Table 3.3 Metabolic Pathways of Carbohydrate Metabolism

Glycogenesis	Making of glycogen
Glycogenolysis	Breakdown of glycogen
Glycolysis	Oxidation of glucose
Glyconeogenesis	Production of glucose from noncarbohydrate intermediates
Hexose monophosphate shunt	Production of 5-carbon monosaccharides and NADPH
Tricarboxylic acid cycle (TCA)	Oxidation of pyruvate and acetyl CoA

detail in the section "Integrated Metabolism in Tissues," are hormonally influenced, primarily by the antagonistic pancreatic hormones insulin and glucagon and the glucocorticoid hormones of the adrenal cortex. The rise in blood glucose following the ingestion of carbohydrate, for example, triggers the release of insulin while reducing the secretion of glucagon. These changes in the two hormone levels increase the uptake of glucose by muscle and adipose tissue, returning blood glucose to homeostatic levels. A fall in blood glucose concentration, conversely, signals a reversal of the pancreatic hormonal secretions—that is, decreased insulin and increased glucagon release. In addition, an increase in the secretion of glucocorticoid hormones, primarily cortisol, occurs in answer to—and to offset—a falling blood glucose level. Glucocorticoids cause increased activity of hepatic gluconeogenesis, a process described in detail in a later section. Several terms used in carbohydrate metabolism sound and appear to be very similar but are in fact quite different. Table 3.3 provides a list of these terms and their definition to provide a path for better understanding glucose metabolism.

Glycemic Response to Carbohydrates

The rate at which glucose is absorbed from the intestinal tract appears to be an important parameter in controlling the homeostasis of blood glucose, insulin release, obesity, and possibly weight loss. The intense research of the last few years appears to give the concept of glycemic index and glycemic load scientific validity [12]. Current research suggests a role for elevated blood glucose in the development of chronic diseases and obesity. The concept of glycemic index and glycemic load is discussed in this section. Their role in insulin resistance and type 2 diabetes is covered in Chapters 7 and 8. See also the Perspective on diabetes following Chapter 7.

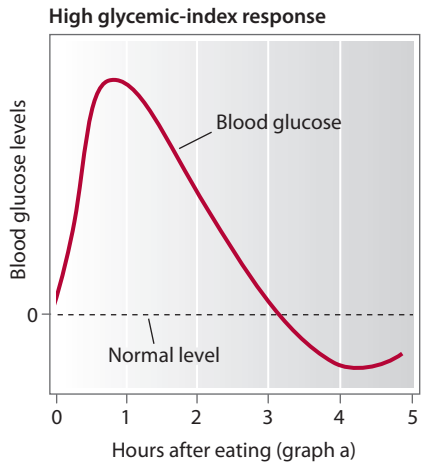
GLYCEMIC INDEX

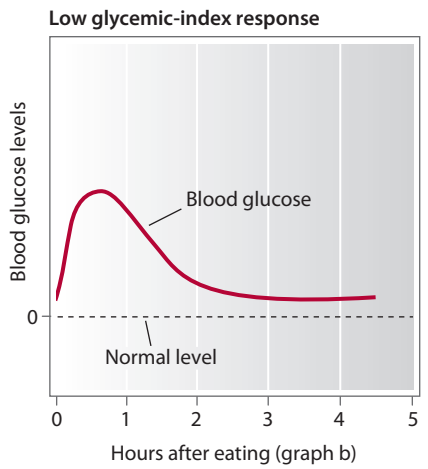
An alternative way to classify dietary carbohydrates is by their ease of absorption and their effect on the elevation of blood glucose levels. The implications of consuming high-glycemic index foods for chronic disease and obesity have recently been reviewed [13–15]. These reviews suggest that the glycemic index and glycemic load (defined below) offer a way to examine the relative risks of diets designed to prevent coronary heart disease (CHD) and obesity.

