Review Article

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Are excess carbohydrates the main link to diabetes & its complications in Asians?

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Dietary carbohydrates form the major source of energy in Asian diets. The carbohydrate quantity and quality play a vital function in the prevention and management of diabetes. High glycaemic index foods elicit higher glycaemic and insulinaemic responses and promote insulin resistance and type 2 diabetes (T2D) through beta-cell exhaustion. This article reviews the evidence associating dietary carbohydrates to the prevalence and incidence of T2D and metabolic syndrome (MS) in control of diabetes and their role in the complications of diabetes. Cross-sectional and longitudinal studies show that higher carbohydrate diets are linked to higher prevalence and incidence of T2D. However, the association seems to be stronger in Asian-Indians consuming diets high in carbohydrates and more marked on a background of obesity. There is also evidence for high carbohydrate diets and risk for MS and cardiovascular disease (CVD). However, the quality of carbohydrates is also equally important. Complex carbohydrates such as brown rice, whole wheat bread, legumes, pulses and green leafy vegetables are good carbs. Conversely, highly polished rice or refined wheat, sugar, glucose, highly processed foods such as cookies and pastries, fruit juice and sweetened beverages and fried potatoes or French fries are obviously 'bad' carbs. Ultimately, it is all a matter of balance and moderation in diet. For Indians who currently consume about 65-75 per cent of calories from carbohydrates, reducing this to 50-55 per cent and adding enough protein (20-25%) especially from vegetable sources and the rest from fat (20-30%) by including monounsaturated fats (*e.g.* groundnut or mustard oil, nuts and seeds) along with a plenty of green leafy vegetables, would be the best diet prescription for the prevention and management of non-communicable diseases such as T2D and CVD.

Key words Bad carbs - carbohydrates - complications - diet - glycaemic index - glycaemic load - good carbs - incidence - prevalence - type 2 diabetes

Introduction

The prevalence of type 2 diabetes (T2D) is increasing at exponential rates. In 2017, it was estimated that there were almost 425 million individuals affected with diabetes and this number is likely to rise to 629 million by 2045[1]. Seventy five per cent of people with diabetes reside in low- and middle-income countries. There were an estimated five million deaths attributable to diabetes in 2015[1]. The overall prevalence of diabetes in India, based on a study of

15 whole States of India, was 7.3 per cent[2]. Asian-Indians have higher predilection to T2D and this is due to the 'Asian-Indian phenotype[3]' which includes features such as central body obesity, insulin resistance (IR), higher insulin, triglyceride levels and low high-density lipoprotein (HDL) cholesterol levels. In addition, physical activity levels are markedly low in India[4]. There have also been rapid changes in the dietary composition of Asian-Indians such that diets today are high in refined carbohydrates, sugars, fats and salt. All these factors contribute to the rising prevalence of diabetes, hypertension and cardiovascular diseases (CVDs).

The three major proximate principles in the diet are carbohydrate, protein and fat. Restriction of any one of these components will have to be made up by increasing the proportion of calories derived from the other two. Since the protein content of Indian diets can rarely be increased above 20-25 per cent, especially in vegetarians, diets can be characterized as either 'high-carbohydrate' or 'high fat', or a diet containing combination of the two in equalproportions.

What are carbohydrates?

Carbohydrates are compounds containing carbon, hydrogen and oxygen. These are digested or metabolically converted directly into glucose or oxidized into pyruvate. Carbohydrates can be categorized as monosaccharides, disaccharides, oligosaccharides and polysaccharides (starch) depending on the degree of polymerization[5]. It is important to consider the physiological basis [as measured by glycaemic index (GI)] of carbohydrate classification rather than its chemical classification into simple and complex carbohydrates (based on their chain length). Carbohydrate is the chief source of energy in many low- and middle-income countries, contributing up to 70-80 per cent of daily calories. Diets of Asian countries including India continue to derive two-thirds of carbohydrate calories from cereal staples[6] and this has not changed during the last three decades in India[7,8].

This review mainly focuses on the effect of carbohydrates on the risk for development of diabetes as well as its role in prevention and management and finally its role in diabetes complications.

