabolic syndrome and its components, were expressed as percentages by sex. To determine the differences in these variables by sex, the multivariate linear regression analysis was used for continuous variables and the χ^2 test for categorical variables.

Total carbohydrate intake, DGL and white rice intake were adjusted for total energy intake by the residual method[28], and were divided into quartiles by sex to examine the relationships between dietary carbohydrate variables and metabolic syndrome risk factors. Metabolic syndrome risk factors were expressed as means with their standard errors of the mean across the quartiles of energy-adjusted total carbohydrate intake, DGL and white rice intake by sex. To estimate means with their standard errors of the mean and to test for a linear trend for these variables across the quartiles, the multivariate linear regression analysis was used after adjustment for potential confounding variables. The prevalence of the metabolic syndrome and paediatric obesity was expressed as percentages across the quartiles of energy-adjusted total carbohydrate intake, DGL and white rice intake by sex. All tests of significance were two-tailed, and $P<0{\cdot}05$ was considered significant.

Results

Characteristics of the study subjects by sex

Table 1 presents the characteristics of the Korean adolescent subjects by sex. The study included 1164 boys and 1045 girls aged 10–18 years. Household incomes were higher for boys

Table 2. Metabolic syndrome risk factors across the quartiles (Q) of total carbohydrate intake in Korean adolescent boys and girls*
(Mean values with their standard errors)

	Quartiles of energy-adjusted total carbohydrate intake†								
	Q1		Q2		Q3		Q4		
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	P_{trend}
Boys									
n	291		291		291		291		
Median intake (g)	288		325		348		386		
Age (years)	14·5	0·2	13·9	0·2	13·8	0·2	14·0	0·2	0·022
Waist circumference‡ (cm)	72·6	0·8	73·2	1·0	71·0	0·9	71·4	0·7	0·114
TAG§ (mmol/l)	0·95	0·05	0·96	0·04	1·01	0·08	1·01	0·04	0·293
HDL-cholesterol§ (mmol/l)	1·25	0·02	1·25	0·02	1·24	0·02	1·21	0·01	0·144
Fasting glucose§ (mmol/l)	4·95	0·03	4·99	0·03	4·99	0·03	5·00	0·03	0·251
Fasting insulin§ (μIU/ml)	13·5	0·4	13·5	0·5	13·2	0·4	12·9	0·4	0·292
HOMA-IR§‖	3·0	0·1	3·0	0·1	3·0	0·1	2·9	0·1	0·444
Systolic blood pressure§ (mmHg)	108	0·8	109	0·9	107	0·8	107	0·7	0·379
Diastolic blood pressure§ (mmHg)	68·1	0·7	65·8	0·9	66·4	0·9	66·7	0·7	0·172
Girls									
n	261		261		262		261		
Median intake (g)	235		269		293		325		
Age (years)	14·2	0·2	14·3	0·2	13·6	0·2	13·9	0·2	0·032
Waist circumference‡ (cm)	69·0	0·6	70·5	0·8	70·0	0·7	70·0	0·7	0·290
TAG§ (mmol/l)	1·00	0·05	0·96	0·05	1·03	0·05	1·06	0·06	0·189
HDL-cholesterol§ (mmol/l)	1·33	0·02	1·33	0·02	1·27	0·02	1·27	0·02	0·010
Fasting glucose§ (mmol/l)	4·89	0·03	4·87	0·04	4·85	0·03	4·89	0·03	0·775
Fasting insulin§ (μIU/ml)	13·7	0·5	14·1	0·5	13·5	0·5	13·9	0·5	0·978
HOMA-IR§‖	3·0	0·1	3·1	0·1	2·9	0·1	3·0	0·1	0·841
Systolic blood pressure§ (mmHg)	102	0·7	101	0·8	103	1·0	103	1·0	0·133
Diastolic blood pressure§ (mmHg)	65·9	0·7	63·3	0·9	65·4	0·8	65·5	0·9	0·860

