Digestive System
and Gastroenterology Procedures

esophagus

hepar

ventriculus

vesica
fellea

colon
transversum

colon
ascendens

jejunum

colon
sigmoideum

appendix

rectum

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Chapter 1

Digestion

Digestion is the mechanical and chemical breakdown of food into smaller components that are more easily absorbed into a blood stream, for instance. Digestion is a form of catabolism: a breakdown of large food molecules to smaller ones.

In mammals, food enters the mouth, being chewed by teeth, with chemical processing beginning with chemicals in the saliva from the salivary glands. This is called mastication. Then it travels down the esophagus into the stomach, where hydrochloric acid kills most contaminating microorganisms and begins mechanical break down of some food (e.g., denaturation of protein), and chemical alteration of some. The hydrochloric acid also has a low pH, which is great for enzymes. After some time (typically an hour or two in humans, 4–6 hours in dogs, somewhat shorter duration in house cats, ...), the resulting thick liquid is called chyme. Chyme will go through the small intestine, where 95% of absorption of nutrients occurs, through the large intestine, and are excreted during defecation.

Other organisms use different mechanisms to digest food.

Digestive systems

Digestive systems take many forms. There is a fundamental distinction between internal and external digestion. External digestion was the first to evolve, and most fungi still rely on it. In this process, enzymes are secreted into the environment surrounding the organism, where they break down an organic material, and some of the products diffuse back to the organism. Later, animals evolved by rolling into a tube and acquiring internal digestion, which is more efficient because more of the broken down products can be captured, and the chemical environment can be more efficiently controlled.

Some organisms, including nearly all spiders, simply secrete biotoxins and digestive chemicals (e.g., enzymes) into the extracellular environment prior to ingestion of the consequent "soup". In others, once potential nutrients or food is inside the organism, digestion can be conducted to a vesicle or a sac-like structure, through a tube, or through several specialized organs aimed at making the absorption of nutrients more efficient.

Secretion systems

Bacteria use several systems to obtain nutrients from other organisms in the environments.

Channel transport system

In a channel transport system several proteins form a contiguous channel traversing the inner and outer membranes of the bacteria. It is a simple system, which consists of only three protein subunits: the ABC protein, membrane fusion protein (MFP), and outer membrane protein (OMP). This secretion system transports various molecules, from ions, drugs, to proteins of various sizes (20 - 900 kDa). The molecules secreted vary in size from the small *Escherichia coli* peptide colicin V, (10 kDa) to the *Pseudomonas fluorescens* cell adhesion protein LapA of 900 kDa.

Molecular syringe

One molecular syringe is used through which a bacterium (e.g. certain types of *Salmonella*, *Shigella*, *Yersinia*) can inject proteins into eukaryotic cells. One such mechanism was first discovered in *Y. pestis* and showed that toxins could be injected directly from the bacterial cytoplasm into the cytoplasm of its host's cells rather than simply be secreted into the extracellular medium.

Conjugation machinery
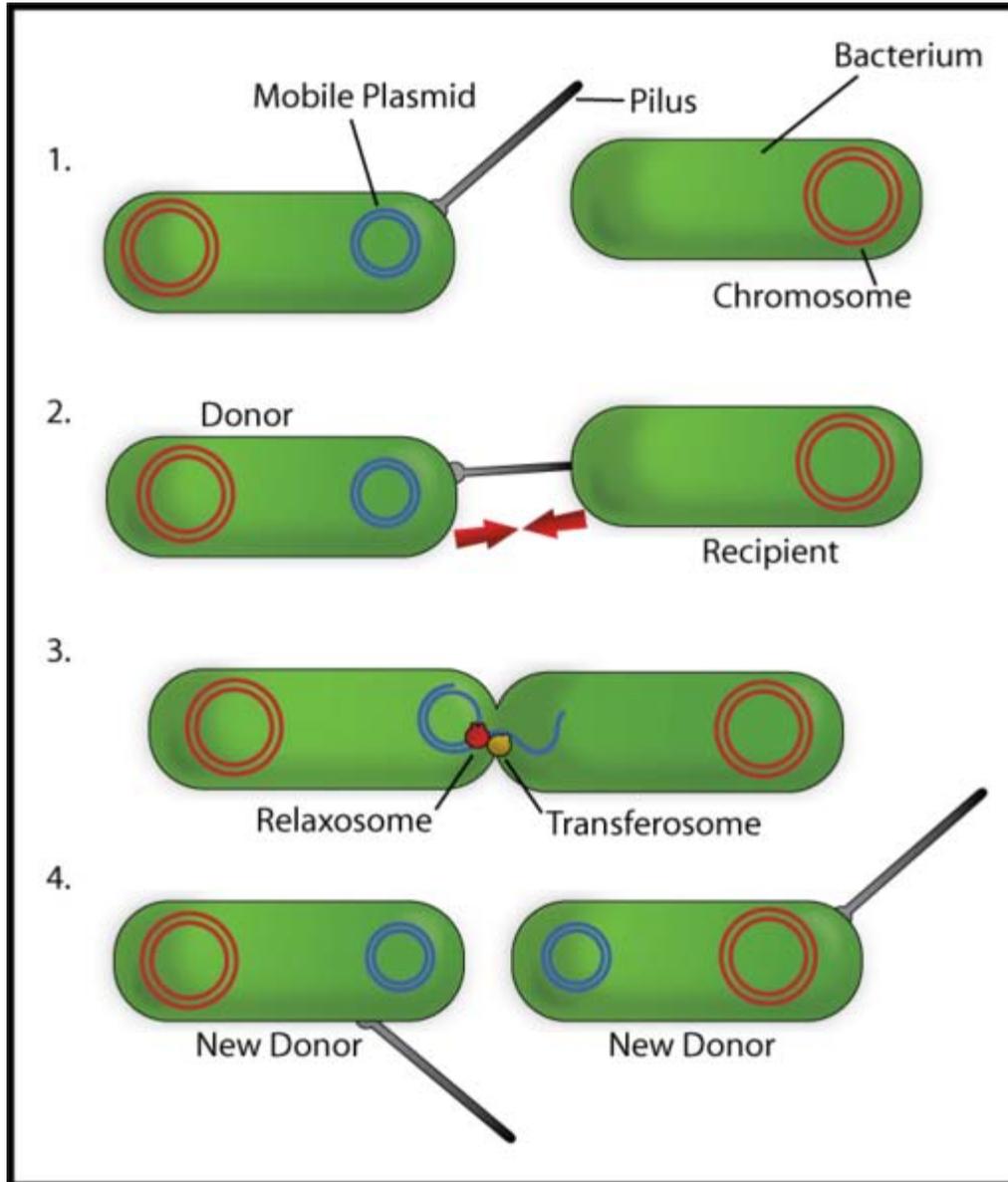
Schematic drawing of bacterial conjugation. **Conjugation diagram 1-** Donor cell produces pilus. **2-** Pilus attaches to recipient cell, brings the two cells together. **3-** The mobile plasmid is nicked and a single strand of DNA is then transferred to the recipient cell. **4-** Both cells recircularize their plasmids, synthesize second strands, and reproduce pili; both cells are now viable donors.

The conjugation machinery of some bacteria (and archaeal flagella) is capable of transporting both DNA and proteins. It was discovered in *Agrobacterium tumefaciens*, which uses this system to introduce the Ti plasmid and proteins into the host which develops the crown gall (tumor). The VirB complex of *Agrobacterium tumefaciens* is the prototypic system.

The nitrogen fixing *Rhizobia* are an interesting case, wherein conjugative elements naturally engage in inter-kingdom conjugation. Such elements as the *Agrobacterium* Ti or Ri plasmids contain elements that can transfer to plant cells. Transferred genes enter the plant cell nucleus and effectively transform the plant cells into factories for the production of opines, which the bacteria use as carbon and energy sources. Infected plant cells form crown gall or root tumors. The Ti and Ri plasmids are thus endosymbionts of the bacteria, which are in turn endosymbionts (or parasites) of the infected plant.

The Ti and Ri plasmids are themselves conjugative. Ti and Ri transfer between bacteria uses an independent system (the *tra*, or transfer, operon) from that for inter-kingdom transfer (the *vir*, or virulence, operon). Such transfer creates virulent strains from previously avirulent *Agrobacteria*.

Release of outer membrane vesicles

In addition to the use of the multiprotein complexes listed above, Gram-negative bacteria possess another method for release of material: the formation of outer membrane vesicles. Portions of the outer membrane pinch off, forming spherical structures made of a lipid bilayer enclosing periplasmic materials. Vesicles from a number of bacterial species have been found to contain virulence factors, some have immunomodulatory effects, and some can directly adhere to and intoxicate host cells. While release of vesicles has been demonstrated as a general response to stress conditions, the process of loading cargo proteins seems to be selective.