Carbohydrates & the prevalence of diabetes

The dietary carbohydrate's quantity and also the quality are found to be linked to the prevalence of diabetes in many parts of the globe. Gross *et al*[9] reported from ecological assessments that the US has witnessed huge surges in the rates of obesity in the 20th century not only in adults but also in children. Their study further suggested that there was a profound shift in the quality of carbohydrates from whole grain-based diets in the first decade of 20th century to refined carbohydrates through processed foods such as corn syrup by the end of 20th century. This resulted in decreased dietary fibre content of the American diets which was associated with the increased prevalence of not only T2D but also obesity. The higher levels of fructose in the corn syrup were linked to metabolic syndrome (MS) and also IR, especially in the US[10].

The prevalence rates of diabetes in India have been increasing steeply. Secular trend studies have reported that the urban regions of India experienced a ten-fold increase in the prevalence of diabetes over a 40 years period (2.3% in 1971[11] as against 22.8% in 2014[12]). During the last decade, the prevalence of diabetes in metropolitan cities in Chennai and Delhi increased by almost 30 per cent every four years from 14.3 to 18.6 per cent and 22.8 per cent[12-15]. Mohan *et al*[16] reported that in Asian-Indians from the urban regions of south India, the dietary carbohydrate and glycaemic load (GL) were linked to increased, dietary fibre intake to decreased, risk of T2D in the Chennai Urban Rural Epidemiological Study. The predominant intake of carbohydrates from polished grains in Indian diets also means that they are low in other healthy carbohydrate foods such as whole grains, fruits and vegetables[6,16].

Both dietary GL and GI have been correlated with several metabolic risk parameters in Japanese female farmers with traditional dietary habits[17]. Rice predominantly contributes to the total carbohydrates and energy intake in this population and in that respect differs from the western populations. Dietary GI was positively correlated with fasting glucose and triacylglycerol, body mass index (BMI), and glycated haemoglobin (HbA_{1c}), while dietary GL was positively correlated with fasting glucose and triacylglycerol and negatively correlated with HDL cholesterol. The GI and GL, primarily determined from white rice (WR), were independently correlated with several metabolic risk parameters[17].

Carbohydrates & the incidence of diabetes

A prospective cohort of the Nurses' Health Study that followed US women for nearly 24 yr had shown that diets with higher starch-to-cereal fibre ratio and lower fibre intake were associated with increased risk for incident cases of T2D[18]. It was reported that, when the first and fifth quintiles were compared, starch intake was associated with a greater risk of T2D [relative risk (RR)=1.23], whereas total fibre (RR=0.80), cereal fibre (RR=0.71) and fruit fibre (RR=0.79) intakes were associated with a lesser risk of T2D. They suggested the starch-to-cereal fibre ratio of the diet as a novel parameter for evaluating the carbohydrate quality in association to T2D. Diets with higher refined carbohydrate content and sugar-sweetened beverages have higher carbohydrate-to-fibre ratio. Hence, the American Heart Association recommends foods with carbohydrate-to-fibre ratio of not higher than10:1[19].

Sakurai *et al*[20] in their cohort study evaluated the risk for developing T2D in Japanese men, based on the percentage of energy intake contributed by carbohydrates and the level of obesity. They reported that higher carbohydrate intake was linked with an increased risk for new-onset T2D in obese individuals rather than in non-obese individuals. They also recommended that obese participants with increased carbohydrate intake (>65% energy) to restrict their intakes within 50-65 per cent energy to prevent T2D. The authors reported a significantly higher hazard ratio (2.01) for diabetes among obese participants with higher carbohydrates intake (>65% energy) than those with lower carbohydrates intake (50-57%).

In urban Indians in Chennai (10 yr follow up study), Anjana *et al*[21] showed that higher diet risk score which included larger intake of refined grains and reduced intake of vegetables and fruits, dairy and nuts doubled the incidence of new-onset T2D.