HOMA-IR, homeostasis model assessment of insulin resistance.
* All analyses accounted for the complex sampling design effect and appropriate sampling weights of the national survey.
† Total carbohydrate intake was energy-adjusted using a residual method and was categorised into quartiles.
‡ Multivariate linear regression analysis was performed after adjustment for age, living area, household income and physical activity.
§ Multivariate linear regression analysis was performed after adjustment for age, living area, household income, physical activity and BMI.
‖ HOMA-IR, a surrogate measure of insulin resistance, was calculated according to the formula: fasting glucose (mmol/l) × fasting insulin (μU/ml)/22·5.

than for girls. Boys were more likely to engage in vigorous physical activity than girls. The prevalence of overweight was higher in girls than in boys (8·9 *v.* 6·0 %), whereas the prevalence of obesity was higher in boys than in girls (13·0 *v.* 8·3 %). Boys had greater waist circumference and higher levels of fasting glucose and systolic and diastolic blood pressure than did girls; however, girls had higher levels of HDL-cholesterol and fasting insulin than did boys. The prevalence of the metabolic syndrome was 1·5 % in boys and 2·0 % in girls. While low HDL-cholesterol was prevalent in boys and girls, its prevalence was higher in girls than in boys (24·2 *v.* 19·9 %). However, the prevalence of elevated blood pressure was higher in boys than in girls (4·1 *v.* 1·1 %). Boys consumed more total energy, P, Na, dietary GI and DGL than did girls.

Because sociodemographic characteristics, lifestyle variables, metabolic syndrome risk factors and dietary intake differed by sex, all the following results are presented by sex. The interaction effect between sex and white rice intake for HDL–cholesterol was significant ($P_{interaction} = 0·034$), but not significant for the other individual metabolic syndrome risk factors (all $P_{interaction} > 0·05$) among the whole population.

Association between total carbohydrate intake and the metabolic syndrome risk factors by sex

The metabolic syndrome risk factors were not associated with total carbohydrate intake in boys. Girls in the highest quartile of total carbohydrate intake had lower HDL-cholesterol levels than did those in the lowest quartile (Q1 *v.* Q4 = 1·33 *v.* 1·27 mmol/l, $P_{trend} = 0·010$). The other metabolic syndrome risk factors were not associated with total carbohydrate intake in girls (Table 2).

Association between dietary glycaemic load and the metabolic syndrome risk factors by sex

Boys in the highest quartile of DGL had higher fasting glucose levels than did those in the lowest quartile (Q1 *v.* Q4 = 4·95 *v.* 5·00 mmol/l, $P_{trend} = 0·043$). In girls, HDL-cholesterol levels decreased significantly across the quartiles of DGL (Q1 *v.* Q4 = 1·34 *v.* 1·24 mmol/l, $P_{trend} < 0·001$). The other metabolic syndrome risk factors were not associated with DGL in either boys or girls (Table 3).

Association between white rice intake and the metabolic syndrome risk factors by sex

Table 4 presents the association between white rice intake and the metabolic syndrome risk factors by sex. In boys, increased white rice intake was marginally associated with reduced HDL-cholesterol levels ($P_{trend} = 0·055$) and increased fasting glucose levels ($P_{trend} = 0·055$). In girls, white rice intake was inversely associated with HDL-cholesterol but positively associated with fasting insulin and HOMA-IR. The other

Table 3. Metabolic syndrome risk factors across the quartiles (Q) of dietary glycaemic load in Korean adolescent boys and girls*
(Mean values with their standard errors)