Phagosome

A phagosome is a vacuole formed around a particle absorbed by phagocytosis. The vacuole is formed by the fusion of the cell membrane around the particle. A phagosome is a cellular compartment in which pathogenic microorganisms can be killed and digested. Phagosomes fuse with lysosomes in their maturation process, forming phagolysosomes. In humans, *Entamoeba histolytica* can phagocytose red blood cells.
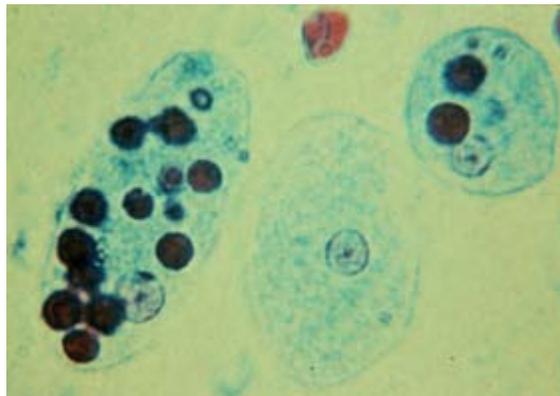
Trophozoites of *Entamoeba histolytica* with ingested erythrocytes

Gastrovascular cavity

The gastrovascular cavity functions as a stomach in both digestion and the distribution of nutrients to all parts of the body. Extracellular digestion takes place within this central cavity which is lined with the gastrodermis, the internal layer of epithelium. This cavity has only one opening to the outside that functions as both a mouth and an anus: waste and undigested matter is excreted through the mouth/anus, which can be described as an incomplete gut.
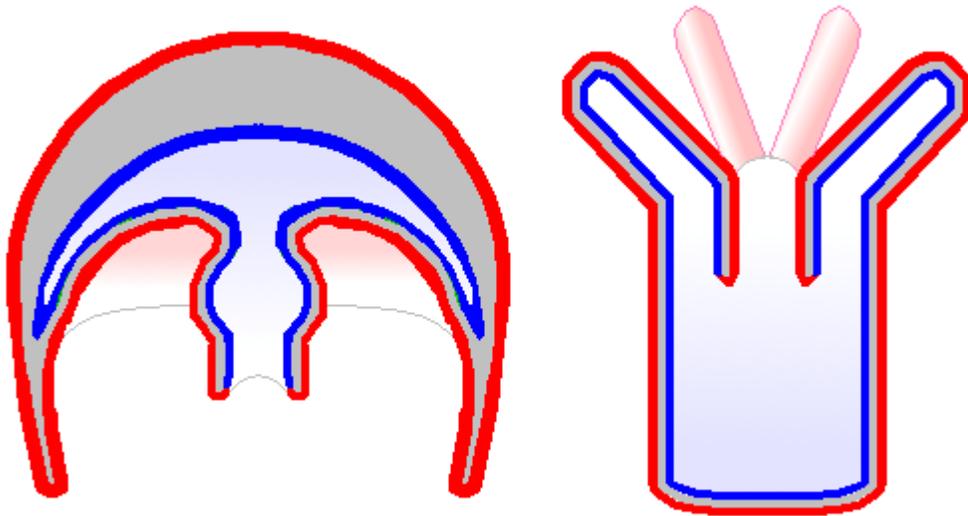
Aboral end
Oral end
Mouth
Oral end
Aboral end
▮ Exoderm
▮ Gastroderm
▮ Mesoglea
▮ Digestive cavity
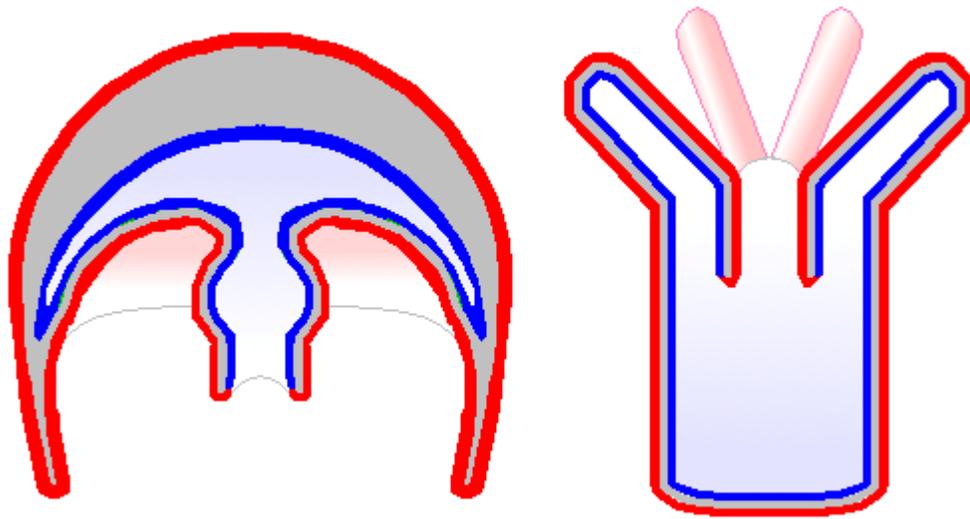
Medusa (left) and polyp (right)

In a plant such as the Venus Flytrap that can make its own food through photosynthesis, it does not eat and digest its prey for the traditional objectives of harvesting energy and carbon, but mines prey primarily for essential nutrients (nitrogen and phosphorus in particular) that are in short supply in its boggy, acidic habitat.

Venus Flytrap (*Dionaea muscipula*) leaf

Specialized organs and behaviors

Catalina Macaw exhibits its seed shearing beak
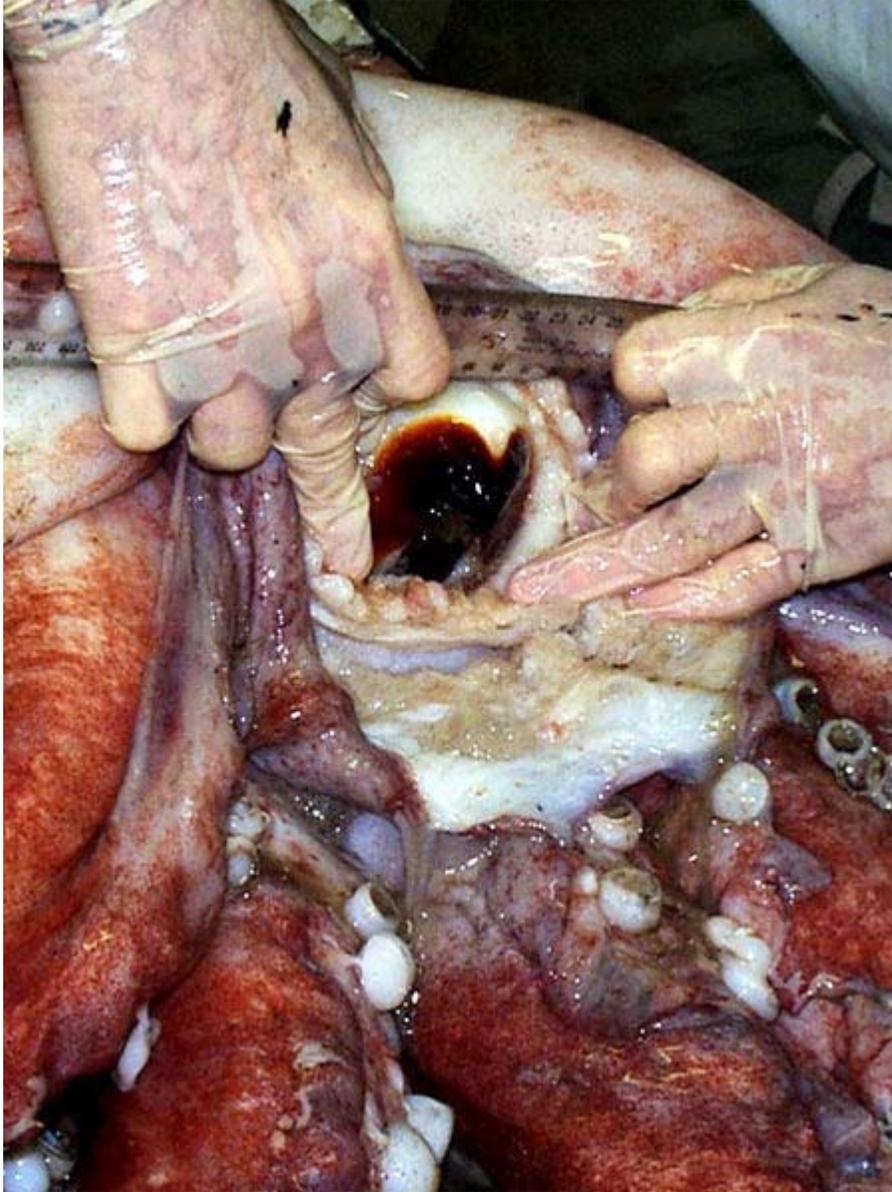
Squid beak and ruler for size comparison

Teeth of a *Carcharodon megalodon*
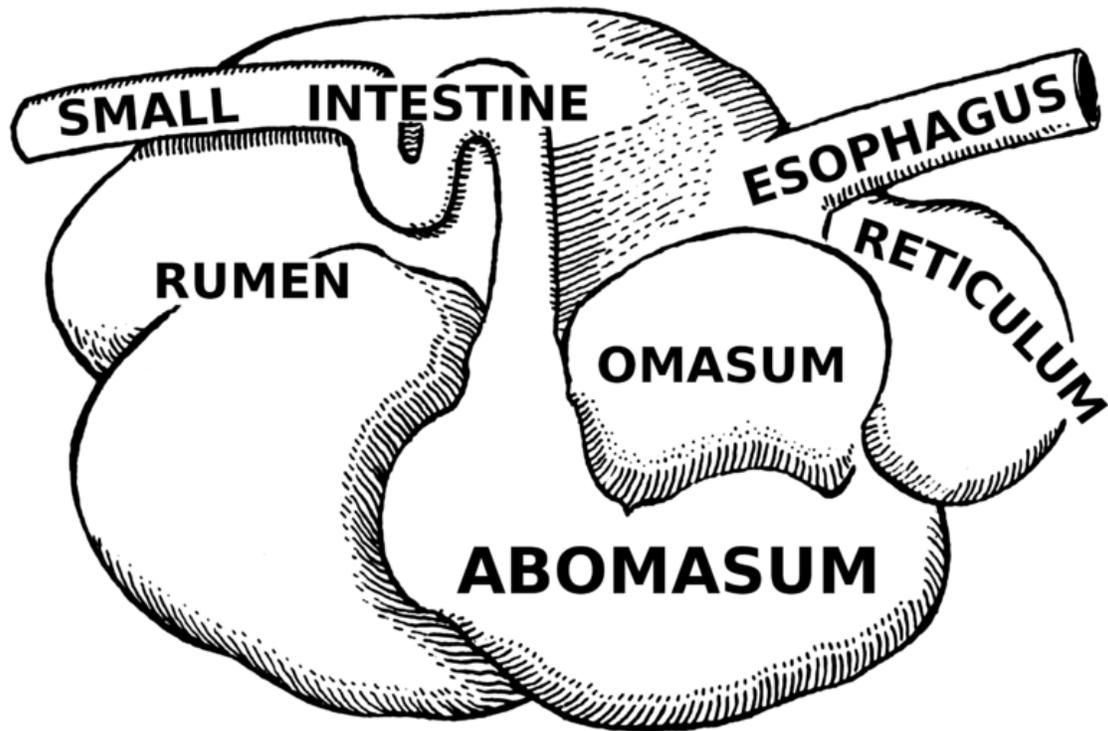
Rough illustration of a ruminant digestive system

To aid in the digestion of their food animals evolved organs such as beaks, tongues, teeth, a crop, gizzard, and others.