Hu *et al*[22] in their systematic review on WR intake and risk for T2D reported that increased consumption of WR was linked with a higher risk of T2D in Japanese and Chinese population. They further indicated that the association between WR consumption and T2D was stronger for Asian population as compared to the western population. In the dose-response analysis, it was shown that for each extra serving of WR, there was an 11 per cent increase in risk for diabetes. Conversely, Sun *et al*[23] showed that brown rice (BR, unpolished rice) intake was linked with a lower risk for diabetes in a western population. Zhang *et al*[24] however, showed that substituting WR with BR for a duration of 16 wk did not alter the metabolic risk parameters in Chinese population at increased diabetes risk, although they reported higher HDL cholesterol and lower diastolic blood pressure (BP) in those who consumed BR. Probably, the substitution with BR needs to be maintained for much longer duration of time to alter the risk of T2D.

Villegas *et al*[25], in a cohort study conducted in Chinese women, reported positive links between dietary carbohydrate intake, GI and GL, and the incidence of T2D and a stronger association was observed between the intake of WR and the risk of developing T2D.

Carbohydrates & metabolic syndrome

The term MS refers to a clustering of metabolic abnormalities including central obesity, dyslipidaemia, glucose intolerance and hypertension. Individuals with MS have a higher risk for CVD and five-fold higher risk for T2D[26]. Radhika *et al*[27] showed that larger intake of refined grains was associated with IR and MS in Asian-Indians who regularly consumed diets containing higher levels of carbohydrate. With increased quintiles of refined grain intake, increased metabolic abnormalities such as body weight, waist circumference, IR, BP, triglycerides and fasting blood glucose were observed, along with lower levels of HDL cholesterol. In this population, WR was the major contributor of the refined grains (≈76%) with an average intake of 253 g/day and this was linked with an eight-fold increase for the risk of MS[27].

Recently, Park *et al*[28] evaluated whether carbohydrate and/or fatty acid intake modified the prevalence of MS and found that high carbohydrate diets (≈74% E) irrespective of fatty acid composition were positively associated with MS in Korean women. A stronger association for higher incidence of IR and higher dietary GL was reported in the Framingham Offspring Study cohort[29] and with dyslipidaemia and coronary heart disease (CHD)[30,31]. McKeown *et al*[29] reported that whole grains, cereal fibre, total dietary fibre and fruit were inversely, and GL and GI were positively, associated with homeostasis model assessment-insulin resistance (HOMA-IR). These studies clearly underscore the significance of whole grain-based, low GI diets in the prevention of MS. One study from south India showed that the prevalence of MS was higher in sunflower oil consumers (30.7%) and was further worsened by the quantity of polished cereals consumed[32]. The authors concluded that the oils rich in PUFA such as sunflower oil could aggravate the risk for MS, particularly in Asian-Indian population who regularly consume diets containing higher levels of refined grains and with low intakes of alpha-linolenic acid. Obviously, the role of dietary factors is multifactorial and these do not act in isolation.

Carbohydrate & control of diabetes

Postprandial hyperglycaemia is an important factor in the control of diabetes. Both the quantity and type of carbohydrate could affect insulin secretion and postprandial glycaemia[33]. Shadman *et al*[34] evaluated the macronutrient distribution and its effect on glycaemic control among individuals with T2D consuming high calories and showed that 25 kcal from carbohydrates/kg body weight was inversely, and 30 kcals of fat/kg body weight positively, associated with HbA_{1c} levels after adjusting for potential confounders. The same study has shown that the substitution of fat for carbohydrates reduced HbA_{1c} levels. However, a critical review that looked at the effect of different carbohydrate diets in individuals with T2D indicated that low carbohydrate diets (LCDs, <45% E) were no different from the high carbohydrate diets with regards to metabolic markers and glycaemic control[35]. The study however commented that LCDs might not have been sustainable in the longer term as most studies used diets containing moderate levels of carbohydrate[35]. Mayer *et al*[36] analyzed participants with T2D in a weight loss trial who were randomized to 48 wk of either a LCD or to a low-fat diet with orlistat. They showed that although both the interventions decreased the BMI, LCD showed better improvement in HbA_{1c} and also led to a greater decrease in anti-glycaemic medications. This was attributed to the reduction in carbohydrate quantity, GI and/or greater improvement in insulin sensitivity. Increasing the dietary fibre content of diets by increasing the vegetable intake and inclusion of low GI carbohydrates may also be helpful in achieving better glycaemic control. A recent systematic review and meta-analysis[37] on carbohydrate restriction in T2D revealed that, in the short term, LCDs containing less than 45 per cent energy had better effect on glycaemic control than high carbohydrate diets. However, no differences existed between LCDs and high carbohydrate diets in the long term on glycaemic control, possibly due to the difficulty in sustaining LCDs for a long time. This analysis also indicated that similar benefits were observed on quality of life, weight gain, low-density lipoprotein cholesterol and between isocaloric diets, LCDs and high carbohydrate diets.