	Quartiles of energy-adjusted dietary glycaemic load†								
	Q1		Q2		Q3		Q4		
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	P_{trend}
Boys									
n	291		291		291		291		
Median intake	167		196		219		248		
Age (years)	14·6	0·2	13·9	0·2	13·8	0·2	13·9	0·2	0·006
Waist circumference‡ (cm)	72·6	0·8	72·7	0·9	71·1	0·8	71·8	0·8	0·258
TAG§ (mmol/l)	0·97	0·05	0·95	0·04	1·08	0·08	0·93	0·04	0·987
HDL-cholesterol§ (mmol/l)	1·26	0·02	1·24	0·02	1·22	0·02	1·23	0·02	0·068
Fasting glucose§ (mmol/l)	4·95	0·03	4·93	0·03	5·03	0·03	5·00	0·03	0·043
Fasting insulin§ (μIU/ml)	13·1	0·4	13·9	0·5	13·6	0·4	12·5	0·4	0·281
HOMA-IR§‖	2·9	0·1	3·1	0·1	3·1	0·1	2·8	0·1	0·521
Systolic blood pressure§ (mmHg)	108	0·8	108	0·8	108	0·7	107	0·8	0·478
Diastolic blood pressure§ (mmHg)	67·6	0·6	66·4	0·9	67·1	0·7	66·0	0·9	0·195
Girls									
n	261		261		262		261		
Median intake	134		161		181		204		
Age (years)	14·4	0·2	14·2	0·1	13·9	0·2	13·4	0·2	<0·001
Waist circumference‡ (cm)	69·4	0·6	69·7	0·8	70·0	0·7	70·2	0·7	0·298
TAG§ (mmol/l)	1·00	0·05	0·98	0·05	1·01	0·05	1·07	0·06	0·222
HDL-cholesterol§ (mmol/l)	1·34	0·02	1·31	0·02	1·30	0·02	1·24	0·02	0·000
Fasting glucose§ (mmol/l)	4·91	0·03	4·83	0·03	4·87	0·03	4·89	0·03	0·675
Fasting insulin§ (μIU/ml)	13·7	0·5	13·5	0·4	14·0	0·6	14·3	0·5	0·178
HOMA-IR§‖	3·0	0·1	2·9	0·1	3·1	0·2	3·1	0·1	0·233
Systolic blood pressure§ (mmHg)	101	0·8	103	0·8	102	1·0	104	1·0	0·083
Diastolic blood pressure§ (mmHg)	65·4	0·7	64·0	0·8	65·3	0·8	65·8	0·9	0·423

HOMA-IR, homeostasis model assessment of insulin resistance.
* All analyses accounted for the complex sampling design effect and appropriate sampling weights of the national survey.
† Dietary glycaemic load was energy-adjusted using a residual method and was categorised into quartiles.
‡ Multivariate linear regression analysis was performed after adjustment for age, living area, household income and physical activity.
§ Multivariate linear regression analysis was performed after adjustment for age, living area, household income, physical activity and BMI.
‖ HOMA-IR, a surrogate measure of insulin resistance, was calculated according to the formula: fasting glucose (mmol/l) × fasting insulin (μU/ml)/22·5.

Table 4. Metabolic syndrome risk factors across the quartiles (Q) of white rice intake in Korean adolescent boys and girls*
(Mean values with their standard errors)

	Quartiles of energy-adjusted white rice intake†								
	Q1		Q2		Q3		Q4		
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	P_{trend}
Boys									
n	291		291		291		291		
Median intake (g)	96		176		229		295		
Age (years)	14·3	0·2	13·9	0·2	13·8	0·2	14·1	0·2	0·468
Waist circumference‡ (cm)	71·5	0·7	72·8	0·9	72·1	0·9	71·9	0·8	0·830
TAG§ (mmol/l)	0·98	0·05	0·94	0·04	0·97	0·04	1·03	0·08	0·511
HDL-cholesterol§ (mmol/l)	1·26	0·02	1·25	0·02	1·23	0·02	1·22	0·02	0·055
Fasting glucose§ (mmol/l)	4·97	0·03	4·95	0·03	4·96	0·03	5·04	0·03	0·055
Fasting insulin§ (μIU/ml)	12·9	0·4	13·0	0·4	13·8	0·6	13·2	0·4	0·320
HOMA-IR§‖	2·9	0·1	2·9	0·1	3·1	0·1	3·0	0·1	0·185
Systolic blood pressure§ (mmHg)	108	0·8	108	0·8	107	0·7	107	0·7	0·330
Diastolic blood pressure§ (mmHg)	67·0	0·7	67·4	0·8	65·9	0·8	67·0	0·6	0·596
Girls									
n	261		261		262		261		
Median intake (g)	67		132		179		238		
Age (years)	14·3	0·2	14·4	0·2	13·6	0·2	13·7	0·2	0·002
Waist circumference‡ (cm)	69·4	0·7	70·0	0·7	69·7	0·8	70·1	0·7	0·452
TAG§ (mmol/l)	1·03	0·06	0·94	0·05	1·02	0·05	1·07	0·05	0·374
HDL-cholesterol§ (mmol/l)	1·35	0·02	1·32	0·02	1·29	0·02	1·25	0·02	<0·001
Fasting glucose§ (mmol/l)	4·86	0·03	4·91	0·03	4·85	0·03	4·88	0·03	0·952
Fasting insulin§ (μIU/ml)	12·9	0·4	13·9	0·5	14·1	0·6	14·4	0·5	0·003
HOMA-IR§‖	2·8	0·1	3·0	0·1	3·1	0·2	3·2	0·1	0·005
Systolic blood pressure§ (mmHg)	102	0·9	103	0·9	102	0·8	103	0·9	0·321
Diastolic blood pressure§ (mmHg)	65·0	0·8	65·2	0·8	64·5	0·7	65·7	0·8	0·654

