

# Dietary Nutrients and Insulin Resistance in Urban Asian Indian Adolescents and Young Adults

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## Key Words

Diet · Insulin resistance · Polyunsaturated fatty acids · Adolescents and young adults

## Abstract

**Background:** Asian Indians have a high prevalence of insulin resistance that may underlie their higher tendency to develop type 2 diabetes mellitus and early-onset atherosclerosis. **Objective:** To investigate the relationship between dietary nutrients and insulin resistance in Asian Indian adolescents and young adults. **Design:** Dietary nutrient intake values (24-hour dietary recall and monthly consumption data) and fasting serum insulin levels were studied in 352 (311 males and 41 females) healthy adolescents and young adults (mean age 18.0 ± 2.3 years; range 14–25 years). Bivariate and multivariate logistic regression analyses were performed with hyperinsulinemia as the outcome variable

and various dietary nutrients and anthropometric variables as covariates. **Results:** Mean fasting serum insulin levels were 107.4 ± 35.0 pmol/l (36.5–230.4 pmol/l). The intake of polyunsaturated fatty acids (PUFAs) was higher, saturated fat and the ω-6 to ω-3 PUFA ratio were in the upper limit, and ω-3 PUFAs (% caloric intake, En) were lower than the recommended dietary allowance for Asian Indians. The PUFAs (% En), BMI, percent body fat and waist circumference were significantly higher in the hyperinsulinemic group compared with the normoinsulinemic group (p = 0.021, 0.0021, 0.0006, and 0.0041, respectively). Multiple regression analysis showed that the lowest tertile of ω-6 (<3% En) PUFA intake [adjusted OR (95% CI) = 0.3 (0.1–0.7)] and BMI [adjusted OR (95% CI) = 2.9 (1.4–6.0)] were the significant independent predictors of fasting hyperinsulinemia. **Conclusion:** For prevention and amelioration of insulin resistance in Asian Indian adolescents and young adults, it is prudent to have normal BMI and low intake of ω-6 PUFAs.

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A.M. and N.K.V. designed this study and the epidemiological trial in school children. K.R. carried out the data collection in various schools and colleges with help from R.S. K.L. contributed to the measure of fasting serum insulin levels. S.I., K.R. and S.A. entered the data. S.I., S.A. and R.M.P. analyzed the data and interpreted the results along with J.S.W. and A.M. S.I., S.A. and A.M. wrote the manuscript.

## Introduction

Insulin resistance is associated with type 2 diabetes mellitus (T2DM), ischemic heart disease, both independently and in association with the insulin resistance syn-

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drome (the metabolic syndrome) [1–3]. We have previously shown that urban Asian Indians have a high prevalence of the metabolic syndrome that may underlie their greater than normal tendency to develop T2DM and early-onset atherosclerosis [4]. Further, a high prevalence of obesity, dyslipidemia and insulin resistance has been shown by us in urban Asian Indian children [4, 5]. Despite possible influences of genetic and perinatal factors, diet and physical activity are likely to have greater and overriding influence in the generation of the metabolic syndrome and T2DM due to rapid lifestyle changes and urbanization occurring in India.

Although dietary nutrients are assumed to be closely interlinked to development of obesity and insulin resistance syndrome, the relationship between dietary nutrients and insulin resistance has been poorly investigated. In animal experiments, high-fat feeding has been presumed to be a cause of obesity and insulin resistance [6]. Deleterious effects of saturated fatty acids and monounsaturated fatty acids (MUFAs) but not polyunsaturated fatty acids (PUFAs) on insulin sensitivity have been reported by some investigators [7–9], whereas others have not found any relation of insulin sensitivity to intake of any type of dietary fats [10, 11]. Most observational studies have not revealed any significant association between carbohydrate intake and insulin resistance [11, 12]. Observational studies have suggested that foods rich in different types of dietary fiber are associated with a reduced probability of developing insulin resistance [9, 11, 12].

A variety of vegetarian and nonvegetarian diets are consumed by Asian Indians. Over the previous three decades, Asian Indians have become more affluent and urbanized [13]. These changes have resulted in higher consumption of calories, fats, simple sugars, carbohydrates and lower intake of fiber as compared to the years preceding the change. Dietary changes are most noticeable in children. Our recent data show high intake of saturated fats and energy-dense 'fast foods' and low intake of MUFAs in urban children in New Delhi [unpubl. obs.]. Whether any of these changes in the quantity and quality of nutrients could influence insulin resistance in Asian Indian children has not been investigated.