Beaks

Macaws primarily eat seeds, nuts, and fruit, using their impressive beaks to open even the toughest seed. First they scratch a thin line with the sharp point of the beak, then they shear the seed open with the sides of the beak.

The mouth of the squid is equipped with a sharp horny beak mainly made of chitin and cross-linked proteins. It is used to kill and tear prey into manageable pieces. The beak is very robust, but does not contain any minerals, unlike the teeth and jaws of many other organisms, including marine species. The beak is the only indigestible part of the squid.

Tongue

The **tongue** is skeletal muscle on the floor of the mouth that manipulates food for chewing (mastication) and swallowing (deglutition). It is sensitive and kept moist by saliva. The underside of the tongue is covered with a smooth mucous membrane. The tongue is utilised to roll food particles into a bolus before being transported down the esophagus through the use of peristalsis. The sublingual region underneath the front of

the tongue is a location where the oral mucosa is very thin, and underlain by a plexus of veins. This is an ideal location for introducing certain medications to the body. The sublingual route takes advantage of the highly vascular quality of the oral cavity, and allows for the speedy application of medication into the cardiovascular system, bypassing the gastrointestinal tract.

Teeth

Teeth (singular, tooth) are small whitish structures found in the jaws (or mouths) of many vertebrates that are used to tear, scrape, milk and chew food. Teeth are not made of bone, but rather of tissues of varying density and hardness. The shape of an animal's teeth is related to its diet. For example, plant matter is hard to digest, so herbivores have many molars for chewing.

The teeth of carnivores are shaped to kill and tear meat, using specially shaped canine teeth. Herbivores' teeth are made for grinding food materials, in this case, plant parts.

Crop

A crop, or croup, is a thin-walled expanded portion of the alimentary tract used for the storage of food prior to digestion. In some birds it is an expanded, muscular pouch near the gullet or throat. In adult doves and pigeons, the crop can produce crop milk to feed newly hatched birds.

Certain insects may have a crop or enlarged esophagus.

Abomasum

Herbivores have evolved cecums (or an abomasum in the case of ruminants). Ruminants have a fore-stomach with four chambers. These are the rumen, reticulum, omasum, and abomasum. In the first two chambers, the rumen and the reticulum, the food is mixed with saliva and separates into layers of solid and liquid material. Solids clump together to form the cud (or bolus). The cud is then regurgitated, chewed slowly to completely mix it with saliva and to break down the particle size.

Fiber, especially cellulose and hemi-cellulose, is primarily broken down into the volatile fatty acids, acetic acid, propionic acid and butyric acid in these chambers (the reticulo-rumen) by microbes: (bacteria, protozoa, and fungi). In the omasum water and many of the inorganic mineral elements are absorbed into the blood stream.

The abomasum is the fourth and final stomach compartment in ruminants. It is a close equivalent of a monogastric stomach (e.g., those in humans or pigs), and digesta is processed here in much the same way. It serves primarily as a site for acid hydrolysis of microbial and dietary protein, preparing these protein sources for further digestion and absorption in the small intestine. Digesta is finally moved into the small intestine, where

the digestion and absorption of nutrients occurs. Microbes produced in the reticulo-rumen are also digested in the small intestine.

Specialized behaviors

A flesh fly "blowing a bubble". One explanation of this behaviour is that the fly regurgitates its food into a bubble in order to increase the concentration of its food by evaporating excessive water content

Regurgitation has been mentioned above under abomasum and crop, referring to crop milk, a secretion from the lining of the crop of pigeons and doves with which the parents feed their young by regurgitation.

Many sharks have the ability to turn their stomachs inside out and evert it out of their mouths in order to get rid of unwanted contents (perhaps developed as a way to reduce exposure to toxins).

Other animals, such as rabbits and rodents, practice coprophagia behaviors - eating specialized feces in order to re-digest food, especially in the case of roughage. Capybara, rabbits, hamsters and other related species do not have a complex digestive system as do, for example, ruminants. Instead they extract more nutrition from grass by giving their food a second pass through the gut. Soft fecal pellets of partially digested food are excreted and generally consumed immediately. They also produce normal droppings, which are not eaten.

Young elephants, pandas, koalas, and hippos eat the feces of their mother, probably to obtain the bacteria required to properly digest vegetation. When they are born, their intestines do not contain these bacteria (they are completely sterile). Without them, they would be unable to get any nutritional value from many plant components.

In earthworms

An earthworm's digestive system consists of a mouth, pharynx, esophagus, crop, gizzard, and intestine. The mouth is surrounded by strong lips which act like a hand to grab pieces of dead grass, leaves, and weeds, with bits of soil to help chew. The lips break the food down into smaller pieces. In the pharynx the food is lubricated by mucus secretions for easier passage. The esophagus adds calcium carbonate to neutralize the acids formed by food matter decay. Temporary storage occurs in the crop where food and calcium carbonate are mixed. The powerful muscles of the gizzard churn and mix the mass of food and dirt. When the churning is complete, the glands in the walls of the gizzard add enzymes to the thick paste which aid in the chemical breakdown of the organic matter. By peristalsis the mixture is sent to the intestine where friendly bacteria continue chemical breakdown. This releases carbohydrates, protein, fat, and various vitamins and minerals for absorption into the body.

Overview of vertebrate digestion

In most vertebrates, digestion is a multi-stage process in the digestive system, starting from ingestion of raw materials, most often other organisms. Ingestion usually involves some type of mechanical and chemical processing. Digestion is separated into four steps:

1. Ingestion: placing food into the mouth (entry of food in the digestive system),
2. Mechanical and chemical breakdown: mastication and the mixing of the resulting bolus with water, acids, bile and enzymes in the stomach and intestine to break down complex molecules into simple structures,
3. Absorption: of nutrients from the digestive system to the circulatory and lymphatic capillaries through osmosis, active transport, and diffusion, and
4. Egestion (Excretion): Removal of undigested materials from the digestive tract through defecation.

Underlying the process is muscle movement throughout the system through swallowing and peristalsis. Each step in digestion requires energy, and thus imposes an "overhead charge" on the energy made available from absorbed substances. Differences in that overhead cost are important influences on lifestyle, behavior, and even physical structures. Examples may be seen in humans, who differ considerably from other hominids (lack of hair, smaller jaws and musculature, different dentition, length of intestines, cooking, etc.).

The major part of digestion takes place in the small intestine. The large intestine primarily serves as a site for fermentation of indigestible matter by gut bacteria and for resorption of water from digesta before excretion.

In mammals, preparation for digestion begins with the cephalic phase in which saliva is produced in the mouth and digestive enzymes are produced in the stomach. Mechanical and chemical digestion begin in the mouth where food is chewed, and mixed with saliva to begin enzymatic processing of starches. The stomach continues to break food down mechanically and chemically through churning and mixing with both acids and enzymes. Absorption occurs in the stomach and gastrointestinal tract, and the process finishes with defecation.

Human digestion process

The whole digestive system is around 9 meters long. In a healthy human adult this process can take between 24 and 72 hours. Food digestion physiology varies between individuals and upon other factors such as the characteristics of the food and size of the meal.

Phases of gastric secretion

- Cephalic phase - This phase occurs before food enters the stomach and involves preparation of the body for eating and digestion. Sight and thought stimulate the cerebral cortex. Taste and smell stimulus is sent to the hypothalamus and medulla oblongata. After this it is routed through the vagus nerve and release of acetylcholine. Gastric secretion at this phase rises to 40% of maximum rate. Acidity in the stomach is not buffered by food at this point and thus acts to inhibit parietal (secretes acid) and G cell (secretes gastrin) activity via D cell secretion of somatostatin.
- Gastric phase - This phase takes 3 to 4 hours. It is stimulated by distension of the stomach, presence of food in stomach and decrease in pH. Distention activates long and myentric reflexes. This activates the release of acetylcholine which stimulates the release of more gastric juices. As protein enters the stomach, it binds to hydrogen ions, which lowers the pH of the stomach to around pH 1-3. Inhibition of gastrin and HCl secretion is lifted. This triggers G cells to release gastrin, which in turn stimulates parietal cells to secrete HCl. HCl release is also triggered by acetylcholine and histamine.
- Intestinal phase - This phase has 2 parts, the excitatory and the inhibitory. Partially digested food fills the duodenum. This triggers intestinal gastrin to be released. Enterogastric reflex inhibits vagal nuclei, activating sympathetic fibers causing the pyloric sphincter to tighten to prevent more food from entering, and inhibits local reflexes.

Oral cavity

In humans, digestion begins in the oral cavity where food is chewed. Saliva is secreted in large amounts (1-1.5 litres/day) by three pairs of exocrine salivary glands (parotid, submandibular, and sublingual) in the oral cavity, and is mixed with the chewed food by the tongue. There are two types of saliva. One is a thin, watery secretion, and its purpose is to wet the food. The other is a thick, mucous secretion, and it acts as a lubricant and

causes food particles to stick together and form a bolus. The saliva serves to clean the oral cavity and moisten the food, and contains digestive enzymes such as salivary amylase, which aids in the chemical breakdown of polysaccharides such as starch into disaccharides such as maltose. It also contains mucous, a glycoprotein which helps soften the food into a bolus.In oral cavity there is another enzyme named ligual lipase which breakdown the lipids in to di and monoglycerole.

Swallowing transports the chewed food into the esophagus, passing through the oropharynx and hypopharynx. The mechanism for swallowing is coordinated by the swallowing center in the medulla oblongata and pons. The reflex is initiated by touch receptors in the pharynx as the bolus of food is pushed to the back of the mouth.

Pharynx

The pharynx is the part of the neck and throat situated immediately posterior to (behind) the mouth and nasal cavity, and cranial, or superior, to the esophagus. It is part of the digestive system and respiratory system. Because both food and air pass through the pharynx, a flap of connective tissue, the epiglottis closes over the trachea when food is swallowed to prevent choking or asphyxiation.

The oropharynx is that part of the pharynx which lies behind the oral cavity and is lined by stratified squamous epithelium. The nasopharynx lies behind the nasal cavity and like the nasal passages is lined with ciliated columnar pseudostratified epithelium.

