Management of insulin resistance involves regular physical activity and a nutritionally adequate diet. A high-carbohydrate diet containing 50% to 60% energy from carbohydrates is recommended, with one or more servings of low glycemic index (GI) foods included with each meal.

Dietary Carbohydrates In The Insulin Resistance Syndrome

The areas of carbohydrates, glycemic index of foods and physical activity all play very important roles in managing insulin-resistant patients, and should be understood before consulting with this patient population.

By Thomas MS Wolever, MD, PhD


Dr. Wolever is professor, departments of nutritional sciences and medicine, University of Toronto, and division of endocrinology and metabolism, St. Michael's Hospital, Toronto, Ontario. His areas of medical interest include hyperlipidemia and diabetes.
Definition of Insulin Resistance

Insulin resistance is a state in which the body is insensitive to the action of insulin. This means the body requires an abnormally high amount of insulin to achieve normal function. For example, an insulin-resistant individual needs to have a high concentration of plasma insulin for the tissues to take up glucose from the blood at a normal rate. The blood glucose concentration will remain normal as long as the pancreas can produce enough insulin to maintain the required high insulin level. If the pancreas cannot secrete enough insulin, however, then the blood glucose concentration will increase. This may lead, eventually, to the development of diabetes.

Unfortunately, there is no standard way to measure insulin sensitivity and no recognized definition of what constitutes insulin resistance. Therefore, there are no precise statistics on its prevalence. Also, values for insulin sensitivity in large population samples vary over a wide range, analogous to the range of concentrations of serum cholesterol in the population. Thus, defining a diagnostic cut-point is somewhat arbitrary. At the very least, we can say that insulin resistance is very common, and it has been estimated that 30% of the population may be insulin resistant.

Measuring Insulin Resistance

Accurate measurement of insulin resistance is an expensive research procedure, taking several hours and involving invasive intravenous glucose and insulin infusions. Since insulin-resistant people have high plasma insulin concentrations, measuring fasting plasma insulin is probably the best clinical test to assess insulin sensitivity. However,
the methods for this test are not standardized, the
cost may not be covered by provincial health plans
and there is no official definition of what constit-
tutes high plasma insulin. Figure 1 shows the fast-
ing plasma glucose and insulin concentrations in
80 non-obese patients (body mass index [BMI]
lower than 30 kg/m²) from the author’s laboratory.
About 10% of the subjects with normal fasting
blood glucose (lower than 6.1 mmol/L) have a plasma
insulin concentration higher than 100 pmol/L,
along with an insulin resistance index three to six
times that of the average lean, young insulin-
sensitive individual (Figure 2). About 25% of
these subjects have plasma insulin higher than 58
pmol/L, and an insulin resistance index more than
1.5 times that of an insulin-sensitive subject.

What is IRS?
Insulin resistance syndrome (IRS) was described
about 15 years ago when researchers noted that
obesity, Type 2 diabetes, dyslipidemia, coronary
heart disease, hypertension and high plasma
insulin tended to cluster in the same individuals.1
The exact definition of the syndrome has not been
clarified. The definition suggested by a working
group consulted by the World Health Organization
is shown in Table 1.

Testing For IRS
Risk factors for IRS are listed in Table 2, and peo-
ple with at least two of the risk factors should be
checked for: blood pressure, glucose, cholesterol,
triglyceride and high-density lipoprotein (HDL). An
oral glucose tolerance test may be indicated in
people at risk for IRS because it may be the only
abnormality detected. Table 3 shows the results of
a screening the author performed in 257 people
with at least one of the following four risk factors:
overweight, first-degree relative with diabetes, his-
tory of gestational diabetes or high blood glucose.2
A total of 89 people (35%) had an abnormal result
— 41 had previously undiagnosed diabetes and 43
had impaired glucose tolerance. The importance of doing an oral glucose tolerance test is shown by the fact that one-third of the subjects with diabetes were not detected using fasting glucose and 85% of the subjects with impaired glucose tolerance had normal fasting glucose. A total of 44 subjects (17%, or about one in six of the entire population of subjects with one risk factor) had an abnormal glucose tolerance with normal fasting glucose. Early detection of impaired glucose tolerance and treatment with diet and exercise can prevent the development of Type 2 diabetes.3

The Role Of Insulin
During periods of fasting, the body breaks down its stores of fat to obtain its energy requirements. After a meal, the process is reversed. The body stops burning its fat stores and starts using dietary carbohydrate and fat for energy, with excess saved in body stores of glycogen and fat. Insulin is the hormone that controls the switch over from the fasted to the fed state. It facilitates this by stopping the body from burning fat and making it burn carbohydrates and store fat.

