Dietary Patterns and Glucose Tolerance Abnormalities in Chinese Adults

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OBJECTIVE — To investigate the association of the dietary pattern with the presence of newly diagnosed glucose tolerance abnormalities among Chinese adults.

RESEARCH DESIGN AND METHODS — A total of 20,210 adults aged 45–69 years from the 2002 China National Nutrition and Health Survey were included. Information on dietary intake was collected using a validated food frequency questionnaire. Factor analysis and cluster analysis were used to identify the food factors and dietary pattern clusters.

RESULTS — Four dietary pattern clusters were identified ("Green Water," "Yellow Earth," "Western Adopter," and "New Affluence"). The prevalence of glucose tolerance abnormalities ranged from 3.9% in the Green Water to 8.0% in the New Affluence. After adjustment for area, age, sex, current smoking, and physical activity, subjects in the Yellow Earth cluster (prevalence ratio 1.22 [95% CI 1.04–1.43]) and New Affluence cluster (2.05 [1.76–2.37]) had significantly higher prevalence rates compared with those for the Green Water cluster. After further adjustment for BMI and waist-to-height ratio, the elevated risk in the New Affluence remained statistically significant.

CONCLUSIONS — Dietary patterns and food factors are associated with the presence of glucose tolerance abnormalities in China, even independent of obesity. A New Affluence diet is an important modifiable risk factor, which needs attention from the prevention point of view.

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The prevalence of type 2 diabetes is increasing rapidly worldwide (1). The 2002 China National Nutrition and Health Survey showed that 2.6% of Chinese adults have diabetes, translating to >20 million people (2). Behavior and lifestyle factors, such as eating habits and physical activity, are recognized as playing an important role in the development of diabetes. The traditional approach to investigate diet-disease associations focuses on single dietary components, such as single nutrients or foods (3–8). However, individuals eat meals instead of foods or nutrients, making it more difficult to separate the effect of individual dietary components. The effect of the overall diet can be studied with dietary pattern analyses. This approach is used increasingly in studies on the relationship between diet and diabetes among Western populations. Some studies suggest that the adoption of a Western dietary pattern, characterized by red meat, processed meat, French fries, high-fat dairy products, refined grains, sweets, and desserts, may be associated with increased incidence of type 2 diabetes (9–12).

Little work, however, has been done to investigate Asian dietary patterns and, in particular, the Chinese diet. Recently four Chinese dietary patterns were identified in a study on dietary habits and obesity among Chinese adults (13). The dietary patterns identified were considered to be highly realistic within the nutrition transition framework in China. In the present study, we used these four dietary patterns to investigate the association with the presence of newly diagnosed glucose tolerance abnormalities in China.

RESEARCH DESIGN AND METHODS

— The 2002 China National Nutrition and Health Survey is a national representative cross-sectional study on diet and chronic disease. It covered all 31 provinces, autonomous regions, and municipalities directly under the central government throughout China (except Taiwan, Hong Kong, and Macao). Participants were recruited by use of a stratified multistage cluster sampling design. The country was divided into six strata: large cities, small to medium cities, class 1 rural areas, class 2 rural areas, class 3 rural areas, and class 4 rural areas, according to their economic characteristics and social development. The first stage of sampling involved the random selection of 22 districts (urban) or counties (rural) from each of the six strata. The second stage involved the random selection of three neighborhoods (urban) or townships (rural) from each of the selected districts/counties. From each of the neighborhoods or townships, two residential committees (urban) or villages (rural) were randomly selected; 90 households were randomly sampled from each village. A total of 795 residential committees or villages and 68,828 families were sampled. About one-third of households were selected to participate in the dietary survey. All participants aged ≥15 years completed an interview with a structured food frequency questionnaire. All family members of these dietary survey participants, who were aged >2 years, were invited for the measurement of fasting blood glucose. An oral glucose tolerance test (OGTT) was undertaken in subjects whose fasting glucose was ≥5.5 mmol/l.

Once the village/neighborhood committee decided to participate, the individual response rate was always >90%. Of the 68,925 subjects who attended the dietary survey, 60,158 participated in the fasting glucose measurement, a response rate of 87%. Among the 5,887 subjects whose fasting glucose level was >5.5 mmol/l and who should therefore have

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participated in the OGTT, 1,818 subjects did (response rate 31%). Among the subjects who finalized the food frequency questionnaire, 6% were excluded because of extreme values, including daily energy intake >5,000 kcal. Further details on this survey have been published elsewhere (2).

