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Original article

Korean diet prevents obesity and ameliorates insulin resistance in mice fed a high-fat diet

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ABSTRACT

Background: Korean diet has received considerable attention because of the low prevalence of obesity and metabolic disorders in Korea. Although the Korean diet has been shown to have health benefits, these effects have been investigated by analyzing individual nutrients or food components. In this study, we used a dietary pattern approach to investigate the effect of the Korean diet on obesity and glucose homeostasis in mice fed a high-fat diet (HFD).

Methods: C57BL/6 mice were fed the HFD for 7 weeks to induce obesity and then fed either the HFD or Korean diet for the next 7 weeks. The Korean diet was based on food frequency data obtained from the 4th Korean National Health and Nutrition Examination Survey and adjusted to have the same energy content as the HFD. Serum insulin and leptin were quantified by enzyme-linked immunosorbent assay, and glucose clearance was assessed using the oral glucose tolerance test. Lipogenic gene expression was determined by quantitative reverse transcription-polymerase chain reaction.

Results: The Korean diet significantly decreased the HFD-induced body weight increase and body fat accumulation and improved serum lipid profiles. Hepatic mRNA levels of lipogenic genes were lower in Korean diet-fed mice, which also showed decreased fasting blood glucose, insulin, and leptin levels, and improved glucose clearance. The Korean diet also ameliorated HFD-induced islet hypertrophy and elevated pancreatic insulin level.

Conclusions: Korean diet prevented obesity and ameliorated insulin resistance in mice fed a HFD. Therefore, Korean diet may be useful as a therapeutic diet to control metabolic disorders.

1. Introduction

In the Seoul Declaration, the definition of Korean diet represented the interpretation as follows: Korean diet is composed of *bab* (cooked rice) and *kuk*, and various *banchan* with one serving called *bapsang*. *Kimchi* is always served at every meal. The principal aspects of Korean diet include proportionally high consumption of fresh or cooked vegetables (*namul*), moderate to high consumption of legumes and fish, and low consumption of red meat. *Banchan* is mostly seasoned with various *jang* (fermented soy products), medicinal herbs, and sesame or perilla oil [1]. Korean diet and Korean food are two separate concepts. Although the concept of Korean diet is used to represent traditional Korean food culture, cooking methods, and dietary habits and patterns, Korean food are the food constituents of Korean diet. Korean food and Korean diet are often described as Korean cuisine or traditional Korean food. A few elements of defining food culture have been put forward, such as frequently consumed foods, raw ingredients or materials, technology or cooking methods, and the fundamental principles found in the country's dietary patterns. These views put differing emphasis on food and diet [1]. The characteristics of Korean diet include: (1) various recipes based on rice and grains; (2) more fermented foods; (3) more vegetables from wild landscapes and the seas; (4) more legumes and fish and less red meat; (5) more medicinal herbs such as garlic, green onion, red pepper, and ginger; (6) more sesame and perilla oil; (7) limited deep-fat fried cooking; (8) more meals based on seasonal produce; (9) various local cuisines; and (10) more home-cooked meals [1].

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Recently, studies have described the benefits of consuming the traditional Korean diet, which is characterized by rice as a main staple [2], along with a high consumption of vegetables and grains and the use of fermentation processes [3,4]. Fermented soy products [5], including *kanjang* (soy sauce), *doenjang* (soybean paste), and *gochujang* (red pepper paste), and various types of *kimchi* [6] with vegetables are the examples of Korean fermentation food, showing unique fermentation techniques in Korea [1,7]. Numerous health benefits have been associated with individual foods that comprise Korean cuisine [1,8]. For example, health benefits have been reported for rice, *kimchi*, and *gochujang* and *chongkukjang* (fermented soybean paste), which are the main components of the traditional Korean diet [9–12]. Rice has been shown to inhibit hyperlipidemia [9], and *kimchi*, used as a side dish at every meal, is a good source of vitamins, minerals, dietary fiber, lactic acid bacteria, and phytochemicals [13]. Kim et al [14] showed that *kimchi* decreases body weight and improves metabolic parameters in overweight and obese patients. *Gochujang* and *chongkukjang*, which contain *meju*, improve insulin sensitivity and contain isoflavonoids and small peptides, which are involved in the modulation of insulin sensitivity [15].