HOMA-IR, homeostasis model assessment of insulin resistance.
* All analyses accounted for the complex sampling design effect and appropriate sampling weights of the national survey.
† White rice intake was energy-adjusted using a residual method and was categorised into quartiles.
‡ Multivariate linear regression analysis was performed after adjustment for age, living area, household income and physical activity.
§ Multivariate linear regression analysis was performed after adjustment for age, living area, household income, physical activity and BMI.
‖ HOMA-IR, a surrogate measure of insulin resistance, was calculated according to the formula: fasting glucose (mmol/l) × fasting insulin (μU/ml)/22·5.

metabolic syndrome risk factors were not associated with white rice intake in either boys or girls.

Association between white rice intake and the prevalence of the metabolic syndrome and paediatric obesity by sex

Table 5 presents the prevalence of the metabolic syndrome and paediatric obesity across the quartiles of white rice intake by sex. The prevalence of elevated blood pressure decreased across the quartiles of white rice intake among boys (Q1 *v.* Q4 = 7·8 *v.* 1·2%, P=0·014). The prevalence of the metabolic syndrome significantly increased across the quartiles of white rice intake in girls (Q1 *v.* Q4 = 0·4 *v.* 2·1%, P=0·003). The prevalence of paediatric obesity was not associated with white rice intake in either boys or girls.

Discussion

In the present study, we found significant associations between dietary carbohydrate variables (e.g. total carbohydrate intake, DGL and white rice intake) and metabolic syndrome risk factors in a nationally representative sample of Korean adolescents, although the strength of the associations varied by sex. Among the metabolic syndrome risk factors, low HDL-cholesterol was strongly associated with all dietary carbohydrate variables, including total carbohydrate intake, DGL and white rice intake in girls. High-carbohydrate diets are known to be associated with elevated TAG and reduced HDL-cholesterol levels[29–33], as observed in previous studies in Asian adult populations[13–15,34,35]. Total carbohydrate intake and DGL have been inversely associated with HDL-cholesterol in South Indian adults[34], and DGL has been inversely associated with HDL-cholesterol and positively associated with TAG and fasting glucose in female Japanese farmers[13]. All types of dietary carbohydrates excluding dietary GI have been positively associated with HDL-cholesterol in the Korean adult population[15]. Even though we did not find a significant relationship between dietary carbohydrate variables and TAG, we presume that reduced HDL-cholesterol levels in this youth population would be an indicator of typical dyslipidaemia, characterised by high TAG and low HDL-cholesterol levels, due to a high-carbohydrate diet in Asian populations.

In the present study, white rice intake was more strongly associated with the metabolic syndrome risk factors than the other carbohydrate variables in both boys and girls. Although the mechanism underlying this phenomenon is unclear, white rice is the major contributor to DGL in the Asian population, and high DGL leads to insulin resistance and glucose abnormalities[13,36]. In addition, high white rice intake has been associated with elevated TAG and reduced HDL-cholesterol levels[17,37]. Therefore, high white rice consumption might

Table 5. Prevalence of the metabolic syndrome and paediatric obesity across the quartiles (Q) of white rice intake in Korean adolescent boys and girls*