Causes Of Insulin Resistance And High Plasma Insulin
Insulin resistance is caused by both genetic and environmental factors. The genes involved are largely unknown.4 High plasma insulin is caused by insulin resistance. Before, during and after a meal, many metabolic and neuro-endocrine signals stimulate insulin. These signals include amino acids and gut hormones, such as gastric-inhibitory peptide (GIP) and glucagon-like peptide 1 (GLP-1), which are stimulated by ingestion of fat and carbohydrates.

The primary stimulus to insulin secretion, however, is the blood glucose concentration. This is increased by dietary carbohydrate. Figure 3 shows the blood glucose and insulin responses in subjects with diabetes after meals containing the same amount of energy, but with differing proportions of fat and carbohydrates. It can be seen that acute blood glucose and insulin responses are reduced

---

**Table 1**

**Definition Of The Insulin Resistance Or Metabolic Syndrome**

- Presence of glucose intolerance and/or insulin resistance, plus two or more of the following:
  - Raised arterial (systolic/diastolic) pressure $\geq 160/90$ (either value)
  - Raised serum triglycerides ($\geq 1.7$ mmol/L) and/or low serum HDL cholesterol ($<0.9$ mmol/L)
  - Central obesity (waist-to-hip ratio $>0.90$) and/or BMI $>30$ kg/m²
  - Microalbuminuria (excretion rate $\geq 20$ µg/min or albumin-to-creatinine ratio $\mu 20$ mg/g)

**Table 2**

**Risk Factors For IRS**

- Age over 45
- Overweight (BMI $\geq 25$ kg/m²)
- Member of high-risk population (e.g., Aboriginal peoples, Hispanic, Asian and African populations)
- Family history of Type 2 diabetes
- History of gestational diabetes
- History of high blood glucose
- History of high serum triglycerides or low HDL
with low-carbohydrate meals, which is the rationale behind low-carbohydrate diets.

**High Blood Insulin And IRS**

Plausible theories implicating high blood insulin levels in the promotion of obesity, insulin resistance, diabetes and cardiovascular disease have become very popular. They also support the concept that low-carbohydrate diets are best for the treatment of obesity and insulin resistance. However, these theories are based on selected scientific evidence, are overly simplistic and do not take everything into account. In addition, the metabolic features of IRS are closely inter-related and it is difficult to know which feature is the primary cause. For example, high plasma insulin is a normal physiologic response to insulin resistance, enabling the body to overcome the effects of insulin resistance. However, insulin resistance is a normal physiologic response to high plasma insulin, which protects the body from the deleterious effects of excessive insulin action (e.g., hypoglycemia). Knowing what causes the other is a bit like asking which came first: the chicken or the egg.

The public is inundated with best-selling diet books promoting low-carbohydrate diets and carbohydrate-reduced food products. Physicians are likely to be asked about the safety and efficacy of these diets by their patients. Low-carbohydrate diets are very successful in producing weight loss in the short term, however, they have a number of problems, which are listed in Table 4. These diets are unsuitable for long-term use in many patients.

**High Insulin And Obesity**

The popular theory is that insulin promotes obesity by causing the liver to turn dietary carbohydrates into fat and, subsequently, causing that fat to be stored. The fact is that insulin primarily causes dietary carbohydrates to be oxidized or stored as glycogen in muscle and the liver. The liver turns only a tiny fraction of dietary carbohydrate (less than 1%) to fat. Substantial amounts of carbohydrates can be turned into fat by the liver, but this only happens with massive carbo-

---

### Table 3

**Results Of 75 g Oral Glucose Tolerance Test in 257 High-Risk Individuals**

<table>
<thead>
<tr>
<th>Categories of Plasma</th>
<th>Normal (&lt; 6.1 mmol/L)</th>
<th>IFG (6.1-6.9 mmol/L)</th>
<th>Diabetes (≥ 7.0 mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose 2 h after GTT</td>
<td>168</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Normal (&lt; 7.8 mmol/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGT (7.8-11.0 mmol/L)</td>
<td>37</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Diabetes (≥ 11.1 mmol/L)</td>
<td>7</td>
<td>6</td>
<td>26</td>
</tr>
</tbody>
</table>

GTT = 75 g oral glucose tolerance test; IFG = impaired fasting glucose; IGT = impaired glucose tolerance

---

The Canadian Journal of CME / November 2001 125
hydrate intake (about 800 g/day, equivalent to eating four loaves of bread daily), which is enough to exceed the body’s total energy requirements and glycogen storage capacity. Elite endurance athletes might approach this level of carbohydrate intake, but this is not turned to fat because of their huge energy expenditure. The average person on a high carbohydrate diet would eat about 200 g to 300 g of carbohydrates per day, which is not nearly enough to stimulate substantial fat synthesis.