We hypothesized that dietary nutrients influence insulin resistance in Asian Indian adolescents and young adults. To investigate this hypothesis, we studied anthropometry, dietary profile, and a measure of insulin resistance in randomly selected schoolchildren in New Delhi, India.

## Subjects and Methods

The institutional ethics committee approved the study. The subjects were selected using multistage cluster sampling based on the modified World Health Organization Expanded Program of Immunization Sampling Plan [14]. First, two separate lists, one containing the names of schools and the other containing the names of colleges located in the defined area, were prepared. For the study, a 'cluster' was defined as a school or a college. A total of 40 clusters were randomly selected from the two lists. The number of schools and colleges was determined based on the proportional allocation to ensure the representativeness of the sample with respect to clusters and socioeconomic strata. For both schools and colleges, a 'section' was considered as the primary sampling unit at the second stage of sampling. Subsequently from each of the schools/colleges, two to four sections were selected depending upon the number of the students in the section. All the students in the selected section were included in the study. A written informed consent was obtained from subjects  $\geq 18$  years of age. For subjects  $< 18$  years of age, written consent was obtained from their parents. A total of 352 subjects (311 males and 41 females) were eligible for the final analysis and the results are reported in this study.

### *Anthropometry*

The measurements for height, weight and body mass index (BMI) were carried out by a physician in a secluded area in the school or college according to the methods described previously [15]. We measured percentage body fat (%BF) using leg-to-leg bioelectrical impedance method (Tanita TBF 300, Tanita Corp., Tokyo, Japan), which has been validated for Asian children and adolescents [16] and has been extensively used by us previously [5, 17]. For the estimation of bioelectrical impedance, subjects were evaluated after an overnight fast. They were instructed to avoid drinking fluids and void urine 1 h prior to the measurements and just before the test. Gender and height details were manually entered into the software of the apparatus. The subject was instructed to stand on the base of the apparatus so that both feet were in firm contact with the surface and that the hands were not touching any surface.

### *Nutrient Profile*

Nutrient information was calculated using a pretested 24-hour food recall questionnaire prepared by the investigating team for Asian Indian food articles according to the guidelines of the National Institute of Nutrition, Hyderabad, India [18]. The first section of the questionnaire dealt with general information concerning the subject. The second section of the questionnaire dealt with dietary habits, frequency of eating out and the type and amount of fat used as the cooking medium. Students were given separate typewritten handouts to be filled in by their mothers to assess the monthly consumption of cooking oils, and these data were randomly rechecked by telephone interviews. The second section was also meant for recording various food items usually not consumed daily. The consumption was recorded on a weekly, bi-weekly and monthly basis. The third section of the questionnaire comprised the 24-hour nutrient intake, listing the details of morning tea, breakfast, mid-morning snack, lunch, evening tea, dinner and bedtime snack for 2 nonconsecutive days, one of them a weekend. The same dietician administered the questionnaire in