	Quartiles of energy-adjusted white rice intake†				
	Q1	Q2	Q3	Q4	*P*‡
Boys					
n	291	291	291	291	
Median intake (g)	96	176	229	295	
Metabolic syndrome and its components§ (%)					
Abdominal obesity	4·2	8·0	9·8	6·0	0·069
Elevated TAG	9·8	11·0	9·1	10·0	0·947
Low HDL-cholesterol	18·3	19·5	20·4	23·1	0·641
Elevated fasting glucose	4·3	5·1	6·2	8·6	0·353
Elevated blood pressure	7·8	5·2	3·9	1·2	0·014
Metabolic syndrome	1·5	2·7	0·5	1·8	0·369
Paediatric obesity‖ (%)					
Underweight	6·5	6·4	9·0	7·7	0·675
Normal	76·8	70·8	73·5	72·4	
Overweight	3·9	7·4	4·3	7·5	
Obese	12·7	15·4	13·2	12·4	
Girls					
n	261	261	262	261	
Median intake (g)	67	132	179	238	
Metabolic syndrome and its components§ (%)					
Abdominal obesity	6·8	10·0	8·6	8·3	0·681
Elevated TAG	8·9	7·3	12·3	13·1	0·168
Low HDL-cholesterol	20·6	26·4	23·2	28·8	0·265
Elevated fasting glucose	3·2	6·4	6·5	4·7	0·447
Elevated blood pressure	1·9	1·9	1·0	0·4	0·531
Metabolic syndrome	0·4	0·8	4·1	2·1	0·003
Paediatric obesity‖ (%)					
Underweight	5·6	7·5	7·9	7·5	0·420
Normal	78·5	73·1	77·8	73·2	
Overweight	8·2	9·1	5·4	12·7	
Obese	7·6	10·3	8·9	6·7	

* All analyses accounted for the complex sampling design effect and appropriate sampling weights of the national survey.
† White rice intake was energy-adjusted using a residual method and was categorised into quartiles.
‡ *P* value was obtained by the χ^2 test.
§ The metabolic syndrome was diagnosed based on the International Diabetes Federation criteria published in 2007, which was based on abdominal obesity plus two or more of the following present components: (1) abdominal obesity as defined by a waist circumference ≥90th percentile for age and sex with reference to the 2007 Korean National Growth Charts for ≤16 years of age, and ≥90 cm in boys and ≥80 cm in girls aged >16 years; (2) elevated TAG level ≥1·7 mmol/l; (3) low HDL-cholesterol level <1·04 mmol/l for ≤16 years of age, and <1·04 mmol/l in boys and <1·3 mmol/l in girls aged >16 years; (4) elevated fasting glucose level ≥5·55 mmol/l; (5) elevated systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg.
‖ Paediatric obesity was defined based on the sex-specific BMI-for-age from Korean children-specific growth charts: underweight (BMI percentile < 5th); normal weight (5th ≤ BMI percentile < 85th); overweight (85th ≤ BMI percentile < 95th); obese (BMI percentile ≥ 95th or BMI ≥ 25 kg/m^2).

lead to glucose abnormalities as well as typical dyslipidaemia in the Asian population.

The association between white rice intake and the metabolic syndrome differed by sex. For girls, high white rice intake was significantly associated with an increased risk of insulin resistance and the metabolic syndrome. High white rice intake was significantly associated with a decreased prevalence of elevated blood pressure in boys, and was associated with reduced HDL-cholesterol levels in both boys and girls. In agreement with previous studies on adults, dietary carbohydrate intake had a stronger association with the metabolic syndrome risk factors in women compared with men[16,35]. Similar findings have been revealed by two prospective studies of diabetes in Asian populations. In the Shanghai Women's Health Study, intake of total carbohydrate, DGL and white rice was associated with an increased risk of type 2 diabetes[36]. In the Japan Public Health Center-based Prospective Study, white rice intake increased the risk of type 2 diabetes in women, but not in men[38]. In addition, a cross-sectional study in a Korean adult population has shown that high intakes of refined grains and white rice are associated with an increased risk of the metabolic syndrome in women only[37].