**Low Carbohydrate Diets And Weight Loss**

People on low-carbohydrate diets regularly report losing 4.5 kg or more in one week. Overweight people want and need to lose body fat, however, weight loss of 4.5 kg in one week cannot be due to a loss of body fat, and here’s why: 1 kg of fat contains 7,700 Kcal; thus, a loss of 4.5 kg represents over 34,000 Kcal. The average person’s total daily energy expenditure is 1,800 Kcal to 2,400 Kcal; thus, total starvation for a week would deplete the body’s energy stores by only 12,600 Kcal to 16,800 Kcal — less than half the amount supplied in 4.5 kg fat.

Where does the weight loss come from? Unfortunately, it is due mainly to a loss of body water, as glycogen stores are used up. The total glycogen storage capacity of the body is about 400 g to 500 g. About one-third of this is in the liver and two-thirds in muscle. Liver glycogen is a short-term store of carbohydrate, and maintains blood glucose during short-term fasting. However, it is almost totally depleted after two to four days of zero carbohydrate intake. Muscle glycogen is used to supply fuel to exercising muscles and is depleted during physical activity. Since each gram of glycogen is stored in association with 10 g of water, depletion of body glycogen stores by 300 g to 400 g after several days of low-carbohydrate intake would result in a loss of 3 kg to 4 kg of water. This would easily account for the majority of the weight loss.

Unfortunately, high-carbohydrate diets are not popular because of a low rate of initial weight loss. If the increased carbohydrate intake causes glyco-

---

**Table 4**

**Problems With Low Carbohydrate Diets**

- Early weight loss is primarily water, not fat
- Expensive
- Risk of nutritional inadequacy (low in vitamins B and C)
- High fat content
  - may raise serum cholesterol
  - raises serum free-fatty acids and impairs insulin action
- High protein content
  - contraindicated for people with chronic renal or liver failure
  - not advised for those with diabetes or hypertension and, thus, for those at risk for renal failure
  - negative calcium balance may exacerbate osteoporosis
  - high purine load not indicated for those with gout or high serum uric acid
gen stores to increase, then there may even be initial weight gain due to the accumulation of water with the glycogen. Patients need to be informed of this and encouraged to persist.

**Recommended Dietary Approach For Weight Loss**

To lose body fat, one’s energy intake has to be less than their energy expenditure. The recommended principles of diet and exercise are those promoted by Canada’s Food Guide to Healthy Eating, and the Nutrition Recommendations of the Canadian Diabetes Association. Increased physical activity is very important. It not only helps people lose more weight, but also helps them lose more fat and less muscle mass. Recent research has shown that regular exercise distinguishes people who are successful at maintaining weight loss from those who are unsuccessful.

A recent clinical trial showed that obese women who undertook a walking program targeted to expend 1,000 Kcal per week (equivalent to walking 16 km) shed an average of 3.5 kg body weight over two years.

To obtain the general health benefits of exercise, patients do not have to walk 16 km (20 min. to 25 min. brisk walk) every day. The activity can be broken up into larger (e.g., a long walk on the weekend) or smaller amounts (e.g., five min. to 10 min. extra walking three times a day). Walking four to five blocks to and from the car or bus/subway stop before and after work five days a week would add up to half of the recommended exercise prescription.

The easiest way to reduce energy intake is to consume a diet with low energy density (i.e., a diet with a relatively small amount of energy for the weight and volume of foods consumed). Carbohydrates have less than one-half the energy density compared to fat (4 Kcal/g versus 9 Kcal/g). Some manufactured low-fat foods are energy dense because the fat has been replaced by carbohydrate. Therefore, labels have to be read carefully.

In general, however, natural high-carbohydrate foods, such as vegetables, fruit, boiled grains (e.g., rice, pasta) or low-fat grain products (e.g., breads, cereals), are less energy dense than fried, baked and manufactured snack foods. High-fat spreads and sauces should be used sparingly. Carbohydrate foods can be made more palatable with sugar, jams or sweet sauces (e.g., ketchup, sweet-and-sour sauce, vegetable pickles) without adding many calories.

The inclusion of a moderate amount of sugar in a low-fat diet has been shown to produce nearly the same amount of body fat loss over a six-month
period as a low-sugar, low-fat diet. Both diets pro-
duced significantly more body-fat loss than a typ-
ical Western diet.7

High-Carbohydrate Diets And Diabetes And Cardiovascular Disease

Short-term studies show that high-carbohydrate diets increase plasma insulin, glucose and triglyc-
erides. They also have been proven to lower HDL cholesterol, leading to the suggestion that they exacer-
bate cardiovascular risk. The increase in insulin from a short-term high-carbohydrate diet has been shown to be greater in people with insulin resistance, leading to the perception that high-carbohydrate diets are particularly deleteri-
ous for them. It is argued that people with diabetes cannot secrete enough insulin to overcome the in-
creased carbohydrate intake, and so their blood glucose control deteriorates. Long-term studies do not support these ideas.