**Table 1.** Nutrient profile and anthropometric measurements (mean  $\pm$  SD)

	All subjects (n = 352)	Hyperinsulinemic (n = 53)	Normoinsulinemic (n = 299)	p value	RDA [19, 20]
Age, years	18.0 $\pm$ 2.3	17.7 $\pm$ 2.4	18.1 $\pm$ 2.3	0.2181	
Energy, kcal	2259.1 $\pm$ 705.0	2277.1 $\pm$ 688.0	2255.9 $\pm$ 709.1	0.8404	
Carbohydrates, g	336.0 $\pm$ 107.9	332.4 $\pm$ 103.6	336.6 $\pm$ 108.8	0.7949	
Carbohydrates, % En	60.1 $\pm$ 10.0	59.0 $\pm$ 9.6	60.3 $\pm$ 9.8	0.3561	55–65%
Proteins, g	69.2 $\pm$ 22.1	68.9 $\pm$ 22.9	69.2 $\pm$ 22.0	0.9179	
Proteins, % En	12.3 $\pm$ 1.6	12.1 $\pm$ 1.6	12.4 $\pm$ 1.7	0.2200	10–15%
Total fat, g	65.8 $\pm$ 33.6	70.3 $\pm$ 34.5	65.0 $\pm$ 33.5	0.2956	
Total fat, % En	25.6 $\pm$ 9.5	27.4 $\pm$ 9.3	25.3 $\pm$ 9.5	0.1515	15–30%
Saturated fat, g	24.5 $\pm$ 15.9	25.3 $\pm$ 17.4	24.4 $\pm$ 15.7	0.7052	
Saturated fat, % En	9.4 $\pm$ 4.8	9.6 $\pm$ 5.0	9.4 $\pm$ 4.8	0.7994	<10%
MUFAs, g	18.1 $\pm$ 11.9	19.5 $\pm$ 12.2	17.9 $\pm$ 11.8	0.3627	
MUFAs, % En	6.9 $\pm$ 3.4	7.4 $\pm$ 3.3	6.8 $\pm$ 3.4	0.2569	10–15%
PUFAs, g	20.4 $\pm$ 10.5	22.9 $\pm$ 10.1	19.9 $\pm$ 10.5	0.0603	
PUFAs, % En	8.2 $\pm$ 3.7	9.2 $\pm$ 3.8	8.0 $\pm$ 3.6*	0.0210	<8%
$\omega$ -3 PUFAs, g	1.7 $\pm$ 1.3	1.9 $\pm$ 1.2	1.7 $\pm$ 1.3	0.2646	
$\omega$ -3 PUFAs, % En	0.7 $\pm$ 0.5	0.8 $\pm$ 0.5	0.7 $\pm$ 0.5	0.1574	>1%
$\omega$ -6 PUFAs, g	10.9 $\pm$ 7.6	12.1 $\pm$ 6.6	10.7 $\pm$ 7.8	0.2170	
$\omega$ -6 PUFAs, % En	4.3 $\pm$ 2.6	4.8 $\pm$ 2.2	4.2 $\pm$ 2.7	0.1365	3–7%
$\omega$ -6 to $\omega$ -3 PUFA ratio	9.4 $\pm$ 9.4	9.3 $\pm$ 9.0	9.5 $\pm$ 9.5	0.9294	5–10
Cholesterol, mg	94.4 $\pm$ 72.0	85.9 $\pm$ 69.7	95.9 $\pm$ 72.4	0.3488	<300 mg
Fiber, g	8.6 $\pm$ 3.0	9.0 $\pm$ 2.9	8.6 $\pm$ 3.0	0.3190	30–40 g
BMI	20.0 $\pm$ 3.4	21.4 $\pm$ 3.3	19.8 $\pm$ 3.4*	0.0021	
BF, %	21.9 $\pm$ 6.8	25.0 $\pm$ 5.9	21.4 $\pm$ 6.8*	0.0006	
Waist circumference, cm	70.3 $\pm$ 7.9	73.2 $\pm$ 8.5	69.8 $\pm$ 7.7*	0.0041	

En = Caloric intake. \*  $p < 0.05$  for statistically significant difference in the insulin groups.

all the subjects. Standard sets of common utensils, utilized in Indian households, were used to assess the portions of food articles. Daily intake of nutrients was finally summarized and calculated by adding all the raw foods consumed on daily, weekly, bi-weekly and monthly basis. Data analysis of the dietary parameters was carried out using software developed and previously used in the research studies by the investigating team using the standard nutrient values of Indian foods [19, 20].

#### Measurement of Insulin Levels

After a 12-hour overnight fast, venous blood samples were drawn and transported immediately to the Metabolic Research Laboratory. Serum from blood samples was separated in a cold centrifuge (Plasto Crafts, Mumbai, India) at 2,000 rpm for 10 min and stored in a deep freezer at  $-20^{\circ}\text{C}$  until assayed. Serum insulin levels were estimated by the radioimmunoassay method using a commercially available kit (Medicorp, Montreal, Canada). The intra-assay coefficient of variation was 2.6%.