A possible explanation for the strong association in girls is an association between insulin resistance and the metabolic syndrome risk factors in Korean adolescent girls but not in boys. Kim *et al.*[39] claimed that insulin-like growth factors or sex hormone differences during puberty differentially increase the risk of insulin resistance. This implies that girls are prone to insulin resistance, and that the adverse effects of high carbohydrate intake on the metabolic syndrome risk factors are more evident in girls. For boys, the prevalence of elevated blood pressure was inversely associated with white rice intake. No possible explanations exist in the literature; however, a previous study[37] on the Korean adult population has also reported that high carbohydrate intake is inversely associated with blood pressure in men only. Subjects who had low white rice intake were more likely to consume bread or noodles; however, we found no difference in Na intake when analysed across the quartiles of white rice intake. Future studies are necessary to identify the underlying mechanism.

We also examined the association between high white rice intake and paediatric obesity defined by sex-specific BMI-for-age percentiles and found no association. The metabolic syndrome in children and adolescents is closely linked with obesity[19]. Several studies have reported that Western dietary patterns – which are characterised by high fat and animal food intakes – are associated with an increased risk of the metabolic syndrome among children and adolescents[40]. We conducted identical analyses and found that total fat intake was not associated with the metabolic syndrome risk factors in either boys or girls. In addition, we found no significant association between the prevalence of the metabolic syndrome or obesity and dietary fat intake (data not shown). Compared with Western populations, Cheung[41] indicated that obesity and insulin resistance in Asian populations are not caused by excessive dietary fat intake, but by carbohydrate intake that exceeds the energy requirement of an individual. This implies that high carbohydrate intake in the Asian population could increase the risk of the metabolic syndrome independently of obesity or high-fat diets, especially in girls. Thus, optimising dietary carbohydrate intake with respect to the type or source would be fundamental to preventing and managing metabolic diseases in Asian adolescents.

The present study has several limitations. First, the metabolic syndrome and its associated risk factors were defined according to the International Diabetes Federation criteria.

These criteria are more restrictive than those of the National Cholesterol Education Program Adult Treatment Panel III, which probably explains the lower prevalence of the metabolic syndrome in the present study compared with previous reports. However, as no universal metabolic syndrome criteria for children and adolescents are available, our ability to compare the present findings with those reported previously was limited. Second, no causal inferences could be drawn from the present study due to the cross-sectional nature of the KNHANES data. Finally, we obtained dietary intake data obtained from a single 24 h recall, which may not represent the typical carbohydrate intake of individual respondents. However, the major strengths of the present study include the use of a large, nationally representative sample of Korean adolescents and comprehensive analysis with regard to the type or source of dietary carbohydrate intake.

This is the first study to examine the associations between dietary carbohydrate intake (e.g. total carbohydrate intake, DGL and white rice intake) and metabolic syndrome risk factors in Asian adolescents. We found that high carbohydrate intake was positively associated with reduced HDL-cholesterol levels in both boys and girls, and high white rice intake was associated with an increased risk of insulin resistance and the metabolic syndrome in girls only. The present study suggests that high carbohydrate intake, including white rice intake, should be cautioned in Asian adolescents in order to develop effective primary prevention strategies, and prospective studies are needed to confirm these findings.

Acknowledgements

The present study was financially supported by the Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (grant no. NRF-2013R1A1A3010359).

The authors' contributions are as follows: Y. S. formulated the study question and performed the study design; S. S. analysed the data and drafted the manuscript; H. Y. P., W. O. S. and Y. S. critically revised the manuscript; Y. S. had primary responsibility for the final content. All authors contributed to the interpretation of the results, and read and approved the final manuscript.

None of the authors has any conflicts of interest to declare.