Like the oropharynx above it the hypopharynx (laryngopharynx) serves as a passageway for food and air and is lined with a stratified squamous epithelium. It lies inferior to the upright epiglottis and extends to the larynx, where the respiratory and digestive pathways diverge. At that point, the laryngopharynx is continuous with the esophagus. During swallowing, food has the "right of way", and air passage temporarily stops.

Esophagus

The esophagus is a narrow muscular tube about 20-30 centimeters long which starts at pharynx at the back of the mouth, passes through the thoracic diaphragm, and ends at the cardiac orifice of the stomach. The wall of the esophagus is made up of two layers of smooth muscles, which form a continuous layer from the esophagus to the open and contract slowly, over long periods of time. The inner layer of muscles is arranged circularly in a series of descending rings, while the outer layer is arranged longitudinally. At the top of the esophagus, is a flap of tissue called the epiglottis that closes during swallowing to prevent food from entering the trachea (windpipe). The chewed food is pushed down the esophagus to the stomach through peristaltic contraction of these muscles. It takes only about seven seconds for food to pass through the esophagus and now digestion takes place.

Stomach

The stomach is a small, 'J'-shaped pouch with walls made of thick, elastic muscles, which stores and helps break down food. Food which has been reduced to very small particles is more likely to be fully digested in the small intestine, and stomach churning has the effect of assisting the physical disassembly begun in the mouth. Ruminants, who are able to digest fibrous material (primarily cellulose), use fore-stomachs and repeated chewing to further the disassembly. Rabbits and some other animals pass some material through their entire digestive systems twice. Most birds ingest small stones to assist in mechanical processing in gizzards.

Food enters the stomach through the cardiac orifice where it is further broken apart and thoroughly mixed with gastric acid, pepsin and other digestive enzymes to break down proteins. The enzymes in the stomach also have an optimum, meaning that they work at a specific pH and temperature better than any others. The acid itself does not break down food molecules, rather it provides an optimum pH for the reaction of the enzyme pepsin and kills many microorganisms that are ingested with the food. It can also denature proteins. This is the process of reducing polypeptide bonds and disrupting salt bridges which in turn causes a loss of secondary, tertiary or quaternary protein structure. The parietal cells of the stomach also secrete a glycoprotein called intrinsic factor which enables the absorption of vitamin B-12. Other small molecules such as alcohol are absorbed in the stomach, passing through the membrane of the stomach and entering the circulatory system directly. Food in the stomach is in semi-liquid form, which upon completion is known as chyme.

After consumption of food, digestive "tonic" and peristaltic contractions begin which help to break down the food and move it through. When the chyme reaches the opening to the duodenum known as the pylorus, contractions "squirt" the food back into the stomach through a process called retropulsion, which exerts additional force and further grinds down food into smaller particles. Gastric emptying is the release of food from the stomach into the duodenum; the process is tightly controlled liquids are emptied much more quickly than solids. Gastric emptying has attracted medical interest as rapid gastric emptying is related to obesity and delayed gastric emptying syndrome is associated with diabetes mellitus, aging, and gastroesophageal reflux.

The transverse section of the alimentary canal reveals four distinct and well developed layers within the stomach:

- Serous membrane, a thin layer of mesothelial cells that is the outermost wall of the stomach.
- Muscular coat, a well-developed layer of muscles used to mix ingested food, composed of three sets running in three different alignments. The outermost layer runs parallel to the vertical axis of the stomach (from top to bottom), the middle is concentric to the axis (horizontally circling the stomach cavity) and the innermost oblique layer, which is responsible for mixing and breaking down ingested food,

runs diagonal to the longitudinal axis. The inner layer is unique to the stomach, all other parts of the digestive tract have only the first two layers.
- Submucosa, composed of connective tissue that links the inner muscular layer to the mucosa and contains the nerves, blood and lymph vessels.
- Mucosa is the extensively folded innermost layer. It can be divided into the epithelium, lamina propria, and the muscularis mucosae, though some consider the outermost *muscularis mucosae* to be a distinct layer, as it develops from the mesoderm rather than the endoderm (thus making a total of five layers). The epithelium and lamina are filled with connective tissue and covered in gastric glands that may be simple or branched tubular, and secrete mucus, hydrochloric acid, pepsinogen and rennin. The mucus lubricates the food and also prevents hydrochloric acid from acting on the walls of the stomach.

Small intestine

After being processed in the stomach, food is passed to the small intestine via the pyloric sphincter. The majority of digestion and absorption occurs here after the milky chyme enters the duodenum. Here it is further mixed with three different liquids:

- Bile, which emulsifies fats to allow absorption, neutralizes the chyme and is used to excrete waste products such as bilin and bile acids. Bile is produced by the liver and then stored in the gallbladder. The bile in the gallbladder is much more concentrated.
- Pancreatic juice made by the pancreas.
- Intestinal enzymes of the alkaline mucosal membranes. The enzymes include maltase, lactase and sucrase (all three of which process only sugars), trypsin and chymotrypsin.

As the pH level changes in the small intestines and gradually becomes basic, more enzymes are activated further that chemically break down various nutrients into smaller molecules to allow absorption into the circulatory or lymphatic systems. Small, finger-like structures called villi, each of which is covered with even smaller hair-like structures called microvilli improve the absorption of nutrients by increasing the surface area of the intestine and enhancing speed at which nutrients are absorbed. Blood containing the absorbed nutrients is carried away from the small intestine via the hepatic portal vein and goes to the liver for filtering, removal of toxins, and nutrient processing.

The small intestine and remainder of the digestive tract undergoes peristalsis to transport food from the stomach to the rectum and allow food to be mixed with the digestive juices and absorbed. The circular muscles and longitudinal muscles are antagonistic muscles, with one contracting as the other relaxes. When the circular muscles contract, the lumen becomes narrower and longer and the food is squeezed and pushed forward. When the longitudinal muscles contract, the circular muscles relax and the gut dilates to become wider and shorter to allow food to enter.

Large intestine

After the food has been passed through the small intestine, the food enters the large intestine. Within it, digestion is retained long enough to allow fermentation due to the action of gut bacteria, which breaks down some of the substances which remain after processing in the small intestine; some of the breakdown products are absorbed. In humans, these include most complex saccharides (at most three disaccharides are digestible in humans). In addition, in many vertebrates, the large intestine reabsorbs fluid; in a few, with desert lifestyles, this reabsorbtion makes continued existence possible.

In humans, the large intestine is roughly 1.5 meters long, with three parts: the cecum at the junction with the small intestine, the colon, and the rectum. The colon itself has four parts: the ascending colon, the transverse colon, the descending colon, and the sigmoid colon. The large intestine absorbs water from the bolus and stores feces until it can be egested. Food products that cannot go through the villi, such as cellulose (dietary fiber), are mixed with other waste products from the body and become hard and concentrated feces. The feces is stored in the rectum for a certain period and then the stored feces is eliminated from the body due to the contraction and relaxation through the anus. The exit of this waste material is regulated by the anal sphincter.

Fat digestion

The presence of fat in the small intestine produces hormones which stimulate the release of lipase from the pancreas, largely to the liver for further processing, or to fat tissue for storage.

Digestive hormones
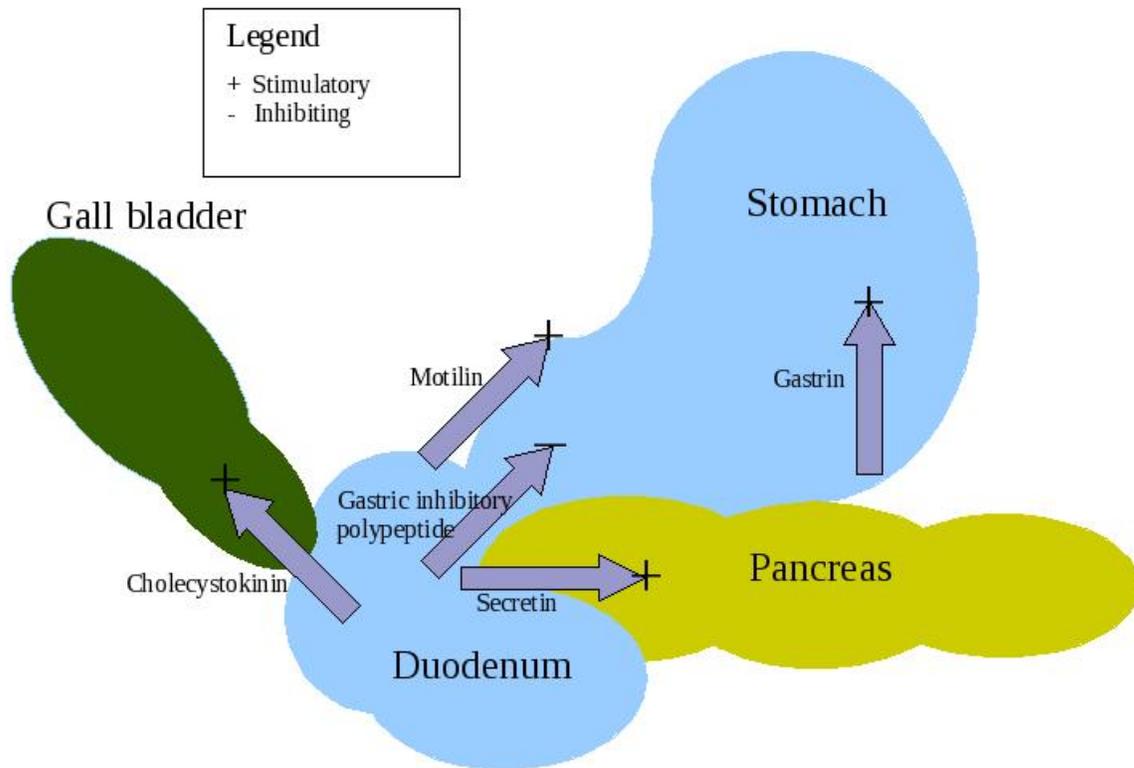
Action of the major digestive hormones

There are at least five hormones that aid and regulate the digestive system in mammals. There are variations across the vertebrates, as for instance in birds. Arrangements are complex and additional details are regularly discovered. For instance, more connections to metabolic control (largely the glucose-insulin system) have been uncovered in recent years.

