Blood sugar

The blood sugar concentration or blood glucose level is the amount of glucose (sugar) present in the blood of a human or animal. Normally in mammals, the body maintains the blood glucose level at a reference range between about 3.6 and 5.8 mM (mmol/L, i.e., millimoles/liter), or 64.8 and 104.4 mg/dL. The human body naturally tightly regulates blood glucose levels as a part of metabolic homeostasis.

Glucose is the primary source of energy for the body's cells, and blood lipids (in the form of fats and oils) are primarily a compact energy store. Glucose is transported from the intestines or liver to body cells via the bloodstream, and is made available for cell absorption via the hormone insulin, produced by the body primarily in the pancreas.

The mean normal blood glucose level in humans is about 4 mM (4 mmol/L, or 72 mg/dL); however, this level fluctuates throughout the day. Glucose levels are usually lowest in the morning, before the first meal of the day (termed "the fasting level"), and rise after meals for an hour or two by a few millimolar.

Blood sugar levels outside the normal range may be an indicator of a medical condition. A persistently high level is referred to as hyperglycemia; low levels are referred to as hypoglycemia. Diabetes mellitus is characterized by persistent hyperglycemia from any of several causes, and is the most prominent disease related to failure of blood sugar regulation. A temporarily elevated blood sugar level may also result from severe stress, such as trauma, stroke, myocardial infarction, surgery, or illness. Intake of alcohol causes an initial surge in blood sugar, and later tends to cause levels to fall. Also, certain drugs can increase or decrease glucose levels.

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Units

The international standard way of measuring blood glucose levels are in terms of a molar concentration, measured in mmol/L (millimoles per litre; or millimolar, abbreviated mM). In the United States, mass concentration is measured in mg/dL (milligrams per decilitre).

Since the molecular weight of glucose $C_6H_{12}O_6$ is about 180 g/mol, for the measurement of glucose, the difference between the two
scales is a factor of 18, so that 1 mmol/L of glucose is equivalent to 18 mg/dL.[2]

**Normal values**

Normal value ranges may vary slightly among different laboratories. Many factors affect a person's blood sugar level. A body's homeostatic mechanism, when operating normally, restores the blood sugar level to a narrow range of about 4.4 to 6.1 mmol/L (82 to 110 mg/dL). (These levels are in contradiction with the levels cited at the beginning of this article, though the latter are quoted for mammals in general).

Despite widely variable intervals between meals or the occasional consumption of meals with a substantial carbohydrate load, human blood glucose levels tend to remain within the normal range. However, shortly after eating, the blood glucose level may rise, in non-diabetics, temporarily up to 7.8 mmol/L (140 mg/dL) or a bit more. The American Diabetes Association recommends a post-meal glucose level of less than 10 mmol/L (180 mg/dl) and a pre-meal plasma glucose of 5 to 7.2 mmol/L (90±130 mg/dL).[5] Persons with levels between 100 and 125 mg/dL have impaired fasting glucose

The actual amount of glucose in the blood and body fluids is very small. In a healthy adult male of 75 kg with a blood volume of 5 litres, a blood glucose level of 5.5 mmol/L (100 mg/dL) amounts to 5 grams, slightly less than two typical American restaurant sugar packets for coffee or tea.[6] Part of the reason why this amount is so small is that, to maintain an influx of glucose into cells, enzymes modify glucose by adding phosphate or other groups to it.

**Regulation**

*Main article: Blood sugar regulation*

The body's homeostatic mechanism keeps blood glucose levels within a narrow range. It is composed of several interacting systems, of which hormone regulation is the most important.

There are two types of mutually antagonistic metabolic hormones affecting blood glucose levels:

- catabolic hormones (such as glucagon, cortisol and catecholamines) which increase blood glucose;
- and one anabolic hormone (insulin), which decreases blood glucose.

**Health effects**

If blood sugar levels drop too low, a potentially fatal condition called hypoglycemia develops. Symptoms may include lethargy, impaired mental functioning; irritability; shaking, twitching, weakness in arm and leg muscles; pale complexion; sweating; paranoid or aggressive mentality and loss of consciousness. Brain damage is even possible.

If levels remain too high, appetite is suppressed over the short term. Long-term hyperglycemia causes many of the long-term health problems associated with diabetes, including eye, kidney, heart disease and nerve damage.