The current epidemic of obesity-related metabolic disorders is a major public health concern worldwide, with diet-related chronic diseases accounting for 65% of global mortality [16]. According to the National Health and Nutrition Examination Survey (NHANES), the obesity rate has increased dramatically, and the prevalence of obesity (body mass index $\geq$30) among adults aged 20 years and older in the United States was 35.7% in 2009–2010 [17]. To prevent or manage metabolic disorders including obesity, it has been strongly suggested that dietary risk factors should be modified. Recent studies have shown the importance of overall dietary patterns on health [18]. For example, the Mediterranean diet, characterized by high consumption of whole grains, fruits, vegetables, olive oil, and legumes and low consumption of red meats, has been recognized as a healthy diet [19]. In addition, the French diet has been reported to lower the incidence of cardiovascular disease, mainly because of resveratrol in wine [20]. Although the standard approach for exploring the health benefits and risks of a particular diet has focused on individual nutrients or food components, it is important to consider the dietary pattern as a whole [18,21]. The diet is a complex exposure variable; therefore, various approaches are needed to examine relationships between diet and disease risk. The dietary pattern approach captures the complex nature of dietary intake and explores its relationship with health outcomes [4,22]. Several recent studies of the Mediterranean and Japanese diets used the dietary pattern approach [23–25] but have the limitations inherent in human intervention studies and few studies have studied dietary patterns using an animal model [26,27]. Therefore, the present study aimed to expand the research on the health benefits of the Korean diet by dietary pattern approach in an animal model with particular interest in the biomarkers for obesity and insulin resistance.

2. Materials and methods

2.1. Korean diet preparation

Food items included in the Korean diet used in this study were based on food frequency data obtained from the 4th Korean NHANES and adjusted to 2,600 kcal daily (based on three meals per day: breakfast, lunch, and dinner) (Table 1). The Korean diet was prepared using traditional cooking methods, lyophilized, and then passed through an 80-mm mesh sieve. Analysis of nutrient composition was carried out using CAN-Pro 3.0 software (Korean Nutrition Society, Korea). The total energy content was adjusted to that of the high-fat diet (HFD).

Table 1
Dishes of rice based Korean diet (KD).

Meal type	Name of food	Weight (g)	Energy (kcal)
Breakfast	Cooked rice	210	313
	Dried Pollack soup	100	147
	Boiled tofu with soy sauce	150	185
	Grilled seaweed	10	13
	Cabbage *kimchi*	60	10
Snack	Banana milk (snack)	200	213
	White bread (snack)	100	277
Lunch	Cooked rice	210	313
	Doenjang stew with tofu	100	99
	Seasoned chicken stew	250	250
	Seaweed with cucumber salad	80	25
	Cabbage *kimchi*	60	10
Snack	Orange juice (snack)	200	90
	Pear (snack)	100	39
Dinner	Cooked rice	210	313
	Bean sprouts with *kimchi* soup	100	34
	Pork *bulgokgi*	200	214
	Lettuce and green pepper with seasoned soybean paste	80	31
	Young radish *kimchi*	40	12

2.2. Animal models

Four-week-old male C57BL/6 mice were maintained with free access to food and water. After a 1-week adaptation, the mice were fed an HFD [20% fat and 0.5% cholesterol (w/w)] *ad libitum* to induce obesity. After 7 weeks on the HFD, the mice ($n = 10$ per group) were randomly divided into two groups and fed either the Korean diet or HFD for the next 7 weeks. The HFD was based on the AIN-76 diet (American Institute of Nutrition, 1980) and consisted of 25% fat (corn oil 5% and lard 20%) with 0.5% cholesterol, 20% protein, and 49.5% carbohydrate (w/w). All procedures were conducted in accordance with the Guidelines for Institutional Animal Care and Use Committee of the Korea Food Research Institute (KFRI-IACUC, KFRI-M-13007).

2.3. Serum and tissue sampling

After consuming the experimental diets, the mice were fasted for 12 hours and then sacrificed. Blood from the abdominal aorta was collected and centrifuged at 1,500*g* for 15 minutes to separate the serum, which was stored at −70°C until analysis. The liver and pancreas were excised, weighed, and stored at −70°C until use.

2.4. Serum and liver analysis

Serum triglycerides, total cholesterol, and high-density lipoprotein (HDL) cholesterol levels were measured using commercial enzyme kits (Shinyang Chemical Co., Seoul, South Korea). Serum insulin and leptin (ALPCO Diagnostics, Salem, NH, USA) were quantified by enzyme-linked immunosorbent assay. Hepatic lipids were extracted using the method described by Folch et al [28]. Hepatic triglyceride and total cholesterol levels were measured using commercial enzyme kits (Shinyang Chemical Co.).

2.5. Glucose and insulin tolerance tests

For the oral glucose tolerance test (OGTT), the animals were fasted for 4 hours prior to testing at 6 weeks after initiation of the

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