#### Definitions

The sample subjects were divided into two groups based on the fasting serum insulin levels,  $>85$ th percentile (hyperinsulinemic;  $166.6 \pm 21.4$  pmol/l) and  $\leq 85$ th percentile (normoinsulinemic;  $96.9 \pm 25.0$  pmol/l). Obesity was defined as BMI  $\geq 23.1$  kg/m<sup>2</sup>,

and high %BF was defined as  $\geq 28.6\%$  for males and  $\geq 34\%$  for females as determined previously in the same cohort [17]. Recommended dietary allowances (RDA) for Asian Indians for each nutrient are given in table 1 according to national guidelines [19, 20].

#### Statistical Methods

Data were recorded on a worksheet, which was reviewed by another investigator for any incomplete information and typing errors. The daily nutrient intakes were obtained as a Microsoft Excel spreadsheet from the software. The fasting serum insulin levels were entered for each subject in the spreadsheet. Means and standard deviations of anthropometric and nutrient variables were calculated. Independent Student's *t* test was used to calculate any differences between the variables for males and females. Bivariate and multivariate logistic regression analyses were performed with insulin (hyperinsulinemic/normoinsulinemic) as the outcome variable and various dietary nutrients and anthropometric variables as covariates. STATA 8.0, Intercooled version (STATA Corporation, College Station, Tex., USA) was used for the statistical analysis. In this study, a  $p$  value  $<0.05$  was considered as statistically significant.

**Table 2.** Bivariate and multivariate logistic regression analysis with insulin (hyperinsulinemic and normoinsulinemic groups) as the outcome variables and various dietary nutrients and anthropometric variables as covariates

Variable		Insulin (n = 352)				p	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
		raised (n = 53)		normal (n = 299)				
		n	%	n	%			
Sex	Male	43	81.2	268	89.6	0.075	1.0	-
	Female	10	18.9	31	10.4			
Carbohydrate, % En	<55	18	34.0	87	29.1	0.461	1.3 (0.7-2.3)	-
	55-65 <sup>1</sup>	21	39.6	107	35.8			
	>65	14	26.42	105	35.12			
Protein, % En	<10	7	13.2	22	7.4	0.152	1.9 (0.7-4.7)	-
	10-15 <sup>1</sup>	45	84.9	256	85.6			
	>15	1	1.9	21	7.0			
Total fat, % En	<15	4	7.5	44	14.7	0.304	0.5 (0.2-1.4)	-
	15-30 <sup>1</sup>	29	54.7	163	54.5			
	>30	20	37.7	92	30.8			
Saturated fat, % En	<10 <sup>1</sup>	32	60.4	174	58.2	0.766	1.0	-
	≥10	21	39.6	125	41.8			
MUFAs, % En	<10	40	75.5	250	83.6	0.341	0.6 (0.3-1.2)	-
	10-15 <sup>1</sup>	12	22.6	44	14.7			
	>15	1	1.9	5	1.7			
PUFAs, % En	<8 <sup>1</sup>	20	37.7	172	57.5	0.008	1.0	-
	≥8	33	62.3	127	42.5			
ω-3 PUFAs, % En	<1	37	69.8	230	76.9	0.265	0.6 (0.4-1.3)	-
	≥1 <sup>1</sup>	16	30.2	69	23.1			
ω-6 PUFAs, % En	<3	13	24.5	126	42.1	0.053	0.4 (0.2-0.9)	0.3 (0.1-0.7)
	3-7 <sup>1</sup>	31	58.5	132	44.1			
	>7	9	17.0	41	13.7			
ω-6 to ω-3 PUFA ratio	<5	22	41.5	125	41.8	0.998	1.0 (0.5-1.8)	-
	5-10 <sup>1</sup>	15	28.3	85	28.4			
	>10	16	30.2	89	29.8			
Fiber, g	<30	53	100.0	299	100.0	-	-	-
	30-40 <sup>1</sup>	0	0.0	0	0.0			
	>40	0	0.0	0	0.0			
Cholesterol, mg	<300 <sup>1</sup>	51	96.2	296	99.0	0.116	1.0	-
	≥300	2	3.8	3	1.0			
BMI	<23.1 <sup>1</sup>	37	72.5	261	88.2	0.003	1.0	-
	≥23.1	14	27.4	35	11.8			
BF, % <sup>2</sup>	Normal	40	78.4	252	87.8	0.072	1.0	-
	High	11	21.6	35	12.2			
Waist circumference, cm	Normal	40	76.9	263	88.3	0.027	1.0	-
	High	12	23.1	35	11.7			

<sup>1</sup> Recommended daily allowance. <sup>2</sup> Cut-off for high BF: males ≥28.6%, females ≥34% [5, 17].