**Low blood sugar**

Mechanisms that restore satisfactory blood glucose levels after hypoglycemia must be quick and effective to prevent extremely serious consequences of insufficient glucose: confusion or unsteadiness and, in the extreme, coma. It is far more dangerous to have too little glucose in the blood than too much, at least temporarily. In healthy individuals, blood glucose-regulating mechanisms are generally quite effective, and symptomatic hypoglycemia is generally found only in diabetics using insulin or other pharmacological treatment. Hypoglycemic episodes can vary greatly between persons and from time to time, both in severity and swiftness of onset. For severe cases, prompt medical assistance is essential, as damage to brain and other tissues and even death will result from sufficiently low blood-glucose levels.

Some healthy individuals report drowsiness or impaired cognitive function several hours after meals, symptoms which they believe are related to a drop in blood sugar, or low blood sugar. For more information, see:

- idiopathic postprandial syndrome
- hypoglycemia

**Comparative content**
Glucose measurement

Further information: Blood glucose monitoring and Glucose meter

Sample type

Glucose is measured in whole blood, plasma or serum. Historically, blood glucose values were given in terms of whole blood, but most laboratories now measure and report the serum glucose levels. Because red blood cells (erythrocytes) have a higher concentration of protein (e.g., hemoglobin) than serum, serum has a higher water content and consequently more dissolved glucose than does whole blood. To convert from whole-blood glucose, multiplication by 1.15 has been shown to generally give the serum/plasma level.

Collection of blood in clot tubes for serum chemistry analysis permits the metabolism of glucose in the sample by blood cells until separated by centrifugation. Red blood cells, for instance, do not require insulin to intake glucose from the blood. Higher than normal amounts of white or red blood cell counts can lead to excessive glycolysis in the sample, with substantial reduction of glucose level if the sample is not processed quickly. Ambient temperature at which the blood sample is kept prior to centrifuging and separation of plasma/serum also affects glucose levels. At refrigerator temperatures, glucose remains relatively stable for several hours in a blood sample. Loss of glucose can be prevented by using Fluoride tubes (i.e., gray-top) since fluoride inhibits glycolysis. However, these should only be used when blood will be transported from one hospital laboratory to another for glucose measurement. Red-top serum separator tubes also preserve glucose in samples after being centrifuged isolating the serum from cells.

To prevent contamination of the sample with intravenous fluids, particular care should be given to drawing blood samples from the arm opposite the one in which an intravenous line is inserted. Alternatively, blood can be drawn from the same arm with an IV line after the IV has been turned off for at least 5 minutes, and the arm has been elevated to drain infused fluids away from the vein. Inattention can lead to large errors, since as little as 10% contamination with a 5% glucose solution (D5W) will elevate glucose in a sample by 500 mg/dl or more. Remember that the actual concentration of glucose in blood is very low, even in the hyperglycemic.

Arterial, capillary and venous blood have comparable glucose levels in a fasting individual. Following meals, venous levels are somewhat lower than those in capillary or arterial blood; a common estimate is about 10%.

Measurement techniques

Two major methods have been used to measure glucose. The first, still in use in some places, is a chemical method exploiting the nonspecific reducing property of glucose in a reaction with an indicator substance that changes color when reduced. Since other blood compounds also have reducing properties (e.g., urea, which can be abnormally high in uremic patients), this technique can produce erroneous readings in some situations (5 to 15 mg/dl has been reported). The more recent technique, using enzymes specific to glucose, is less susceptible to this kind of error. The two most common employed enzymes are glucose oxidase and hexokinase.

In either case, the chemical system is commonly contained on a test strip which is inserted into a meter, and then has a blood sample applied. Test-strip shapes and their exact chemical composition vary between meter systems and cannot be interchanged. Formerly, some test strips were read (after timing and wiping away the blood sample) by visual comparison against a color chart printed on the vial label. Strips of this type are still used for urine glucose readings, but for blood glucose levels they are obsolete. Their error rates were, in any case, much higher.

Urine glucose readings, however taken, are much less useful. In properly functioning kidneys, glucose does not appear in urine until the renal threshold for glucose has been exceeded. This is substantially above any normal glucose level, and is evidence of an existing severe hyperglycemic condition. However, as urine is stored in the bladder, any glucose in it might have been produced at any time since the last time the bladder was emptied. Since metabolic conditions change rapidly, as a result of any of several factors, this is delayed news and gives no warning of a developing condition. Blood glucose monitoring is far preferable, both clinically and for home monitoring by patients. Healthy urine glucose levels were first standardized and published in 1965 [7] by Hans Renschler.
Blood sugar - Wikipedia, the free encyclopedia