- Gastrin - is in the stomach and stimulates the gastric glands to secrete pepsinogen(an inactive form of the enzyme pepsin) and hydrochloric acid. Secretion of gastrin is stimulated by food arriving in stomach. The secretion is inhibited by low pH .
- Secretin - is in the duodenum and signals the secretion of sodium bicarbonate in the pancreas and it stimulates the bile secretion in the liver. This hormone responds to the acidity of the chyme.
- Cholecystokinin (CCK) - is in the duodenum and stimulates the release of digestive enzymes in the pancreas and stimulates the emptying of bile in the gall bladder. This hormone is secreted in response to fat in chyme.
- Gastric inhibitory peptide (GIP) - is in the duodenum and decreases the stomach churning in turn slowing the emptying in the stomach. Another function is to induce insulin secretion.

- Motilin - is in the duodenum and increases the migrating myoelectric complex component of gastrointestinal motility and stimulates the production of pepsin.

Significance of pH in digestion

Digestion is a complex process which is controlled by several factors. pH plays a crucial role in a normally functioning digestive tract. In the mouth, pharynx, and esophagus, pH is typically about 6.8, very weakly acidic. Saliva controls pH in this region of the digestive tract. Salivary amylase is contained in saliva and starts the breakdown of carbohydrates into monosaccharides. Most digestive enzymes are sensitive to pH and will not function in a low-pH environment like the stomach. A pH below 7 indicates an acid, while a pH above 7 indicates a base; the concentration of the acid or base, however, does also play a role.

The pH of the stomach is very low (highly acidic) which inhibits the breakdown of carbohydrates while there. The strong acid content of the stomach provides two benefits; it serves to denature proteins for further digestion in the small intestines, and provides non-specific immunity, retarding or eliminating various pathogens.

In the small intestines, the duodenum provides critical pH balancing to activate digestive enzymes. The liver secretes bile into the duodenum to neutralise the acidic conditions from the stomach. Also the pancreatic duct empties into the duodenum, adding bicarbonate to neutralize the acidic chyme, thus creating a neutral environment. The mucosal tissue of the small intestines is alkaline with a pH of about 8.5.

Uses of animal gut by humans

- The stomachs of calves have commonly been used as a source of rennet for making cheese.
- The use of animal gut strings by musicians can be traced back to the third dynasty of Egypt. In the recent past, strings were made out of lamb gut. With the advent of the modern era, musicians have tended to use strings made of silk, or synthetic materials such as nylon or steel. Some instrumentalists, however, still use gut strings in order to evoke the older tone quality. Although such strings were commonly referred to as "catgut" strings, cats were never used as a source for gut strings .
- Sheep gut was the original source for natural gut string used in racquets, such as for tennis. Today, synthetic strings are much more common, but the best gut strings are now made out of cow gut.
- Gut cord has also been used to produce strings for the snares which provide the snare drum's characteristic buzzing timbre. While the snare drum currently almost always uses metal wire rather than gut cord, the North African bendir frame drum still uses gut for this purpose.

- "Natural" sausage hulls (or casings) are made of animal gut, especially hog, beef, and lamb. Similarly, Haggis is traditionally boiled in, and served in, a sheep stomach.
- Chitterlings, a kind of food, consist of thoroughly washed pig's gut.
- Animal gut was used to make the cord lines in longcase clocks and for fusee movements in bracket clocks, but may be replaced by metal wire.
- The oldest known condoms, from 1640 AD, were made from animal intestine.

Chapter 2

Human Gastrointestinal Tract
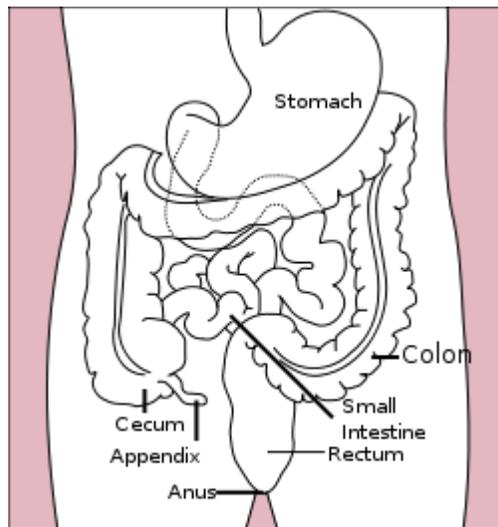
Stomach colon rectum diagram

The **human gastrointestinal tract** refers to the stomach and intestine, and sometimes to all the structures from the mouth to the anus. (The "digestive system" is a broader term that includes other structures, including the accessory organs of digestion).

In an adult male human, the gastrointestinal (GI) tract is 5 metres (20 ft) long in a live subject, or up to 9 metres (30 ft) without the effect of muscle tone, and consists of the upper and lower GI tracts. The tract may also be divided into foregut, midgut, and hindgut, reflecting the embryological origin of each segment of the tract.

The GI tract releases hormones as to help regulate the digestion process. These hormones, including gastrin, secretin, cholecystokinin, and grehlin, are mediated through either intracrine or autocrine mechanisms, indicating that the cells releasing these hormones are conserved structures throughout evolution.

Upper gastrointestinal tract

The upper gastrointestinal tract consists of the esophagus, stomach, and duodenum.

Some sources also include the mouth cavity and pharynx.

The exact demarcation between "upper" and "lower" can vary. Upon gross dissection, the duodenum may appear to be a unified organ, but it is often divided into two parts based upon function, arterial supply, or embryology.

Lower gastrointestinal tract

The lower gastrointestinal tract includes most of the small intestine and all of the large intestine. According to some sources, it also includes the anus.

- Bowel or intestine
  - Small intestine, which has three parts:
    - Duodenum - Here the digestive juices from pancreas (digestive enzymes) and liver (bile) mix together. The digestive enzymes break down proteins and bile emulsifies fats into micelles. Duodenum contains Brunner's glands which produce bicarbonate and pancreatic juice contains bicarbonate to neurtralize hydrochloric acid of stomach
    - Jejunum - It is the midsection of the intestine, connecting duodenum to ileum. Contain plicae circulares, and villi to increase surface area.
    - Ileum - It has villi in where all soluble molecules are absorbed into the blood (capillaries and lacteals).
  - Large intestine, which has three parts:
    - Cecum (the vermiform appendix is attached to the cecum).
    - Colon (ascending colon, transverse colon, descending colon and sigmoid flexure). The main function of colon is to absorb water, but it also contains bacteria that produce beneficial vitamins like Vitamin K.
    - Rectum
  - Anus

The ligament of Treitz is sometimes used to divide the upper and lower GI tracts.

Embryology

The gut is an endoderm-derived structure. At approximately the sixteenth day of human development, the embryo begins to fold ventrally (with the embryo's ventral surface becoming concave) in two directions: the sides of the embryo fold in on each other and the head and tail fold toward one another. The result is that a piece of the yolk sac, an

endoderm-lined structure in contact with the ventral aspect of the embryo, begins to be pinched off to become the primitive gut. The yolk sac remains connected to the gut tube via the vitelline duct. Usually this structure regresses during development; in cases where it does not, it is known as Meckel's diverticulum.

During fetal life, the primitive gut can be divided into three segments: foregut, midgut, and hindgut. Although these terms often are used in reference to segments of the primitive gut, they nevertheless are used regularly to describe components of the definitive gut as well.

Each segment of the gut gives rise to specific gut and gut-related structures in later development. Components derived from the gut proper, including the stomach and colon, develop as swellings or dilatations of the primitive gut. In contrast, gut-related derivatives—that is, those structures that derive from the primitive gut, but are not part of the gut proper—in general develop as outpouchings of the primitive gut. The blood vessels supplying these structures remain constant throughout development.

Part	Part in adult	Gives rise to	Arterial supply
Foregut	the pharynx, to the upper duodenum	pharynx, esophagus, stomach, upper duodenum, respiratory tract (including the lungs), liver, gallbladder, and pancreas	branches of the celiac artery
Midgut	lower duodenum, to the first two-thirds of the transverse colon	lower duodenum, jejunum, ileum, cecum, appendix, ascending colon, and first two-thirds of the transverse colon	branches of the superior mesenteric artery
Hindgut	last third of the transverse colon, to the upper part of the anal canal	last third of the transverse colon, descending colon, rectum, and upper part of the anal canal	branches of the inferior mesenteric artery

Transit time

The time taken for food or other ingested objects to transit through the gastrointestinal tract varies depending on many factors, but roughly, it takes 2.5 to 3 hours after meal for 50% of stomach contents to empty into the intestines and total emptying of the stomach takes 4 to 5 hours. Subsequently, 50% emptying of the small intestine takes 2.5 to 3 hours. Finally, transit through the colon takes 30 to 40 hours.

Pathology

There are a number of diseases and conditions affecting the gastrointestinal system, including:

- Cholera
- Colorectal cancer
- Diverticulitis
- Enteric duplication cyst
- Gastroenteritis, also known as "stomach flu"; an inflammation of the stomach and intestines
- Giardiasis
- Inflammatory bowel disease (including Crohn's disease and ulcerative colitis)
- Irritable bowel syndrome
- Pancreatitis
- Peptic ulcer disease
- Appendicitis
- Celiac Disease

Immune function

The gastrointestinal tract also is a prominent part of the immune system. The surface area of the digestive tract is estimated to be the surface area of a football field. With such a large exposure, the immune system must work hard to prevent pathogens from entering into blood and lymph.

The low pH (ranging from 1 to 4) of the stomach is fatal for many microorganisms that enter it. Similarly, mucus (containing IgA antibodies) neutralizes many of these microorganisms. Other factors in the GI tract help with immune function as well, including enzymes in saliva and bile. Enzymes such as Cyp3A4, along with the antiporter activities, also are instrumental in the intestine's role of detoxification of antigens and xenobiotics, such as drugs, involved in first pass metabolism.

Health-enhancing intestinal bacteria serve to prevent the overgrowth of potentially harmful bacteria in the gut. These two types of bacteria compete for space and "food," as there are limited resources within the intestinal tract. A ratio of 80-85% beneficial to 15-20% potentially harmful bacteria generally is considered normal within the intestines. Microorganisms also are kept at bay by an extensive immune system comprising the gut-associated lymphoid tissue (GALT).