Another randomized crossover trial over a one-year period demonstrated similar beneficial effects on glycaemic markers for both high-monounsaturated fatty acid (MUFA) and high carbohydrate diets in which the total energy intake was controlled, suggesting that a variety of diets may benefit individuals with diabetes and that the total calories are probably more important[38].

Carbohydrate & remission of diabetes

The Diabetes Prevention Programme (DPP) and ACTNOW studies suggest that the rate of conversion of impaired glucose tolerance (IGT) to T2D was almost 7-10 per cent per year and that the primary driver of the conversion to T2D was obesity. Obesity increases the risk for health diseases and lifestyle intervention such as weight loss and physical activity reduced the risk for diabetes by almost 58 per cent[39]. Stentz *et al*[40] reported 100 per cent remission of pre-diabetes to normal glucose levels in adults with obesity with a high protein diet as compared to only 33 per cent remission which was observed with a diet high in carbohydrate. The high protein diet group had greater insulin sensitivity, greater reduction in diabetogenic risk factors and less inflammation and oxidative stress than the high carbohydrate diet group. Moreover, lean body mass percentage increased, while fat mass percentage decreased. Apart from inclusion of lean meat, fish, chicken and egg white, inclusion of legumes and pulses could help in increasing the protein content of diets in vegetarians.

Weber *et al*[41] reported on the 'Diabetes Community Lifestyle Improvement Program', translation trial (a randomized, controlled) rendered in Asian-Indian overweight/obese adults in Chennai with isolated IGT, isolated impaired fasting glucose (IFG) or combined IFG+IGT. The participants were randomized to a standard lifestyle advice (control, standard of care for pre-diabetes: one day visit to a physician, a dietitian, fitness trainer and a one-day group class focusing on diabetes prevention which advocated a diet rich in complex carbohydrate and with lower fat content, inclusion of fruits and vegetables and increasing exercise). The intervention group followed a culturally tailored, U.S. DPP-based lifestyle curriculum for duration of six months which included diet training to reduce dietary intake by maintaining weekly food diaries on weekly basis, adhering to individualized goals for carbohydrate restriction, portion size reduction and increasing fiber-rich food intake. In addition, metformin was added for participants who did not respond to lifestyle modification after a follow up of four months. The incidence of diabetes was assessed twice a year and compared between the two groups. This study showed that customized tailoring of diet with special reference to both quantity and quality of carbohydrate along with increasing physical activity can help in the prevention of diabetes.

Carbohydrates & complications of diabetes

Chronic complications of diabetes include micro-angiopathy (retinopathy, nephropathy and neuropathy) and macro-angiopathy (ischaemic heart disease, cerebrovascular disease and peripheral vascular disease). Through postprandial hyperglycaemia, high GI carbohydrates and high GL diets may mediate the risk of these complications. Juraschek *et al*[42] reported on the effect of the type of carbohydrate on kidney function. Overweight or obese adults with no diabetes or kidney diseases were provided with each of four isocaloric diets (in a randomized crossover design) namely high GI (≥65) with higher carbohydrate percentage (58% kcal) reference diet, low GI (≤45) with low percentage carbohydrate (40% kcal), low GI with high percentage carbohydrate and high GI with low percentage carbohydrate. The LCDs had higher per cent protein. The results indicated that reducing the GI and the percentage carbohydrate and increasing the protein and fat calories increased the glomerular filtration rate and improved biomarkers of renal disease. Another group studied the effect of GI and GL of carbohydrates on the risk for CVD[43]. Overweight or obese adults were assigned either to one of the four diets with reduced-fat and high-fibre content for a duration of 12 wk. First two diets had higher carbohydrate content (55% of total energy intake), with either high or low GIs, third and fourth diets had higher protein content (25% of total energy intake), with high or low GIs. The GL was highest in the first diet and lowest in the fourth diet. They concluded that both high-protein and low-GI regimens increased body fat loss. However, cardiovascular risk reduction was optimized by a high-carbohydrate, low-GI diet. This emphasizes the role of carbohydrate quality in mediating risk for CVD.