For the present study, we used data of 20,866 subjects aged 45–69 years who had a completed a food frequency questionnaire and underwent fasting blood sampling for analysis of blood glucose. All subjects who were known to have diabetes before the survey were excluded from the analyses (n = 656), because they may have changed their dietary habits. The final study population comprised 20,210 individuals.

Dietary assessment

A validated semiquantitative food frequency questionnaire was used to investigate the usual diet in the previous 1 year before the study (14). A previous article described the construction of dietary patterns by using factor analysis combined with cluster analysis in 56,442 men and women aged >18 years in the 2002 China National Nutrition and Health Survey for whom dietary data were complete (13). In short, four factors were identified by applying the principal components method with oblique rotation based on the quartiles of the consumption quantity (online Appendix 1, available at http://care.diabetesjournals.org/cgi/content/full/dc09-0714/DC1).

Subsequently, we used the factor scores in cluster analysis with a two-step approach. First, hierarchical cluster analysis by randomly filtering 1% of the total number of participants was used to help identify the number of clusters and to determine the initial cluster centers for the subsequent K-means cluster analysis. A plot of the agglomeration coefficients in the successive steps revealed an elbow at the four-cluster solution. We then saved the means of the four clusters as initial cluster centers for the K-means cluster. By using the output from the hierarchical clustering, the K-means cluster method was used to calibrate the solution for all cases. In the end, all cases were assigned to each of the four clusters (online Appendix 2). We calculated the average food consumption of different diet patterns as the average amount (grams) per reference men per day, a man being an 18-year-old man with light physical activity level, whose reference energy intake is 2,400 kcal. Mean values of individual amounts in reference men among each group were then calculated. According to these characteristic of food intake, the four dietary patterns were labeled as "Green Water" (like the rice area in the Southeast), "Yellow Earth" (their food is mainly produced on the dry and hilly land, like the mountain area in the Northwest), "New Affluence" (mainly well-to-do individuals), and "Western Adopter" (mainly young individuals, a more Western-oriented food style), respectively.

Ascertainment of glucose tolerance abnormality

Fasting blood glucose levels were measured by trained technicians, and an OGTT was taken from subjects whose fasting glucose was ≥5.5 mmol/l. For interpretation of the fasting and 2-h OGTT glucose levels, criteria from the World Health Organization Expert Committee on Diabetes Mellitus (1999 criteria) were used. Subjects were classified as diabetes (type 2 diabetes), impaired glucose tolerance (IGT), or impaired fasting glucose (IFG). In the present study, the diagnosis glucose tolerance abnormality includes type 2 diabetes, IGT, and IFG.

Measurement of behavioral factors

Information on current smoking and drinking was collected by trained investigators from face-to-face interviews. Current smoking was identified as having smoked at least one piece a week in the past 30 days, and alcohol drinking was identified as drinking alcohol at least once per week.

BMI (weight in kilograms divided by the square of height in meters) was calculated from direct measurements of fasting body weight and height. Our recent study (15) showed that the waist-to-height ratio (WHtR) was more strongly associated with (pre-)diabetes than waist circumference in Chinese adults, so we used WHtR as an indicator of abdominal obesity. Physical activity was recorded as a three-level variable (light, moderate, and heavy), as recommended by the China Nutrition Society (16), to reflect total energy expenditure.

Statistical methods

Factor analysis and cluster analysis were performed by using the SPSS statistical system (version 13.0; SPSS, Chicago, IL). Subjects' characteristics were compared between the dietary clusters using the χ^2 statistic for discrete variables and ANOVA for continuous variables. The age-adjusted and multiple adjusted prevalence ratios and their 95% CIs of glucose tolerance abnormality between different dietary clusters and different food factors were calculated after adjustment for age, family history of diabetes, smoking status, WHtR, and physical activity level using the Cox regression analysis PHREG Procedure in SAS (version 9.1; SAS Institute, Cary, NC), in which survival time is artificially set equal to 1 (17).

RESULTS

Subject characteristics

As shown in Tables 1 and 2, the Green Water cluster was characterized by living in rural areas, having higher physical activity, being more likely to smoke and drink alcohol, but being less frequently overweight and obese, and having a higher consumption of rice and vegetables and a moderate intake of animal foods. The Yellow Earth cluster was characterized by higher consumption of wheat flour, tubers, and other cereals and lower consumption of vegetables, fruit, and animal food. The New Affluence cluster was characterized by living in urban areas, being less physical active, having more smokers, alcohol users, and overweight individuals, and having a higher intake of animal foods and soybean products. The Western Adaptor diet was characterized by a high consumption of animal food, cakes, and drinks.