Histology
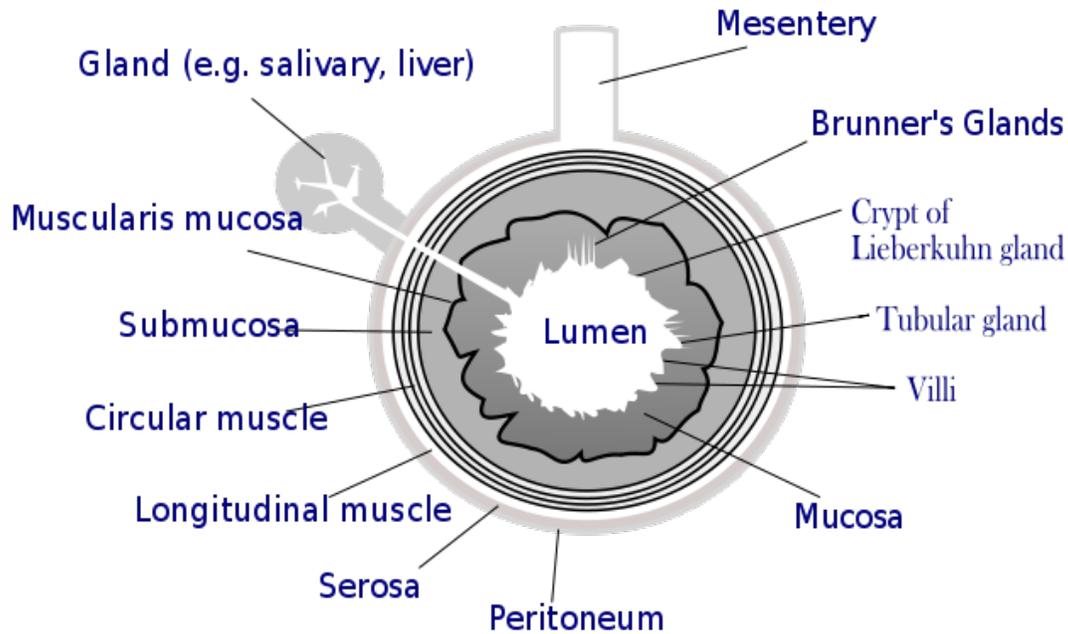
General structure of the gut wall

The gastrointestinal tract has a form of general histology with some differences that reflect the specialization in functional anatomy. The GI tract can be divided into four concentric layers:

- Mucosa
- Submucosa
- *Muscularis externa* (the external muscle layer)
- Adventitia or serosa

Mucosa

The mucosa is the innermost layer of the gastrointestinal tract that is surrounding the lumen, or space within the tube. This layer comes in direct contact with food (or bolus), and is responsible for absorption and secretion, important processes in digestion.

The mucosa can be divided into:

- Epithelium
- *Lamina propria*

- *Muscularis mucosae*

The mucosae are highly specialized in each organ of the gastrointestinal tract, facing a low pH in the stomach, absorbing a multitude of different substances in the small intestine, and also absorbing specific quantities of water in the large intestine. Reflecting the varying needs of these organs, the structure of the mucosa can consist of invaginations of secretory glands (e.g., gastric pits), or it can be folded in order to increase surface area.

Submucosa

The submucosa consists of a dense irregular layer of connective tissue with large blood vessels, lymphatics, and nerves branching into the mucosa and muscularis externa. It contains Meissner's plexus, an enteric nervous plexus, situated on the inner surface of the *muscularis externa*.

Muscularis externa

The *muscularis externa* consists of an inner circular layer and a longitudinal outer muscular layer. The circular muscle layer prevents food from traveling backward and the longitudinal layer shortens the tract. The coordinated contractions of these layers is called peristalsis and propels the bolus, or balled-up food, through the GI tract.

Between the two muscle layers are the myenteric or Auerbach's plexus.
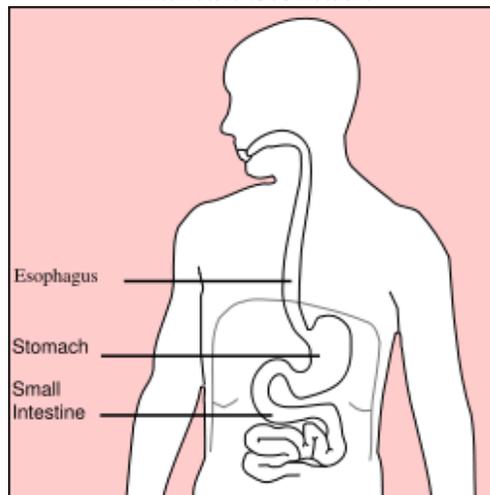
Adventitia

The adventitia consists of several layers of epithelia.

When the adventitia is facing the mesentery or peritoneal fold, the adventitia is covered by a mesothelium supported by a thin connective tissue layer, together forming a serosa, or serous membrane.
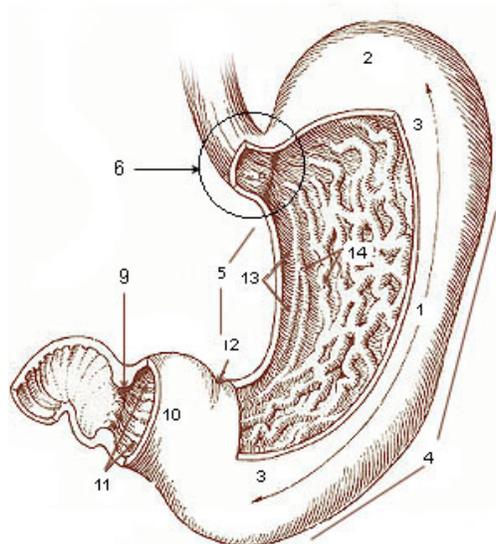
Chapter 3

Stomach

Human Stomach

The location of the stomach in the human body

In some animals, including vertebrates, echinoderms, insects (mid-gut) and molluscs, the **stomach** is a muscular, hollow, dilated part of the alimentary canal which functions as an important organ of the digestive tract. It is involved in the second phase of digestion, following mastication (chewing). The stomach is located between the oesophagus and the small intestine. It secretes protein-digesting enzymes and strong acids to aid in food digestion, (sent to it via oesophageal peristalsis) through smooth muscular contortions (called segmentation) before sending partially-digested food (chyme) to the small intestines.

The word *stomach* is derived from the Latin *stomachus* which is derived from the Greek word *stomachos*, ultimately from *stoma* (στόμα), "mouth". The words *gastro-* and *gastric* (meaning related to the stomach) are both derived from the Greek word *gaster* (γαστήρ).

Role in Digestion

Bolus (masticated food) enters the stomach through the esophagus via the esophageal sphincter. The stomach releases proteases (protein-digesting enzymes such as pepsin) and hydrochloric acid, which kills or inhibits bacteria and provides the acidic pH for the proteases to work. Food is churned by the stomach through muscular contractions of the wall - reducing the volume of the fundus, before looping around the fundus and the body of stomach as the boluses are converted into chyme (partially-digested food). Chyme slowly passes through the pyloric sphincter and into the duodenum, where the extraction of nutrients begins. Depending on the quantity and contents of the meal, the stomach will digest the food into chyme anywhere between 40 minutes and a few hours.

Anatomy of the Stomach

The stomach lies between the oesophagus and the duodenum (the first part of the small intestine). It is on the left upper part of the abdominal cavity. The top of the stomach lies against the diaphragm. Lying behind the stomach is the pancreas. The greater omentum hangs down from the *greater curvature*.

Two sphincters, keep the contents of the stomach contained. They are the oesophageal sphincter (found in the cardiac region, not an anatomical sphincter) dividing the tract above, and the Pyloric sphincter dividing the stomach from the small intestine.

The stomach is surrounded by parasympathetic (stimulant) and orthosympathetic (inhibitor) plexuses (networks of blood vessels and nerves in the anterior gastric, posterior, superior and inferior, celiac and myenteric), which regulate both the secretions activity and the motor (motion) activity of its muscles.

In humans, the stomach has a relaxed, near empty volume of about 45 ml. It is a distensible organ. It normally expands to hold about 1 litre of food, but will hold as much as 2-3 litres (whereas a newborn baby will only be able to retain 30ml).

Sections

The stomach is divided into 4 sections, each of which has different cells and functions. The sections are:

Cardia	Where the contents of the oesophagus empty into the stomach.
Fundus	Formed by the upper curvature of the organ.
Body or Corpus	The main, central region.
Pylorus	The lower section of the organ that facilitates emptying the contents into the small intestine.
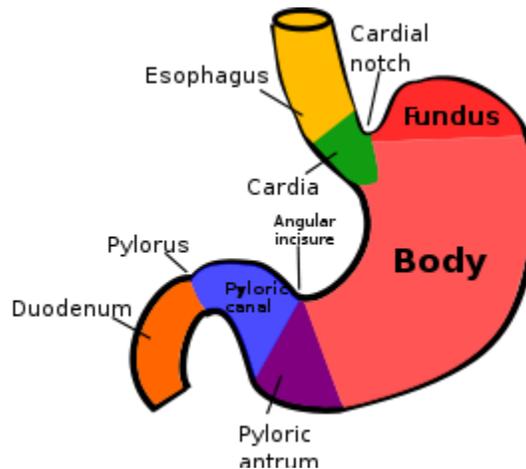
Sections of the stomach