Jenkins *et al*[44] studied T2D participants who were on either a low-GI legume diet or a diet with higher insoluble fibre from wheat based products for three months. They showed that the HbA_{1c} values were reduced by 0.5 per cent in the low-GI legume diet as compared to the high wheat fibre diet (-0.3%). The CHD risk reduction in the low-GI legume diet (-0.8%) was attributed to the higher relative reduction in systolic blood pressure in this group as compared to the high wheat fibre diet. Thus, inclusion of wholegrain legumes in the diets not only improves the protein and dietary fibre intake but also improves the glycaemic properties of the diet and thus help in CHD risk reduction in patients with T2D.

Carbohydrates & mortality

Dehghan *et al*[45] recently reported on the results of the Prospective Urban and Rural Epidemiological (PURE) study conducted on 135,335 individuals aged 35-70 yr (enrolled between 2003 and 2013) in almost 18 countries with a median follow up of 7.4 yr (interquartile range 5.3-9.3) using validated food frequency questionnaires. Primary outcomes measured were total mortality and major cardiovascular events including fatal CVD, non-fatal myocardial infarction, stroke and heart failure. Secondary outcomes included all myocardial infarctions, CVD mortality, non-CVD mortality and stroke. The associations between consumption of total fat, and each type of fat, carbohydrate with CVD and total mortality were assessed. The study reported that with increase in the percentage of energy from carbohydrates, the incidence of mortality increased. The incidence of mortality was 4.1 [per 1000 person-years; 95% confidence interval (CI)] in the first quintile with median 46.4 per cent of energy from carbohydrates and 7.2 (per 1000 person-years; 95% CI) in the fifth quintile with median 77.2 per cent of energy from carbohydrates. Conversely, with increase in percentage of energy from fat (including saturated fat), the total mortality decreased.

Recently, Seidelmann *et al*[46] have shown in an elegant study that very low carbohydrate (and hence, very high-fat) diets also increase the mortality. The authors reported that there was a U-shaped curve between carbohydrate intake and mortality. The optimal intake of carbohydrate appeared to be around 50-55 per cent of the total calories. As the carbohydrate percentage increases or decreases from this level, the mortality appeared to increase. They also showed that in the low carbohydrate group, those who ate animal protein and fat derived from meat products fared worse than those who took plant products.

Conclusions

There are evidence to suggest that excess carbohydrate is linked to both the susceptibility to T2D and also to poor control of diabetes and proneness to complications of diabetes, particularly in Asian populations. However, more than the quantity of carbohydrates, it is the quality of carbohydrates which is important. Thus, there are 'good carbs' such as whole grains, legumes, vegetables, whole fruits, nuts and seeds which canbe included in the diet. Conversely, the 'bad carbs' such as refined cereals such as WR and white bread, sugar-sweetened drinks or fruit juices, cookies and pastries should be restricted. Ultimately, it is all a matter of balanced diets and moderation in what one eats, is the key to a healthy diet. The take-home message for Indians (and Asians) would be to cut down the carbohydrate intake from the present 65-75 per cent to around 50-55 per cent add enough proteins, 20-25 per cent probably from vegetable sources such as legumes and pulses and the rest 20-30 per cent from healthy monounsaturated fats such as groundnut or mustard oil, nuts and seeds. This would make our diets healthier and sustainable in the long run.

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