<table>
<thead>
<tr>
<th>Method</th>
<th>Reaction</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Alkaline copper reduction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folin-Wu method</td>
<td>$\text{Cu}^{++} + \text{Phosphomolybdic acid} \xrightarrow{\text{Oxidation}} \text{Phosphomolybdenum oxide}$</td>
<td>Blue end-product</td>
</tr>
<tr>
<td>Benedict's method</td>
<td>- Modification of Folin-Wu method for qualitative urine glucose</td>
<td></td>
</tr>
<tr>
<td>Nelson-Somogyi method</td>
<td>$\text{Cu}^{++} + \text{Arsenomolybdic acid} \xrightarrow{\text{Oxidation}} \text{Arsenomolybdenum oxide}$</td>
<td>Blue end-product</td>
</tr>
<tr>
<td>Neocuproine method</td>
<td>$\text{Cu}^{++} + \text{Neocuproine} \xrightarrow{\text{Oxidation}} \text{Cu}^{++} \text{neocuproine complex}$*</td>
<td>Yellow-orange color</td>
</tr>
<tr>
<td>Shaeffer-Hartmann-Somogyi method</td>
<td>- Uses the principle of iodine reaction with cuprous byproduct.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Excess I$_2$ is then titrated with thiosulfate.</td>
<td></td>
</tr>
<tr>
<td><strong>2. Alkaline Ferricyanide Reduction</strong></td>
<td></td>
<td>Colorless end product, other reducing substances interfere with reaction</td>
</tr>
<tr>
<td>Hagedorn-Jensen</td>
<td>Glucose + Alkaline ferricyanide $\rightarrow$ Ferrocyanide</td>
<td></td>
</tr>
<tr>
<td><strong>B. Condensation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthotoluidine method</td>
<td>- Uses aromatic amines and hot acetic acid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Forms Glycosylamine and Schiff's base which is emerald green in color</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- This is the most specific method, but the reagent used is toxic</td>
<td></td>
</tr>
<tr>
<td>Anthrone (phenols) method</td>
<td>- Forms hydroxymethyl furfural in hot acetic acid</td>
<td></td>
</tr>
<tr>
<td><strong>II. ENZYMATIC METHODS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Glucose oxidase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose + O$_2$ $\xrightarrow{\text{Glucose oxidase}}$ Cuprous oxide</td>
<td>Inhibited by reducing substances like BUA, bilirubin, glutathione, ascorbic acid</td>
<td></td>
</tr>
<tr>
<td>Siafer–Gerstenfeld method</td>
<td>$\text{H}_2\text{O}_2 + \text{O-} \text{dianisidine} \xrightarrow{\text{Peroxidase}} \text{H}_2\text{O} + \text{oxidized chromogen}$</td>
<td></td>
</tr>
<tr>
<td>Trinder method</td>
<td>- uses 4-aminophenazone (<a href="http://www.online-medical-dictionary.org/4-Aminophenazone.asp?q=4-Aminophenazone">http://www.online-medical-dictionary.org/4-Aminophenazone.asp?q=4-Aminophenazone</a>) oxidatively coupled with phenol</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Subject to less interference by increases serum levels of creatinine, uric acid or hemoglobin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Inhibited by catalase</td>
<td></td>
</tr>
<tr>
<td>Kodak Ektachem</td>
<td>- A dry chemistry method</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Uses reflectance spectrophotometry to measure the intensity of color through a lower transparent film</td>
<td></td>
</tr>
</tbody>
</table>
Blood sugar - Wikipedia, the free encyclopedia

Glucometer
- Home monitoring blood glucose assay method
- Uses a strip impregnated with a glucose oxidase reagent

B. Hexokinase

\[
\text{Glucose + ATP} \xrightarrow{\text{Hexokinase + Mg}^{++}} \text{G-6PO}_4 + \text{ADP}
\]
\[
\text{G-6PO}_4 + \text{NADP} \xrightarrow{\text{G-6PD Oxidation}} \text{G-Phosphogluconate} + \text{NADPH + H}^+
\]

- NADP as cofactor
- NADPH (reduced product) is measured in 340 nm
- More specific than glucose oxidase method due to G-6PO\(_4\), which inhibits interfering substances except when sample is hemolyzed

Blood glucose laboratory tests

1. Fasting blood sugar (i.e., glucose) test (FBS)
2. Urine glucose test
3. Two-hr postprandial blood sugar test (2-h PPBS)
4. Oral glucose tolerance test (OGTT)
5. Intravenous glucose tolerance test (IVGTT)
6. Glycosylated hemoglobin (HbA\(_{1C}\))
7. Self-monitoring of glucose level via patient testing

Clinical correlation

The fasting blood glucose level, which is measured after a fast of 8 hours, is the most commonly used indication of overall glucose homeostasis, largely because disturbing events such as food intake are avoided. Conditions affecting glucose levels are shown in the table below. Abnormalities in these test results are due to problems in the multiple control mechanism of glucose regulation.