Blood supply
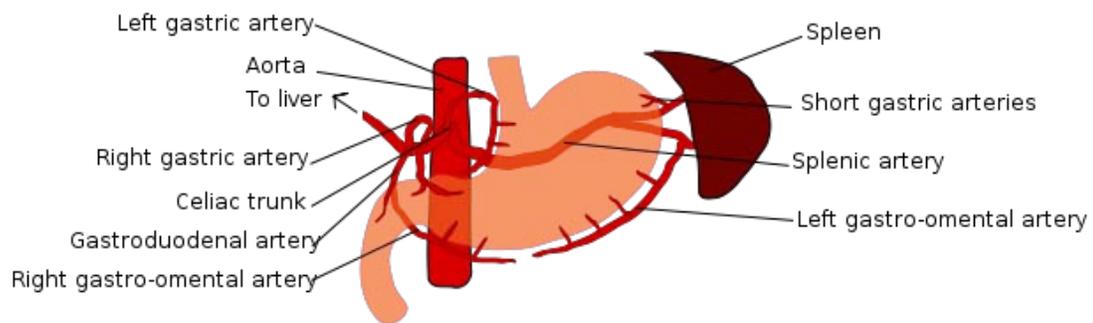
Schematic image of the blood supply to the stomach: left and right gastric artery, left and right gastro-omental artery and short gastric artery.
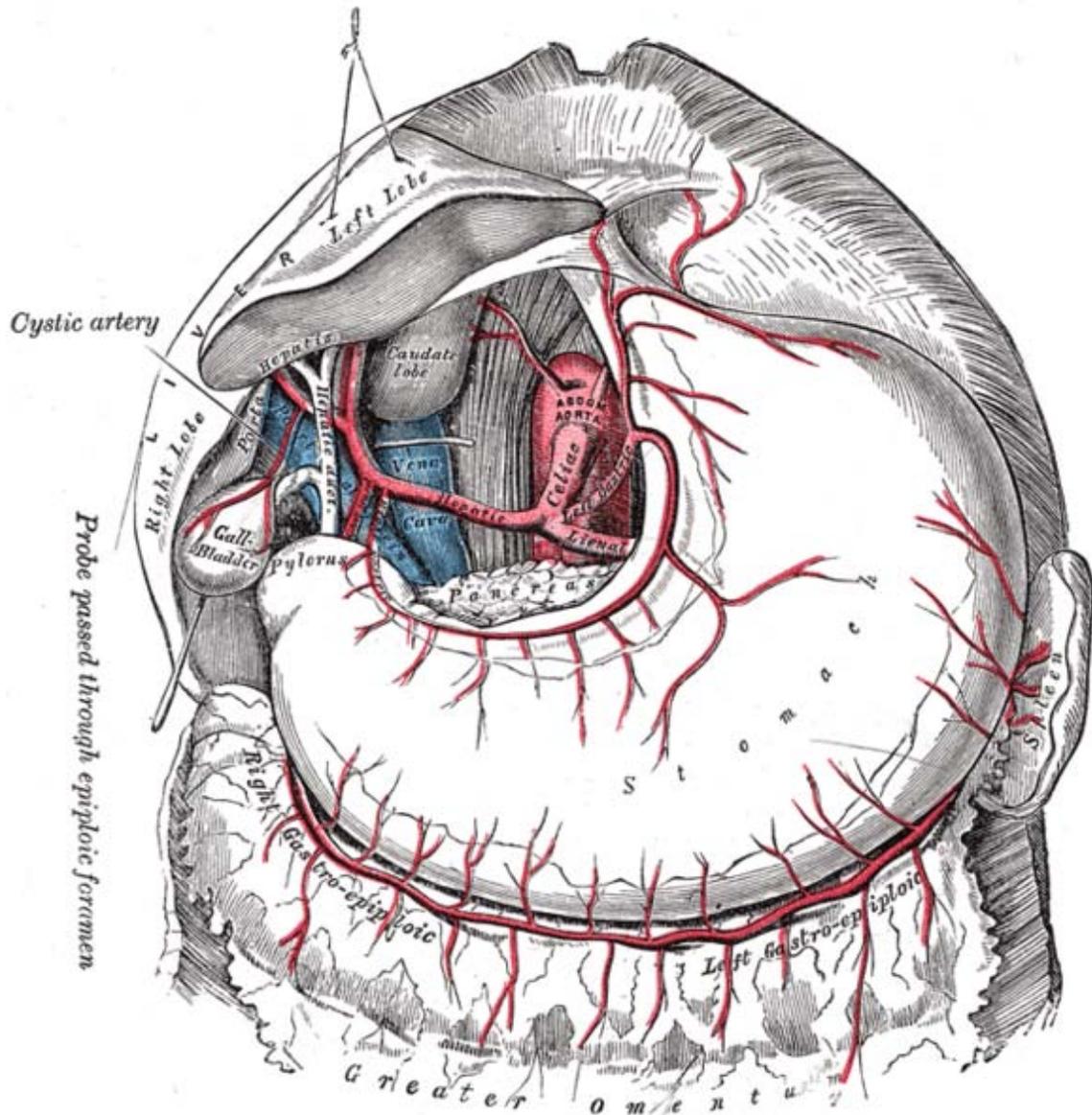
A more realistic image, showing the celiac artery and its branches; the liver has been raised, and the lesser omentum and anterior layer of the greater omentum removed.

The lesser curvature of the stomach is supplied by the right gastric artery inferiorly, and the left gastric artery superiorly, which also supplies the cardiac region. The greater curvature is supplied by the right gastroepiploic artery inferiorly and the left gastroepiploic artery superiorly. The fundus of the stomach, and also the upper portion of the greater curvature, are supplied by the short gastric artery.

Like the other parts of the gastrointestinal tract, the stomach walls are made of the following layers, from inside to outside:

mucosa   The first main layer. This consists of an epithelium, the lamina propria

	composed of loose connective tissue and which has gastric glands in it underneath, and a thin layer of smooth muscle called the muscularis mucosae.
submucosa	This layer lies over the mucosa and consists of fibrous connective tissue, separating the mucosa from the next layer. The Meissner's plexus is in this layer.
	Over the submucosa, the muscularis externa in the stomach differs from that of other GI organs in that it has three layers of smooth muscle instead of two.
muscularis externa	• *inner oblique layer:* This layer is responsible for creating the motion that churns and physically breaks down the food. It is the only layer of the three which is not seen in other parts of the digestive system. The antrum has thicker skin cells in its walls and performs more forceful contractions than the fundus. • *middle circular layer:* At this layer, the pylorus is surrounded by a thick circular muscular wall which is normally tonically constricted forming a functional (if not anatomically discrete) pyloric sphincter, which controls the movement of chyme into the duodenum. This layer is concentric to the longitudinal axis of the stomach. • *outer longitudinal layer:* Auerbach's plexus is found between this layer and the middle circular layer.
serosa	This layer is over the muscularis externa, consisting of layers of connective tissue continuous with the peritoneum.
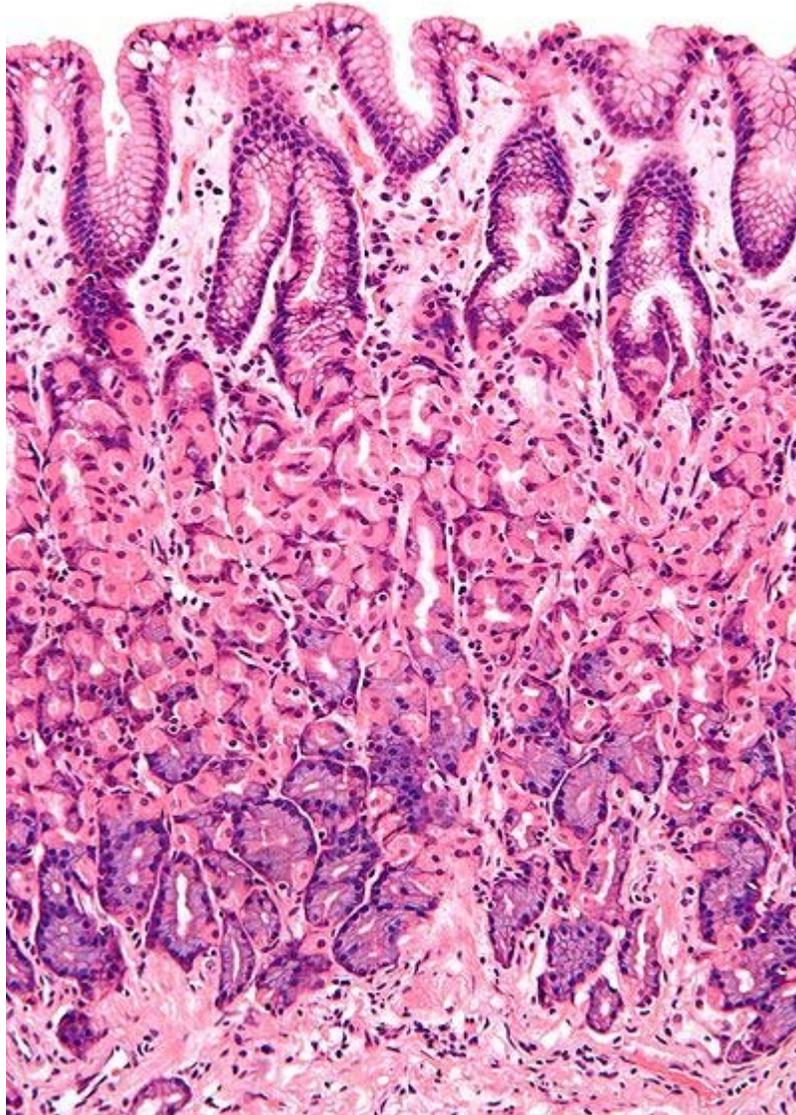
Micrograph showing a cross section of the stomach wall, in the body portion of the stomach. H&E stain.
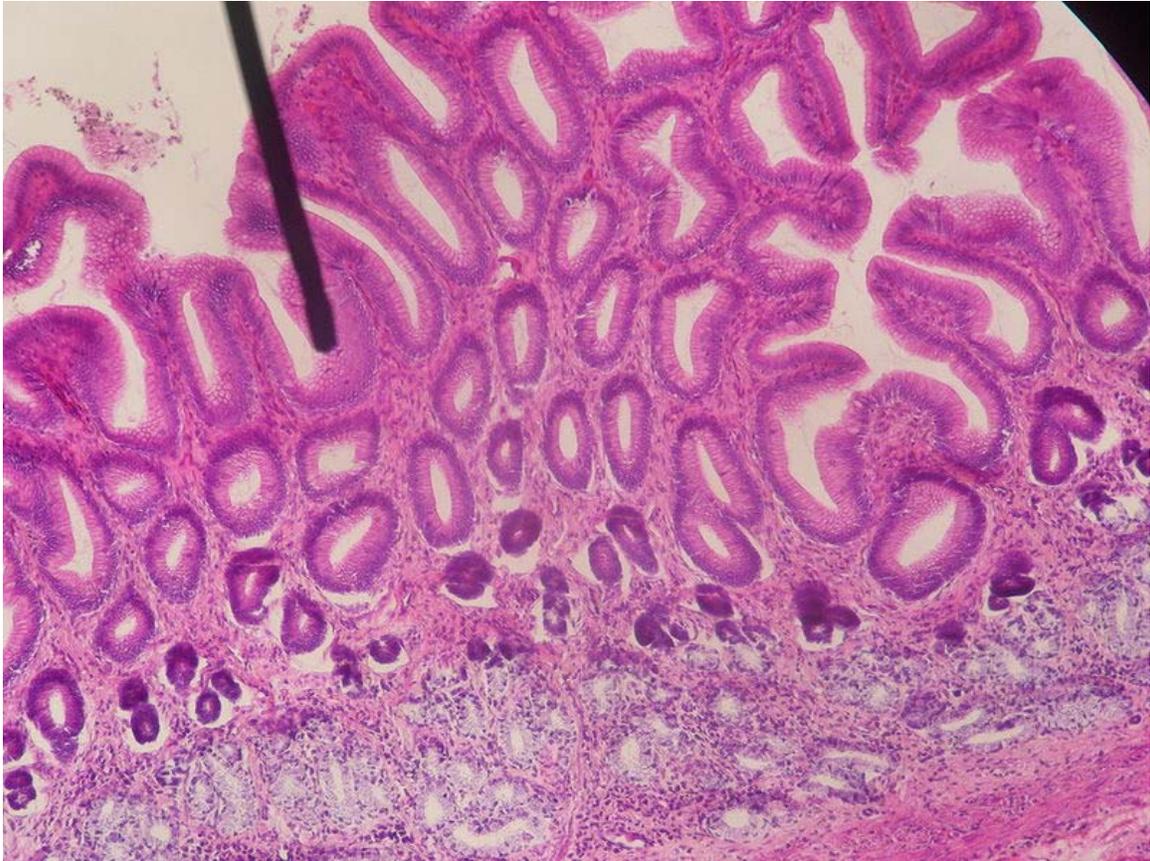
Microscopic cross section of the pyloric part of the stomach wall