References

1. Lim S, Shin H, Song JH, *et al.* (2011) Increasing prevalence of metabolic syndrome in Korea: the Korean National Health and Nutrition Examination Survey for 1998–2007. *Diabetes Care* **34**, 1323–1328.
2. Nestel P, Lyu R, Low LP, *et al.* (2007) Metabolic syndrome: recent prevalence in East and Southeast Asian populations. *Asia Pac J Clin Nutr* **16**, 362–367.
3. Kubena KS (2011) Metabolic syndrome in adolescents: issues and opportunities. *J Am Diet Assoc* **111**, 1674–1679.
4. Weiss R, Dziura J, Burgert TS, *et al.* (2004) Obesity and the metabolic syndrome in children and adolescents. *N Engl J Med* **350**, 2362–2374.
5. Lim S, Jang HC, Park KS, *et al.* (2013) Changes in metabolic syndrome in American and Korean youth, 1997–2008. *Pediatrics* **131**, E214–E222.
6. Ministry of Health and Welfare, Korea Centers for Disease Control and Prevention (2010) *Korea Health Statistics 2009: Korea National Health and Nutrition Examination Survey (KNHANES IV-3)*. Seoul, Republic of Korea: Ministry of Health and Welfare.
7. US Department of Agriculture, Agricultural Research Service (2012) *Energy Intakes: Percentages of Energy from Protein, Carbohydrate, Fat, and Alcohol, by Gender and Age, What We Eat in America, NHANES 2009–2010*. Washington DC: US Department of Agriculture.
8. Atkinson FS, Foster-Powell K & Brand-Miller JC (2008) International tables of glycemic index and glycemic load values: 2008. *Diabetes Care* **31**, 2281–2283.
9. Barclay AW, Petocz P, McMillan-Price J, *et al.* (2008) Glycemic index, glycemic load, and chronic disease risk – a meta-analysis of observational studies. *Am J Clin Nutr* **87**, 627–637.
10. Livesey G, Taylor R, Livesey H, *et al.* (2013) Is there a dose-response relation of dietary glycemic load to risk of type 2 diabetes? Meta-analysis of prospective cohort studies. *Am J Clin Nutr* **97**, 584–596.
11. Mirrahimi A, de Souza RJ, Chiavaroli L, *et al.* (2012) Associations of glycemic index and load with coronary heart disease events: a systematic review and meta-analysis of prospective cohorts. *J Am Heart Assoc* **1**, e000752.
12. Murakami K, Sasaki S, Takahashi Y, *et al.* (2008) Reproducibility and relative validity of dietary glycaemic index and load assessed with a self-administered diet-history questionnaire in Japanese adults. *Br J Nutr* **99**, 639–648.
13. Murakami K, Sasaki S, Takahashi Y, *et al.* (2006) Dietary glycemic index and load in relation to metabolic risk factors in Japanese female farmers with traditional dietary habits. *Am J Clin Nutr* **83**, 1161–1169.
14. Kim K, Yun SH, Choi BY, *et al.* (2008) Cross-sectional relationship between dietary carbohydrate, glycaemic index, glycaemic load and risk of the metabolic syndrome in a Korean population. *Br J Nutr* **100**, 576–584.
15. Choi H, Song S, Kim J, *et al.* (2012) High carbohydrate intake was inversely associated with high-density lipoprotein cholesterol among Korean adults. *Nutr Res* **32**, 100–106.
16. Nakashima M, Sakurai M, Nakamura K, *et al.* (2010) Dietary glycemic index, glycemic load and blood lipid levels in middle-aged Japanese men and women. *J Atheroscler Thromb* **17**, 1082–1095.
17. Shi ZM, Taylor AW, Hu G, *et al.* (2012) Rice intake, weight change and risk of the metabolic syndrome development among Chinese adults: the Jiangsu Nutrition Study (JIN). *Asia Pac J Clin Nutr* **21**, 35–43.
18. Carlson JJ, Eisenmann JC, Norman GJ, *et al.* (2011) Dietary fiber and nutrient density are inversely associated with the metabolic syndrome in US adolescents. *J Am Diet Assoc* **111**, 1688–1695.
19. Ventura EE, Davis JN, Alexander KE, *et al.* (2008) Dietary intake and the metabolic syndrome in overweight Latino children. *J Am Diet Assoc* **108**, 1355–1359.
20. O'Sullivan TA, Lyons-Wall P, Bremner AP, *et al.* (2010) Dietary glycaemic carbohydrate in relation to the metabolic syndrome in adolescents: comparison of different metabolic syndrome definitions. *Diabet Med* **27**, 770–778.
21. Katzmarzyk PT, Perusse L, Malina RM, *et al.* (2001) Stability of indicators of the metabolic syndrome from childhood and adolescence to young adulthood: the Quebec Family Study. *J Clin Epidemiol* **54**, 190–195.