The author recently completed a study suggesting the potentially deleterious effects of high-carbohydrate diets on blood lipid risk factors are only temporary and do not persist in the long term.8 It was found that a 10% increase in carbohydrate intake in diabetic subjects caused an increase in the serum total:HDL cholesterol ratio after three months, but that by six months this difference had disappeared (Figure 4). Similarly, blood glucose control tended to be worse on the high-carbohydrate diet initially, but by six months glycemic control tended to have deteriorated most on the low-carbohydrate diet (Figure 5). The low carbohydrate diet was associated with lower mean plasma insulin and a 33% increase in mean plasma free fatty acid concentrations (Figure 6).

Since the body must use the fuels that are con-
tained in the diet, if more fat is consumed then more fat has to be burned. The body burns fat by releasing the fatty acids stored in adipose tissue or that which is consumed in the diet into the blood. Chronic elevation of blood-free fatty acids impairs both insulin action and insulin secretion.

Role Of The GI In Choosing Food

How can insulin secretion be minimized while keeping carbohydrate intake high to prevent a rise in blood-free fatty acids? The answer has to do with the appropriate choice of carbohydrate foods. Not all carbohydrate foods elicit the same blood glucose and insulin responses. Returning to Figure 3, it can be seen that the responses after eating spaghetti are about 40% less than those after eating bread. The spaghetti meal, containing 70% energy from carbohydrates, produced somewhat lower glucose and insulin responses than the bread meal, containing 50% energy from carbohydrates. The blood glucose

Figure 4. Mean fasting total: HDL cholesterol ratio of Type 2 diabetic subjects randomized to high-carbohydrate (n = 29) or low-carbohydrate (n = 32) diets for six months.
responses of carbohydrate foods are classified by the GI, an index that measures how much foods raise blood glucose relative to the same amount of available carbohydrates from glucose.

Effects Of Low GI Diets In Diabetes

Including low GI foods in a high-carbohydrate diet reduces serum triglycerides in people with high triglycerides. It also is associated with significant improvement in overall blood glucose control. A significant reduction in glycated hemoglobin or glycated albumin was found in eight of 11 randomized, controlled trials of low GI diets in people with diabetes published over the last 12 years. The average improvement in all 11 studies was 9%, and this difference was highly statistically significant.

By contrast, there have been six randomized, controlled trials of low-carbohydrate, high-monounsaturated fat diets in people with diabetes. These trials reported measurements of glycated hemoglobin or glycated albumin. Each of these studies documented reduced postprandial blood glucose on the low-carbohydrate diet, but none were able to demonstrate a statistically significant reduction in glycated hemoglobin or albumin (the average reduction was about 2%, which is insignificant).

The author concludes from this evidence that while low-carbohydrate diets reduce acute blood glucose responses, they have no long-term benefit on overall glycemic control. In contrast, a high-carbohydrate diet containing low GI foods does improve overall glycemic control. For this
reason, the Canadian Diabetes Association recommends that 50% to 60% of daily energy should come from carbohydrates and that low GI foods may be helpful in optimizing glycemic control.\(^5\)

Low-GI diets may also be useful for the management of insulin resistance. It has been shown that a low-GI diet improved insulin sensitivity in non-diabetic women at risk of cardiovascular disease.\(^9\) It has been demonstrated that low-GI diets improved insulin secretion in subjects with impaired glucose tolerance, as compared to both a high-carbohydrate, high-GI diet and a low-carbohydrate, high-monounsaturated fat diet.\(^10\)

**Practical Application Of The GI**

The application of low GI does not mean the patient can forget about everything else they have learned about a healthy diet. The principle is that the diet should be high in carbohydrates (50% to 60% energy) with an increased use of starchy low-GI foods. Using low-GI foods will displace both high-GI and high-fat foods from the diet, but it doesn’t mean that all high-GI or high-fat foods have to be completely avoided. To achieve a meaningful effect, patients should aim to have one or more servings of low-GI foods at every meal, especially at breakfast and dinner. For example, some whole grain pumpernickel bread could be used instead of some regular wheat bread, or spaghetti or barley used in place of rice or potatoes. Legumes are high protein foods that can be used to replace some meats or dairy products in the diet with the effect not only of reducing dietary saturated fat, but also increasing overall carbohydrate intake from a low GI source.\(^{CME}\)

References

10. Wolever TMS, Mehling C: Low glycemic index (GI) diet improves glucose disposition index in subjects with impaired glucose tolerance (IGT). Diabetes 2000; 49(Suppl. 1):A306.

Suggested Reading