## Results

The mean age of the subjects was 18.0 ± 2.3 years (range 14-25 years). The mean insulin level was 107.4 ± 35.0 pmol/l. The mean insulin levels in males and females were 106.3 ± 34.2 pmol/l, and 115.3 ± 40.1 pmol/l respectively (p = NS).

The dietary nutrient intake and anthropometrical measurements are given in table 1. The carbohydrate, protein, cholesterol and fiber intakes are comparable between hyperinsulinemic and normoinsulinemic groups. The total fat, saturated fat and MUFA intakes in the hyperinsulinemic group were higher than in the normoinsulinemic group, but the difference was not statistically

significant. On the other hand, the mean percentage of caloric intake contributed by PUFAs was significantly higher in the hyperinsulinemic group (9.2%) than the normoinsulinemic group (8.0%;  $p = 0.021$ ). PUFA intake was much higher than the RDA in the hyperinsulinemic group. Percentage energy contribution of  $\omega$ -3 and  $\omega$ -6 PUFAs in the hyperinsulinemic (0.8 and 4.8%, respectively) and normoinsulinemic groups (0.7 and 4.2%, respectively) were similar ( $p = 0.1574$  and  $0.1365$ , respectively). BMI, %BF and waist circumference were significantly higher in the hyperinsulinemic group as compared to the normoinsulinemic group ( $p = 0.0021$ ,  $0.0006$  and  $0.0041$ , respectively), consistent with results from our previous study on the same cohort of adolescents and young adults [5].

We analyzed the odds ratios (ORs) and confidence intervals (CIs) for fasting hyperinsulinemia in subjects with dietary intake of nutrients not in the RDA range and in subjects with higher values of BMI, %BF and waist circumference (table 2). The bivariate analysis showed that higher intake of PUFAs was associated with higher fasting serum insulin levels (OR: 2.2, CI: 1.2–4.1). The relationship was the same when comparing BMI, %BF and waist circumference with insulin levels. The odds of being hyperinsulinemic were 2.8 (CI: 1.3–5.7), 2.0 (CI: 0.9–4.2) and 2.2 times (CI: 1.1–4.7) if the subjects had a high BMI, %BF or waist circumference, respectively. Interestingly, the unadjusted ORs (95% CI) of being hyperinsulinemic were 0.4 (0.2–0.9) if the  $\omega$ -6 PUFA intake contributed to <3% of the caloric intake (RDA for  $\omega$ -6 PUFAs: 3–7% of caloric intake). When all the dietary nutrients, gender and anthropometry data were considered together in multiple regression analysis,  $\omega$ -6 PUFA intake [adjusted OR (95% CI) = 0.3 (0.1–0.7)] and BMI [adjusted OR (95% CI) = 2.9 (1.4–6.0)] were the significant independent predictors of hyperinsulinemia with lower intake of  $\omega$ -6 PUFAs associated with lower insulin levels.

The  $\omega$ -3 and  $\omega$ -6 PUFAs exist in a delicate balance in metabolic pathways. Therefore, we looked at the interactions of these PUFAs and fasting serum insulin levels. The fasting serum insulin levels were lowest for the  $\omega$ -6 PUFA intake below the RDA (i.e. <3% caloric intake) irrespective of  $\omega$ -3 PUFA intake. The mean fasting serum insulin level was lower when the dietary  $\omega$ -3 PUFA intake was according to the RDA ( $\geq 1\%$  caloric intake), while consumption of  $\omega$ -6 PUFAs was <7% of caloric intake. As soon as the  $\omega$ -6 PUFA intake exceeded >7% of caloric intake, higher fasting serum insulin levels were observed. This could either be due to the elevated  $\omega$ -6 to

$\omega$ -3 PUFA ratio or because of a small number of subjects in the category which had  $\omega$ -6 >7% and  $\omega$ -3  $\geq 1\%$  of caloric intake.