Dietary pattern and glucose tolerance abnormality

The prevalence of glucose tolerance abnormalities was significantly different among subjects with different dietary patterns. Subjects of the Green Water cluster had the lowest prevalence of glucose tolerance abnormality (3.9%), whereas the highest prevalence was found in the New Affluence pattern (8.0%) (Table 1).

After adjustment for area, age, sex, smoking, alcohol drinking, physical activity level, and family history of diabetes, the association between diet clusters and glucose tolerance abnormalities was attenuated but remained significant for the New Affluence (prevalence ratio 1.45 [95% CI 1.21–1.72]) and Yellow Earth (1.26 [1.07–1.48]) clusters. The association disappeared after further adjustment for BMI or WHtR in the Yellow Earth cluster but remained significant in the New Affluence cluster (Table 3).

Table 1—*Selected characteristics of Chinese adults according to dietary cluster (2002 China National Nutrition and Health Survey)*

	Green Water	Yellow Earth	New Affluence	Western Adopter
n (%)	7,314 (36.2)	5,651 (28.0)	4,923 (24.4)	2,322 (11.5)
Sex (% men)	49.6	45.2*	46.5*	50.3
Age (%)				
45–59 years	74.3	72.0*	69.1*	75.1
60–69 years	25.7	28.0	30.9	24.9
Area (%)				
Urban	24.1	15.9*	64.2*	65.4*
Rural	75.9	84.1	35.8	34.6
Current smoker (%)	32.6	28.6*	27.8*	30.3*
Alcohol drinker (%)	28.7	16.5*	22.8*	29.0
BMI (%)				
$<$18.5 kg/m^2	8.9	5.2*	2.6*	3.2*
18.5–23.9 kg/m^2	61.8	53.3	40.3	44.4
24–27.9 kg/m^2	22.9	29.7	39.8	37.5
$\geq$28 kg/m^2	6.4	11.8	17.3	14.9
WHtR $>$0.5 (%)	37.1	45.6*	59.9*	55.8*
Physical activity level (%)				
Light	33.9	32.5*	71.5*	72.6*
Medium	17.7	20.5	12.2	15.9
Heavy	48.4	47.0	16.3	11.5
Annual family income per person (%)				
$<$2000 RMB	45.9	65.7*	25.0*	16.2*
2000–4,999 RMB	34.1	24.5	27.2	26.3
$\geq$5,000 RMB	20.0	9.8	47.8	57.5
Education level (%)				
Illiterate	21.3	23.1*	8.2*	6.9*
Primary school	45.9	41.0	27.1	26.5
High school	31.1	34.7	55.9	55.8
Above high school	1.7	1.2	8.8	10.8
Glucose tolerance abnormality (%)	285 (3.9)	271 (4.8)*	394 (8.0)*	146 (6.3)*
Diabetes	148 (2.0)	123 (2.2)	213 (4.3)*	80 (3.5)*
IFG	107 (1.5)	114 (2.0)*	134 (2.7)*	54 (2.3)*
IGT	55 (0.8)	56 (1.0)	77 (1.6)	24 (1.0)

Data are *n* (%) or %. *Significantly different from Green Water pattern (Pearson χ^2 test), $P < 0.05$.

CONCLUSIONS— Currently, China is undergoing a remarkably fast shift toward a stage of nutrition transition dominated by a high intake of fat and animal foods, as well as a high prevalence of diet-related chronic diseases, such as obesity, diabetes, and cardiovascular disease (2,18). The four dietary patterns identified reflect the main dietary characteristics of the Chinese population under nutrition transition. In addition, we found that these dietary patterns are associated with the presence of glucose tolerance abnormalities. The Green Water pattern, characteristically high in rice and vegetables and moderate in animal foods, was found in the rich rural areas. It was the largest cluster but had the lowest prevalence of glucose tolerance abnormality and was therefore used as the reference. Compared with the Green Water pattern, the New Affluence pattern was associated with a substantially higher risk of glucose tolerance abnormalities, independent of confounders as well as of indicators of body fatness.

The individuals with the Green Water pattern are rice eaters foremost and have the highest consumption of vegetables and moderate use of animal food. This pattern represents the traditional Chinese diet. Our finding that the prevalence of glucose tolerance abnormalities is low in this cluster is in line with results of previous studies in different populations, which have shown an inverse association between consumption of vegetables and the risk of type 2 diabetes (8,10,19,20). Unlike others (9,10,19), we found that fruit was located in a dietary factor different from vegetables and was positively associated with diabetes. This finding may be explained by the fact that fruit is considered a healthy, but expensive, food in some Chinese populations.