22. Rural Development Administration, National Rural Resources Development Institute (2006) *Food Composition Table*, 7th ed. Suwon, Republic of Korea: Rural Development Administration.
23. Song S, Choi H, Lee SY, *et al.* (2012) Establishing a table of glycemic index values for common Korean foods and an evaluation of the dietary glycemic index among the Korean adult population. *Korean J Nutr* **45**, 80–93.
24. Foster-Powell K, Holt SHA & Brand-Miller JC (2002) International table of glycemic index and glycemic load values: 2002. *Am J Clin Nutr* **76**, 5–56.
25. Moon JS, Lee SY, Nam CM, *et al.* (2008) 2007 Korean National Growth Charts: review of developmental process and an outlook. *Korean J Pediatr* **51**, 1–25.
26. Matthews DR, Hosker JP, Rudenski AS, *et al.* (1985) Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia* **28**, 412–419.
27. Zimmet P, Alberti KG, Kaufman F, *et al.* (2007) The metabolic syndrome in children and adolescents – an IDF consensus report. *Pediatr Diabetes* **8**, 299–306.
28. Willett WC (2013) *Nutritional Epidemiology*, 3rd ed. New York: Oxford University Press.
29. McKeown NM, Meigs JB, Liu S, *et al.* (2009) Dietary carbohydrates and cardiovascular disease risk factors in the Framingham offspring cohort. *J Am Coll Nutr* **28**, 150–158.
30. Liu SM, Manson JE, Stampfer MJ, *et al.* (2001) Dietary glycemic load assessed by food-frequency questionnaire in relation to plasma high-density-lipoprotein cholesterol and fasting plasma triacylglycerols in postmenopausal women. *Am J Clin Nutr* **73**, 560–566.
31. Frost G, Leeds AA, Dore CJ, *et al.* (1999) Glycaemic index as a determinant of serum HDL-cholesterol concentration. *Lancet* **353**, 1045–1048.
32. Culberson A, Kafai MR & Ganji V (2009) Glycemic load is associated with HDL cholesterol but not with the other components and prevalence of metabolic syndrome in the third National Health and Nutrition Examination Survey, 1988–1994. *Int Arch Med* **2**, 3.
33. Finley CE, Barlow CE, Halton TL, *et al.* (2010) Glycemic index, glycemic load, and prevalence of the metabolic syndrome in the Cooper Center Longitudinal Study. *J Am Diet Assoc* **110**, 1820–1829.
34. Radhika G, Van Dam RM, Sudha V, *et al.* (2009) Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). *Metabolism* **58**, 675–681.
35. Park SH, Lee KS & Park HY (2010) Dietary carbohydrate intake is associated with cardiovascular disease risk in Korean: analysis of the third Korea National Health and Nutrition Examination Survey (KNHANES III). *Int J Cardiol* **139**, 234–240.
36. Villegas R, Liu SM, Gao YT, *et al.* (2007) Prospective study of dietary carbohydrates, glycemic index, glycemic load, and incidence of type 2, diabetes mellitus in middle-aged Chinese women. *Arch Intern Med* **167**, 2310–2316.
37. Song S, Lee JE, Song WO, *et al.* (2014) Carbohydrate intake and refined-grain consumption are associated with metabolic syndrome in the Korean adult population. *J Acad Nutr Diet* **114**, 54–62.
38. Nanri A, Mizoue T, Noda M, *et al.* (2010) Rice intake and type 2 diabetes in Japanese men and women the Japan Public Health Center-based Prospective Study. *Am J Clin Nutr* **92**, 1468–1477.
39. Kim HA, Lee SY, Kwon HS, *et al.* (2013) Gender differences in the association of insulin resistance with metabolic risk factors among Korean adolescents: Korea National Health and Nutrition Examination Survey 2008–2010. *Diabetes Res Clin Pract* **99**, 54–62.
40. Joung H, Hong S, Song Y, *et al.* (2012) Dietary patterns and metabolic syndrome risk factors among adolescents. *Korean J Pediatr* **55**, 128–135.
41. Cheung BM (2005) The cardiovascular continuum in Asia – a new paradigm for the metabolic syndrome. *J Cardiovasc Pharmacol* **46**, 125–129.

British Journal of Nutrition