The metabolic response to a carbohydrate challenge is conveniently assessed by a postprandial glucose level drawn 2 hours after a meal or a glucose load. In addition, the glucose tolerance test, consisting of several timed measurements after a standardized amount of oral glucose intake, is used to aid in the diagnosis of diabetes. It is regarded as the gold standard of clinical tests of the insulin/glucose control system, but is difficult to administer, requiring much time and repeated blood tests. In comparison, the fasting blood glucose level is a much poorer screening test because of the high variability of the experimental conditions such as the carbohydrate content of the last meal and the energy expenditure between the last meal and the measurement. Actually, many people with prediabetes or diabetes can have a fasting blood glucose below the prediabetic/diabetic threshold if their last meal happened to be low in carbohydrate and they burnt all the related glucose in their blood stream before taking the test. Note that food commonly includes carbohydrates which don't participate in the metabolic control system; simple sugars such as fructose, many of the disaccharides (which either contain simple sugars other than glucose or cannot be digested by humans) and the more complex sugars which also cannot be digested by humans. And there are carbohydrates which are not digested even with the assistance of gut bacteria; several of the fibres (soluble or insoluble) are chemically carbohydrates. Food also commonly contains components which affect glucose (and other sugar's) digestion; fat, for example slows down digestive processing, even for such easily handled food constituents as starch. Avoiding the effects of food on blood glucose measurement is important for reliable results since those effects are so variable.

Error rates for blood glucose measurements systems vary, depending on laboratories, and on the methods used. Colorimetry techniques can be biased by color changes in test strips (from airborne or finger borne contamination, perhaps) or interference (e.g., tinting contaminants) with light source or the light sensor. Electrical techniques are less susceptible to these errors, though not to others. In home use, the most important issue is not accuracy, but trend. Thus if a meter / test strip system is consistently wrong by 10%, there will be little consequence, as long as changes (e.g., due to exercise or medication adjustments) are properly tracked. In the US, home use blood test meters must be approved by the Federal Food and Drug Administration before they can be sold.

Finally, there are several influences on blood glucose level aside from food intake. Infection, for instance, tends to change blood glucose levels, as does stress either physical or psychological. Exercise, especially if prolonged or long after the most recent meal, will have an effect as well. In the normal person, maintenance of blood glucose at near constant levels will nevertheless be quite effective.

Causes of abnormal glucose levels
<table>
<thead>
<tr>
<th>Persistent hyperglycemia</th>
<th>Transient hyperglycemia</th>
<th>Persistent hypoglycemia</th>
<th>Transient hypoglycemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes mellitus</td>
<td>Pheochromocytoma</td>
<td>Insulinoma</td>
<td>Acute alcohol ingestion</td>
</tr>
<tr>
<td>Adrenal cortical hyperactivity</td>
<td>Severe liver disease</td>
<td>Adrenal cortical insufficiency</td>
<td>Drugs: salicylates, antituberculosis agents</td>
</tr>
<tr>
<td>Cushing's syndrome</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperthyroidism</td>
<td>Acute stress reaction</td>
<td>Hypopituitarism</td>
<td>Severe liver disease</td>
</tr>
<tr>
<td>Acromegaly</td>
<td>Shock</td>
<td>Galactosemia</td>
<td>Several glycogen storage diseases</td>
</tr>
<tr>
<td>Obesity</td>
<td>Convulsions</td>
<td>Ectopic insulin production from tumors</td>
<td>Hereditary fructose intolerance</td>
</tr>
</tbody>
</table>

**Reference range, FBG: 70–110 mg/dl**

**Etymology and use of term**

In a physiological context, the term is a misnomer because it refers to glucose, yet other sugars besides glucose are always present. Food contains several different types (e.g., fructose (largely from fruits/table sugar/industrial sweeteners), galactose (milk and dairy products), as well as several food additives such as sorbitol, xylose, maltose, etc.). But because these other sugars are largely inert with regard to the metabolic control system (i.e., that controlled by insulin secretion), since glucose is the dominant controlling signal for metabolic regulation, the term has gained currency, and is used by medical staff and lay folk alike. The table above reflects some of the more technical and closely defined terms used in the medical field.

**See also**
- Current research – Boronic acids in supramolecular chemistry: Saccharide recognition
- Blood glucose monitoring
- Glucagon

**References**


**Further reading**


Categories: Human homeostasis | Blood tests | Diabetes

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