Members of New Affluence and Western Adopter clusters are to a large extent less poor, more highly educated, and, in general, living in urban areas. They can afford more expensive foods. These Chinese individuals have benefited most from the dramatically enhanced economic opportunities, and they have broken away from the traditional Chinese food culture. As the classic food pattern shifts, intakes of cereals, vegetables, and many lower-fat, mixed dishes are being replaced, animal foods are becoming popular, and the consumption of edible oil is increasing quickly. High consumption of animal foods is probably accompanied by a greater intake of saturated fatty acids, which may increase the risk of diabetes (21–23). Western studies showed that the Western dietary pattern, characterized by higher intakes of red and processed meat, sweets, and dessert, may increase the risk of type 2 diabetes (11,21).

The Yellow Earth pattern is a typical Chinese high-carbohydrate diet, which consists of a variety of cereal products and tubers, contributing as the primary source of caloric intake. The Yellow Earth pattern is characterized by the highest intake of staples compared with the other three patterns. A high intake of staples was associated with the risk of developing type 2 diabetes in China (24). The members of the Yellow Earth cluster were primarily concentrated in the Northwest rural areas in China. Malnutrition and overnutrition coexist in this area. This is a vulnerable group that deserves special attention from researchers and policy makers.

In our study, the association between dietary patterns and glucose tolerance abnormalities was attenuated after adjustment for lifestyle and socioeconomic factors. Because obesity may be an intermediate step in the pathway between diet and type 2 diabetes, one can argue that the models adjusted for BMI or WHtR present an overadjustment. After adjustment for obesity, the elevated risk disappeared in the Yellow Earth and Western Adopter clusters but remained significant in the New Affluence cluster. Thus, body

Table 2—*Dietary intake of Chinese adults according to dietary cluster (2002 China National Nutrition and Health Survey)*

	Green Water	Yellow Earth	New Affluence	Western Adopter
Rice and rice products	399.6 ± 157.7	91.0 ± 115.5*	156.4 ± 118.3*	233.1 ± 144.7*
Wheat and products	26.4 ± 51.1	264.9 ± 183.3*	170.5 ± 165.1*	99.1 ± 122.2*
Other cereals	4.6 ± 28.2	59.8 ± 85.8*	27.3 ± 54.3*	16.9 ± 34.9*
Starchy tubers	18.3 ± 41.4	70.8 ± 104.9*	42.0 ± 68.2*	30.5 ± 48.9*
Pork	47.8 ± 55.8	16.1 ± 33.8*	52.4 ± 60.5*	64.7 ± 65.7*
Beef/lamb	2.1 ± 8.7	2.9 ± 19.5*	14.2 ± 35.3*	12.5 ± 35.9*
Poultry	8.0 ± 24.6	1.4 ± 8.8*	12.9 ± 35.1*	16.1 ± 27.3*
Fish and shrimp	23.7 ± 45.7	3.3 ± 14.5*	27.7 ± 48.9*	35.5 ± 47.6*
Eggs	19.6 ± 24.4	29.2 ± 34.1*	47.0 ± 38.5*	39.3 ± 33.2*
Dairy products	6.6 ± 44.9	15.1 ± 74.4*	104.8 ± 168.6*	98.1 ± 159.0*
Soybean products	9.9 ± 14.0	7.2 ± 10.3*	14.7 ± 16.8*	14.4 ± 13.5*
Dry beans	5.1 ± 30.8	6.4 ± 35.1*	10.0 ± 44.5*	11.9 ± 39.4*
Vegetables	309.0 ± 175.6	184.9 ± 155.9*	248.7 ± 160.5*	273.1 ± 161.4*
Dry vegetables	3.3 ± 21.7	3.3 ± 22.6*	5.0 ± 33.4*	4.5 ± 26.0*
Cake	3.4 ± 16.3	2.2 ± 10.2*	12.6 ± 28.7*	18.7 ± 30.4*
Fruit	43.1 ± 63.8	50.6 ± 73.1*	113.0 ± 101.1*	114.6 ± 98.6*
Nuts	3.0 ± 14.4	2.5 ± 12.2	8.5 ± 22.4*	12.5 ± 25.6*
Low-degree alcohol	11.9 ± 63.3	5.2 ± 71.8*	5.8 ± 30.6*	8.5 ± 38.9*
High-degree alcohol	14.5 ± 182.0	5.4 ± 29.6*	10.7 ± 83.9	8.3 ±35.0
Beer	28.2 ± 317.0	7.1 ± 60.0*	25.4 ± 177.2	67.0 ± 596.1*
Wine	0.7 ± 29.2	0.2 ± 7.2	0.8 ± 13.3	6.2 ± 207.6
Juice	2.5 ± 19.2	1.4 ± 16.0*	4.4 ± 29.1*	32.9 ± 66.7*
Other beverages	9.2 ± 65.6	3.6 ± 53.7*	23.3 ± 143.2*	38.7 ± 117.5*
Vegetable oil	30.0 ± 31.0	34.0 ± 34.4*	39.9 ± 31.6*	38.2 ± 30.4*
Animal fat	13.4 ± 24.2	6.9 ± 19.9*	3.7 ± 13.2*	4.1 ± 13.5*