## Discussion

The relationship between dietary nutrients and insulin sensitivity has been investigated for the first time in Asian Indian adolescents and young adults. The important findings included  $\omega$ -6 PUFA intake and BMI as significant independent predictors of fasting hyperinsulinemia. More importantly, subjects with a lower than recommended intake of  $\omega$ -6 PUFAs exhibited less fasting hyperinsulinemia. Specifically, the mean fasting serum insulin levels were lower when dietary  $\omega$ -3 PUFAs were per recommended allowance and  $\omega$ -6 PUFAs were <7% of caloric intake.

In animal studies, an impressive body of evidence has suggested the connection between dietary lipids, membrane lipid profiles and insulin resistance [21–23]. An elegant study by Storlien et al. [23] showed that replacement of safflower oil (containing high levels of  $\omega$ -6 PUFAs) with fish oil (containing high levels of  $\omega$ -3 PUFAs) in rats being fed high sucrose and fat diets was able to attenuate the development of insulin resistance. Later, other investigators corroborated these data: diets high in saturated fat led to insulin resistance, whereas diets high in  $\omega$ -3 PUFAs, with a low  $\omega$ -6 to  $\omega$ -3 PUFA ratio, resulted in normal action of insulin [24, 25]. In human subjects, similar results have been reported in some but not in all instances [9, 10, 26]. Dietary fiber and whole grain intake have showed inverse relation with insulin resistance in humans [9, 12]. In our study, although intakes of total fat, saturated fat and MUFAs were higher in the hyperinsulinemic group, no significant relationships between insulin sensitivity and saturated fat or MUFA were observed.

Further, we showed that the intake of PUFAs was higher, saturated fat and the  $\omega$ -6 to  $\omega$ -3 PUFA ratio were at the upper limit, and  $\omega$ -3 PUFA intake was lower than the RDA for Asian Indians. A significantly higher intake of PUFAs, mainly as  $\omega$ -6 PUFAs from vegetable oils [27, 28], and a significantly lower intake of  $\omega$ -3 long-chain PUFA eicosapentaenoic acid and docosahexaenoic acid have been reported in Indo-Asians as compared to British Caucasians [29]. Consistent with the dietary findings, a higher proportion of total fatty acids as the  $\omega$ -6 PUFAs, linoleic acid and arachidonic acid and a lower proportion of the  $\omega$ -3 long-chain PUFAs were observed in plasma

and membrane phospholipids in Indo-Asians than in British Caucasians [29]. These investigators further showed that a supplemental dose of eicosapentaenoic acid and docosahexaenoic acid, whether given in combination with a high or a moderate  $\omega$ -6 PUFA background dietary intake, had no effect on measures of insulin resistance, although serum triacylglycerol levels improved [29, 30]. Unfortunately, the data regarding  $\omega$ -6 and  $\omega$ -3 PUFAs and their relation to insulin sensitivity are scarce, particularly in Asian Indians. Furthermore, while the role of  $\omega$ -3 PUFAs in insulin sensitivity has been investigated, the same role of  $\omega$ -6 PUFAs has not been properly researched. Such studies are particularly required in view of our data showing a potentially important role of  $\omega$ -6 PUFAs in insulin-mediated glucose uptake in young Asian Indians. Finally, alterations in the  $\omega$ -6 to  $\omega$ -3 PUFA ratio due to high intake of  $\omega$ -6 PUFAs may be an important factor in the pathogenesis of insulin resistance in Asian Indians and need to be investigated further.

Our study adds useful data in the diet-insulin resistance research area. Importantly, previous studies regarding diet and insulin resistance have either been carried out on adults only or were nutrient intervention studies. Further, our sample selection was careful and representative of the urban population of North India. Of note, our sample comprised urban adolescents and young adults undergoing rapid nutritional transition; an important component of dietary transition is increased intake of fats. This trend of high intake of dietary fat in young Asian Indians is disconcerting, since it would contribute to obesity and thus increasing insulin resistance, and may contribute independently to insulin resistance due to high intake of  $\omega$ -6 PUFAs as shown by us in this study.

The following are the limitations of our study: the proportion of females was low, the 24-hour dietary recall method has well-known limitations, and physical activity data were not included. This study could have been improved by use of better methods for assessment of insulin sensitivity (e.g. hyperinsulinemic euglycemic clamp).