The effect that carbohydrate-containing foods have on blood glucose concentration, called the glycemic response of the food, varies with the time it takes to digest and absorb the carbohydrates in that food. Some foods cause a rapid rise and fall in blood glucose levels, whereas others cause a slower and more extended rise with a lower peak level and a gradual fall. The concept of the glycemic index of a food was developed to provide a numerical value to represent the effect of the food on blood glucose levels. It provides a quantitative comparison between foods. Glycemic index is defined as the increase in blood glucose level over the baseline level during a 2-hour period following the consumption of a defined amount of carbohydrate (usually 50 g) compared with the same amount of carbohydrate in a reference food. Earlier studies typically used glucose as the test food. More recently, white bread is being used, and white bread is assigned a score of 100. In practice, the glycemic index is measured by determining the elevation of blood glucose for 2 hours following ingestion. The area under the curve after plotting the blood glucose level following ingestion of the reference food is divided by the area under the curve for the reference food times 100 (Figure 3.11). If glucose is used as the reference food, it is arbitrarily assigned a glycemic index of 100. With glucose as the reference food white bread has a glycemic index of about 71. The use of white bread as the reference assigns the glycemic index of white bread of 100. The use of white bread as the standard causes some foods to have a glycemic index of greater than 100. One criticism of glycemic index is the variation of glycemic index for apparently similar foods. One cause could be the difference in the reference food used. This variation may reflect methodological differences as well as differences in the food preparation and the ingredients used in preparing the food. The difference could also reflect real differences in the biological variety of the food. For instance, the glycemic index for a baked russet potato is 76.5 and for an instant mashed potato is 87.7 (using glucose as the reference food) [16]. Even the temperature of the food can make a difference: A boiled red potato hot has a glycemic index of 89.4, and the same potato cold has a glycemic index of 56.2 (Table 3.4).

GLYCEMIC LOAD

The question has been raised as to whether the glycemic index has any practical relevance, because we do not eat a single food but meals that are made up of a number of foods. To address this question, the concept of glycemic load was introduced. Glycemic load considers both the quantity and the quality of the carbohydrate in a meal. The glycemic load (GL) equals the glycemic index times the grams of carbohydrate in a serving of the food. The higher the GL, the greater the expected elevation in blood glucose and in





Calculation of Glycemic Index

❶ The elevation in blood glucose level above the baseline following consumption of a high glycemic-index food or 50 g of glucose in a reference food (glucose or white bread). The glycemic index of the reference food is by definition equal to 100 (graph a).

❷ The elevation of blood glucose levels above the baseline following the intake of 50 g of glucose in a low glycemic-index food (graph b).

❸ The glycemic index is calculated by dividing the area under the curve for the test food by the area under the curve by the reference times 100.

Figure 3.11 Blood glucose changes following carbohydrate intake (glycemic index).

the insulinogenic effect of the food. Long-term consumption of a diet with a relatively high GL is associated with an increased risk of type 2 diabetes and coronary heart disease [17]. The literature suggests that the longer and higher the elevation of blood glucose, the greater the risk of developing chronic diseases and obesity [13,14].

Table 3.4 Glycemic Index of Common Foods with White Bread and Glucose Used as the Reference Food

Food Tested	Glycemic Index	
	White Bread =100	Glucose = 100
White Bread[1]	100	71
Baked Russet Potato[1]	107.7	76.5
Instant Mashed Potatoes[1]	123.5	87.7
Boiled Red Potato (hot)[1]	125.9	89.4
Boiled Red Potato (cold)[1]	79.2	56.2
Bran Muffin[2]	85	60
Coca Cola[2]	90	63
Apple Juice, Unsweetened[2]	57	40
Tomato Juice[2]	54	38
Bagel[2]	103	72
Whole-Meal Rye Bread[2]	89	62
Rye-Kernal Bread[2] (Pumpernickel)	58	41
Whole Wheat Bread[2]	74	52
All-Bran Cereal[2]	54	38
Cheerios[2]	106	74
Corn Flakes[2]	116	81
Raisin Bran[2]	87	61
Sweet Corn[2]	86	60
Couscous[2]	81	61
Rice[2]	73	51
Brown Rice[2]	72	50
Ice Cream[2]	89	62
Soy Milk[2]	63	44
Raw Apple[2]	57	40
Banana[2]	73	51
Orange[2]	69	48
Raw Pineapple[2]	94	66
Baked Beans[2]	57	40
Dried Beans[2]	52	36
Kidney Beans[2]	33	23
Lentils[2]	40	28
Spaghetti, Durum Wheat (boiled)[2]	91	64
Spaghetti, Whole Meal (boiled)[2]	32	46
Sucrose[2]	83	58

[1] Fernandes G, Velangi A, Wolever T. Glycemic Index of Potatoes Commonly Consumed in North America. J Am Diet Assoc 2005; 105:557-62.
[2] From Foster-Powell, K., Holt, S., Brand-Miller, J., "International Table of Glycemic Index and Glycemic Load Values." *American Journal of Clinical Nutrition,* 2002; 76:5–56. Reprinted by permission.

Many published tables provide the glycemic index for different foods. The most complete is an international table [18]. Selected examples from this publication have been reproduced in Table 3.4 along with the glycemic index of potatoes. Remember that the food products differ in different regions of the world. The glycemic indices listed in Table 3.4 are intended to be used to show trends and not to prepare diets. Glycemic index and glycemic load have proven useful in evaluating the risk of developing chronic disease and obesity. One of the risk factors for these chronic diseases appears to be related to the degree of blood glucose elevation and the length of time glucose levels are elevated.