Your body needs a steady supply of amino acids for use in growth and repairs. Each day, a typical adult needs something in the range of 35–90 grams of protein, depending on their weight. Quite surprisingly, a large fraction of this may come from inside. A typical North American diet may contain 70–100 grams of protein each day. But your body also secretes 20–30 grams of digestive proteins, which are themselves digested when their finish their duties. Dead intestinal cells and proteins leaking out of blood vessels are also digested and reabsorbed as amino acids, showing that our bodies are experts at recycling.

**Protein Scissors**
Proteins are tough, so we use an arsenal of enzymes to digest them into their component amino acids. Digestion of proteins begins in the stomach, where hydrochloric acid unfolds proteins and the enzyme pepsin begins a rough disassembly. The real work then starts in the intestines. The pancreas adds a collection of protein-cutting enzymes, with trypsin playing the central role, that chop the protein chains into pieces just a few amino acids long. Then, enzymes on the surfaces of intestinal cells and inside the cells chop them into amino acids, ready for use throughout the body.
The Protein–Cutting Machinery

Trypsin uses a special serine amino acid in its protein–cutting reaction, and is consequently known as a serine protease. The serine proteases are a diverse family of enzymes, all of which use similar enzymatic machinery. In digestion, trypsin, chymotrypsin and elastase work together to chop up proteins. Each has a particular taste for protein chains: trypsin (shown at the top from PDB entry 2ptn) cuts next to lysine and arginine, chymotrypsin (shown in the middle from PDB entry 2cha) cuts next to phenylalanine and other large amino acids, and elastase likes chains with small amino acids like alanine (shown at the bottom from PDB entry 3est). In each picture, the key serine is shown at center in red, with a histidine (white and blue) and an aspartate (only one red oxygen can be seen) highlighted below it. Trypsin–like enzymes are also found in many other places in the body. Some of these are highly specific, cleaving only a specific target protein. For instance, thrombin, presented in the Molecule of the Month in January 2003, is designed to make a specific cut in fibrinogen, creating a blood clot.
October 2003: Trypsin

Sturdy Enzymes
Serine proteases played a central role in the discovery and study of enzymes. This is because they are particularly easy to study. They are plentiful in digestive juices and very stable, so they are relatively easy to collect and purify. It is also easy to study their function: you just toss in some protein and see how fast it is digested. Chymotrypsin was among the first proteins to be studied by X-ray crystallography, revealing its complex machinery for holding the protein targets and performing a precise atomic change. Today, there are hundreds of structures of serine proteases available in the PDB, waiting to be explored.

The Perils of Proteases
As you might imagine, the digestion of proteins in your body is a delicate business. Protein makes up about one fifth of the material in each of your cells, so you must be careful when creating protein–cutting machines. For digestive enzymes, the trick is to create the enzyme in an inactive form (termed a zymogen), and then to activate it once it is in the intestine. Trypsin is built with an extra piece of protein chain, colored in green in the structure on the left (PDB entry 1tgs). Actually, only two amino acids of this extra bit are seen in crystal structure, so you have to imagine the rest flopping around away from the protein. This longer form of trypsin, called trypsinogen, is inactive and cannot cut protein chains. Then, when it enters the intestine, the enzyme enteropeptidase makes one cut in the trypsin chain, clipping off the little tail. This allows the new end of the chain, colored here in purple, to tuck into the folded protein and stabilize the active form of the enzyme, as shown on the right (PDB entry 2ptc). As extra insurance, the pancreas also makes a small protein, trypsin inhibitor (shown in red), that binds to any traces of active trypsin that might be present before it is secreted into the intestine. It binds to the active site of trypsin, blocking its action but not itself being cut into tiny pieces.
As you look through the PDB, you will find many other examples of serine proteases, built for digestion, hormone activation, blood clotting, immune system activation, and many other functions. They share an unusual collection of amino acids designed to assist protein–cutting reactions, which have been discovered again and again by evolution. The center of the machinery is a serine amino acid that is activated by a histidine and an aspartate. Together, these three amino acids have been termed the charge relay system. The histidine and the aspartate assist in the removal of the hydrogen atom from the serine (colored white), which makes it more reactive when attacking the target protein chain. This illustration was created using PDB entry 2ptc, which has an inhibitor protein (colored pink) bound in the active site. The site of cleavage in this inhibitor, colored green here, is held just far enough away that it is not cleaved the way most proteins would be in this location. Notice also the long lysine amino acid extending down to the lower right from the cleavage site, where it interacts with another aspartate in the enzyme (shown down in the lower right corner with red oxygens). Through this interaction, trypsin favors cutting at places next to lysine or arginine amino acids.