To summarize, we have shown, for the first time, that  $\omega$ -6 PUFA is an independent correlate of insulin resistance in Asian Indian adolescents and young adults. In the view of increasing obesity and high prevalence of cardiovascular risk factors in urban adolescents and young adult population in India, it is prudent to restrict the intake of  $\omega$ -6 PUFAs. Finally, detailed dietary studies and intervention trials are required to corroborate these data, and to evaluate the effects of individual fats and micro-nutrients on insulin resistance.

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### References

- 1 Reaven G: Insulin resistance, type 2 diabetes mellitus, and cardiovascular disease: the end of the beginning. *Circulation* 2005;112:3030–3032.
- 2 Zavaroni I, Bonini L, Gasparini P, Barilli AL, Zuccarelli A, Dall'Aglio E, Delsignore R, Reaven GM: Hyperinsulinemia in a normal population as a predictor of non-insulin-dependent diabetes mellitus, hypertension, and coronary heart disease: the Barilla factory revisited. *Metabolism* 1999;48:989–994.
- 3 Gazzaruso C, Solerte SB, De Amici E, Mancini M, Pujia A, Fratino P, Giustina A, Garzaniti A: Association of the metabolic syndrome and insulin resistance with silent myocardial ischemia in patients with type 2 diabetes mellitus. *Am J Cardiol* 2006;97:236–239.
- 4 Misra A, Vikram NK: Insulin resistance syndrome (metabolic syndrome) and obesity in Asian Indians: evidence and implications. *Nutrition* 2004;20:482–491.
- 5 Misra A, Vikram NK, Arya S, Pandey RM, Dhingra V, Chatterjee A, Dwivedi M, Sharma R, Luthra K, Guleria R, Talwar KK: High prevalence of insulin resistance in postpubertal Asian Indian children is associated with adverse truncal body fat patterning, abdominal adiposity and excess body fat. *Int J Obes Relat Metab Disord* 2004;28:1217–1226.
- 6 Storlien LH, James DE, Burleigh KM, Chisholm DJ, Kraegen EW: Fat feeding causes widespread in vivo insulin resistance, decreased energy expenditure, and obesity in rats. *Am J Physiol* 1986;251:E576–E583.
- 7 Maron DJ, Fair JM, Haskell WL: Saturated fat intake and insulin resistance in men with coronary artery disease. The Stanford Coronary Risk Intervention Project Investigators and Staff. *Circulation* 1991;84:2020–2027.
- 8 Parker DR, Weiss ST, Troisi R, Cassano PA, Vokonas PS, Landsberg L: Relationship of dietary saturated fatty acids and body habitus to serum insulin concentrations: the Normative Aging Study. *Am J Clin Nutr* 1993;58:129–136.