Data are means ± SD grams per day. *Mean is significantly different from the Green Water pattern (ANOVA), $P < 0.05$.

fatness may partly mediate the association between diet and glucose tolerance abnormalities and from a public health point of view, the elevated risks in the Yellow Earth and New Affluence clusters are certainly relevant, as they identify high-risk groups. However, after taking into account overall overweight or abdominal obesity, the risk remains elevated in the New Affluence cluster. This finding supports the independent effect of diet on glucose metabolism and warrants even more public health attention to this dietary pattern. Adjustment for body fatness is often also used for methodological reasons. Because BMI and waist are important predictors of glucose tolerance and diabetes, the statistical efficiency of a model is improved by adding these important determinants. In addition, overweight subjects are in general known to selectively report their dietary intake, which is also possibly true in China, and including BMI in a model may partly account for this. However, residual confounding may have been present, resulting in underadjustment as BMI or WHtR because body fatness and composition were estimated rather than perfectly measured using these anthropometric indicators.

Table 3—*Prevalence ratios (95% CI) of glucose tolerance abnormality according to dietary cluster (2002 China National Nutrition and Health Survey)*

	Green Water	Yellow Earth	New Affluence	Western Adopter
Model 1	1.0 (reference)	1.22 (1.04–1.43)*	2.05 (1.76–2.37)†	1.60 (1.32–1.95)†
Model 2	1.0	1.26 (1.07–1.48)*	1.45 (1.21–1.72)†	1.07 (0.84–1.36)
Model 3	1.0	1.04 (0.88–1.22)	1.19 (1.01–1.41)*	0.95 (0.76–1.19)
Model 4	1.0	1.12 (0.93–1.35)	1.24 (1.04–1.49)*	0.99 (0.78–1.26)

Model 1: unadjusted. Model 2: adjusted for area (urban/rural), age, sex, current smoking, physical activity level, family history of diabetes, education level, and family income. Model 3: additionally adjusted for BMI. Model 4: Model 2 additionally adjusted for WHtR. $*P < 0.05$; $†P < 0.0001$.

The strengths of this study include the extensive information on diet and lifestyle, the high quality of the data collected, and the national representative sample size available for analysis that has allowed us to assess the risk of development of glucose tolerance abnormalities in the general Chinese population. Another strength is the statistical technique that combined factor analysis and cluster analysis to identify Chinese dietary patterns. Factor analysis is widely used to reduce data and to extract a small number of factors depending on the correlation matrix, whereas cluster analysis is performed to further classify elements of different sources on the basis of their similarities. Cluster analysis based on factor analysis can better embody the effect of every diet factor.

There are also some limitations. First, by using a cross-sectional study, we cannot formally draw conclusions about causality. However, it should be noted that when diet and nonclinically diagnosed glucose abnormalities are investigated, it is unlikely that reverse causality has played a role. Second, dietary intake was assessed by a single food frequency questionnaire referring to a period of 1 year. Dietary habits may change over a lifetime, and these changes in dietary habits may have had an additional impact on diabetes. Above all, after rapid economic and social changes, Chinese dietary patterns and lifestyle have changed substantially, and an unbalanced dietary pattern, including undernutrition and overnutrition, may increase the risk of development of type 2 diabetes in China. Another limitation of the present study is the low response rate for the OGTT. The individuals whose fasting glucose level was <6.1 mmol/l and 2-h glucose level was >7.8 mmol/l were misclassified from glucose tolerance abnormalities to normal. This may have diluted the association between dietary pattern and glucose tolerance abnormalities. However, the amount of misclassification is likely to have been relatively small. Among the 31% of subjects who underwent an OGTT, only 8% were found to have IGT or diabetes, In addition, subgroup analysis with or without subjects who were tested for glucose tolerance did not change the our results.

As the number of diabetic patients has already been estimated to be >20 million in 2002, we can expect a considerable public health burden in the near future in China and prevention is urgently warranted. Analysis of the dietary patterns and food factors that are related to the presence of glucose tolerance abnormalities, i.e., newly diagnosed diabetes and pre-diabetes, will provide the basis for future prevention studies and thereafter hopefully prevention action.

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