- 9 Feskens EJ, Loeber JG, Kromhout D: Diet and physical activity as determinants of hyperinsulinemia: the Zutphen Elderly Study. *Am J Epidemiol* 1994;140:350–360.
- 10 Mayer-Davis EJ, Monaco JH, Hoen HM, Carmichael S, Vitolins MZ, Rewers MJ, Haffner SM, Ayad MF, Bergman RN, Karter AJ: Dietary fat and insulin sensitivity in a tri-ethnic population: the role of obesity. The Insulin Resistance Atherosclerosis Study (IRAS). *Am J Clin Nutr* 1997;65:79–87.
- 11 Ludwig DS, Pereira MA, Kroenke CH, Hillner JE, Van Horn L, Slattery ML, Jacobs DR Jr: Dietary fiber, weight gain, and cardiovascular disease risk factors in young adults. *JAMA* 1999;282:1539–1546.
- 12 McKeown NM, Meigs JB, Liu S, Saltzman E, Wilson PW, Jacques PF: Carbohydrate nutrition, insulin resistance, and the prevalence of the metabolic syndrome in the Framingham Offspring Cohort. *Diabetes Care* 2004;27:538–546.
- 13 Wasir JS, Misra A: The metabolic syndrome in Asian Indians: the impact of nutritional and socio-economic transition in India. *Metab Syndr Relat Disord* 2004;2:14–23.
- 14 Lemeshow S, Stroh GJ: *Sampling Techniques for Evaluating Health Parameters in Developing Countries*. Washington, National Academy Press, 1988.
- 15 Dudeja V, Misra A, Pandey RM, Devina G, Kumar G, Vikram NK: BMI does not accurately predict overweight in Asian Indians in northern India. *Br J Nutr* 2001;86:105–112.
- 16 Sung RY, Lau P, Yu CW, Lam PK, Nelson EA: Measurement of body fat using leg to leg bioimpedance. *Arch Dis Child* 2001;85:263–267.
- 17 Vikram NK, Misra A, Dwivedi M, Sharma R, Pandey RM, Luthra K, Chatterjee A, Dhingra V, Jaikhani BL, Talwar KK, Guleria R: Correlations of C-reactive protein levels with anthropometric profile, percentage of body fat and lipids in healthy adolescents and young adults in urban North India. *Atherosclerosis* 2003;168:305–313.
- 18 Thimmayamma BVS: Diet survey methods; in Thimmayamma BVS (ed): *A Handbook of Schedule and Guidelines in Socio-Economic and Diet Survey*. New Delhi, National Institute of Nutrition, Indian Council of Medical Research, 1987.
- 19 Gopalan C, Rama Sastri BV, Balasubramanian SC: *Nutritive Value of Indian Foods*. Hyderabad, National Institute of Nutrition, Indian Council of Medical Research, 1996.
- 20 Ghafoorunissa KK: *Diet and Heart Disease*. Hyderabad, National Institute of Nutrition, 1994.
- 21 Storlien LH, Baur LA, Kriketos AD, Pan DA, Cooney GJ, Jenkins AB, Calvert GD, Campbell LV: Dietary fats and insulin action. *Diabetologia* 1996;39:621–631.
- 22 Storlien LH, Jenkins AB, Chisholm DJ, Pascoe WS, Khouri S, Kraegen EW: Influence of dietary fat composition on development of insulin resistance in rats. Relationship to muscle triglyceride and omega-3 fatty acids in muscle phospholipid. *Diabetes* 1991;40:280–289.
- 23 Storlien LH, Kraegen EW, Chisholm DJ, Ford GL, Bruce DG, Pascoe WS: Fish oil prevents insulin resistance induced by high-fat feeding in rats. *Science* 1987;237:885–888.
- 24 Ghafoorunissa, Ibrahim A, Rajkumar L, Acharya V: Dietary (n-3) long chain polyunsaturated fatty acids prevent sucrose-induced insulin resistance in rats. *J Nutr* 2005;135:2634–2638.
- 25 Fickova M, Hubert P, Cremel G, Leray C: Dietary (n-3) and (n-6) polyunsaturated fatty acids rapidly modify fatty acid composition and insulin effects in rat adipocytes. *J Nutr* 1998;128:512–519.
- 26 Rodriguez Y, Christophe AB: Long-chain omega6 polyunsaturated fatty acids in erythrocyte phospholipids are associated with insulin resistance in non-obese type 2 diabetics. *Clin Chim Acta* 2005;354:195–199.
- 27 McKeigue PM, Marmot MG, Adelman AM, Hunt SP, Shipley MJ, Butler SM, Riemersma RA, Turner PR: Diet and risk factors for coronary heart disease in Asians in northwest London. *Lancet* 1985;2:1086–1090.
- 28 Miller GJ, Kotecha S, Wilkinson WH, Wilkes H, Stirling Y, Sanders TA, Broadhurst A, Allison J, Meade TW: Dietary and other characteristics relevant for coronary heart disease in men of Indian, West Indian and European descent in London. *Atherosclerosis* 1988;70:63–72.
- 29 Lovegrove JA, Lovegrove SS, Lesauvage SV, Brady LM, Saini N, Minihane AM, Williams CM: Moderate fish-oil supplementation reverses low-platelet, long-chain n-3 polyunsaturated fatty acid status and reduces plasma triacylglycerol concentrations in British Indo-Asians. *Am J Clin Nutr* 2004;79:974–982.
- 30 Brady LM, Lovegrove SS, Lesauvage SV, Gower BA, Minihane AM, Williams CM, Lovegrove JA: Increased n-6 polyunsaturated fatty acids do not attenuate the effects of long-chain n-3 polyunsaturated fatty acids on insulin sensitivity or triacylglycerol reduction in Indian Asians. *Am J Clin Nutr* 2004;79:983–991.