Glands

The epithelium of the stomach forms deep pits. The glands at these locations are named for the corresponding part of the stomach:

Cardiac glands Pyloric glands Fundic glands
(at cardia)   (at pylorus)   (at fundus)
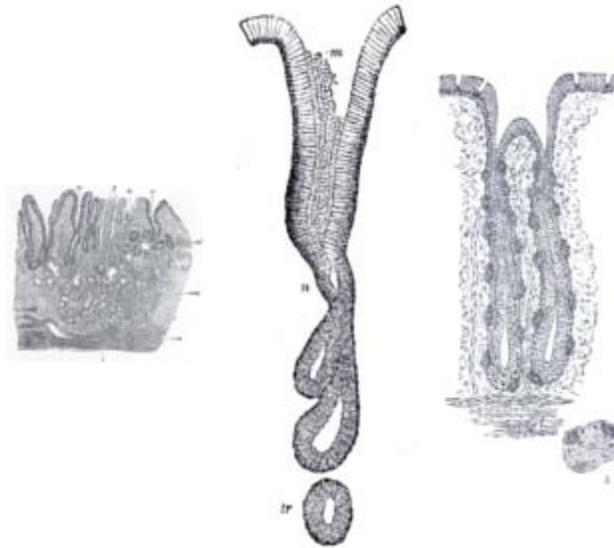
Different types of cells are found at the different layers of these glands:

Layer of stomach	Name	Secretion	Region of stomach	Staining
Isthmus of gland	Mucous neck cells	mucus gel layer	Fundic, cardiac, pyloric	Clear
Body of gland	parietal (oxyntic) cells	gastric acid and intrinsic factor	Fundic, cardiac, pyloric	Acidophilic
Base of gland	chief (zymogenic) cells	pepsinogen	Fundic only	Basophilic
Base of gland	enteroendocrine (APUD) cells	hormones gastrin, histamine, endorphins, serotonin, cholecystokinin and somatostatin	Fundic, cardiac, pyloric	-

Control of secretion and motility

The movement and the flow of chemicals into the stomach are controlled by both the autonomic nervous system and by the various digestive system hormones:

Gastrin	The hormone *gastrin* causes an increase in the secretion of HCl from the parietal cells, and pepsinogen from chief cells in the stomach. It also causes increased motility in the stomach. Gastrin

	is released by G-cells in the stomach in response to distenstion of the antrum, and digestive products(especially large quantities of incompletely digested proteins). It is inhibited by a pH normally less than 4 (high acid), as well as the hormone somatostatin.
Cholecystokinin	*Cholecystokinin* (CCK) has most effect on the gall bladder, causing gall bladder contractions, but it also decreases gastric emptying and increases release of pancreatic juice which is alkaline and neutralizes the chyme.
Secretin	In a different and rare manner, *secretin*, produced in the small intestine, has most effects on the pancreas, but will also diminish acid secretion in the stomach.
Gastric inhibitory peptide	*Gastric inhibitory peptide* (GIP) decreases both gastric acid release and motility.
Enteroglucagon	*enteroglucagon* decreases both gastric acid and motility.

Other than gastrin, these hormones all act to turn off the stomach action. This is in response to food products in the liver and gall bladder, which have not yet been absorbed. The stomach needs only to push food into the small intestine when the intestine is not busy. While the intestine is full and still digesting food, the stomach acts as storage for food.

EGF in gastric defense

Epidermal growth factor or EGF results in cellular proliferation, differentiation, and survival. EGF is a low-molecular-weight polypeptide first purified from the mouse submandibular gland, but since then found in many human tissues including submandibular gland, parotid gland. Salivary EGF, which seems also regulated by dietary inorganic iodine, plays also an important physiological role in the maintenance of oro-oesophageal and gastric tissue integrity. The biological effects of salivary EGF include healing of oral and gastroesophageal ulcers, inhibition of gastric acid secretion, stimulation of DNA synthesis as well as mucosal protection from intraluminal injurious factors such as gastric acid, bile acids, pepsin, and trypsin and to physical, chemical and bacterial agents.

Stomach as nutrition sensor

The stomach can "taste" sodium glutamate using glutamate receptors and this information is passed to the lateral hypothalamus and limbic system in the brain as a palatability signal through the vagus nerve. The stomach can also sense independently to tongue and oral taste receptors glucose, carbohydrates proteins, and fats. This allows the brain to link nutritional value of foods to their tastes.

Diseases of the stomach

Historically, it was widely believed that the highly acidic environment of the stomach would keep the stomach immune from infection. However, a large number of studies have indicated that most cases of peptic ulcers, gastritis, and stomach cancer are caused by *Helicobacter pylori* infection.

In other animals
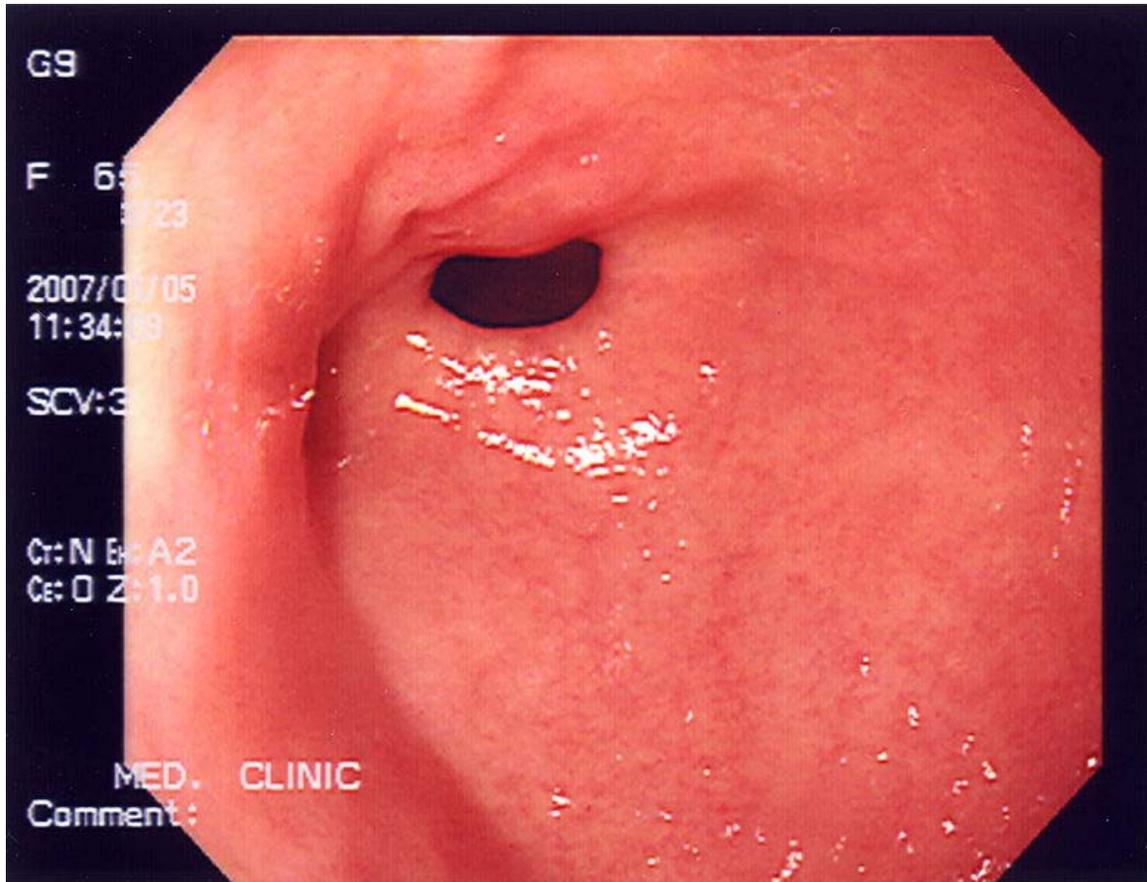
An endoscopy of a normal stomach of a healthy 65-year old woman

Although the precise shape and size of the stomach varies widely between different vertebrates, the relative positions of the oesophageal and duodenal openings remain relatively constant. As a result, the organ always curves somewhat to the left before curving back to meet the pyloric sphincter. However, lampreys, hagfishes, chimaeras, lungfishes, and some teleost fish have no stomach at all, with the oesophagus opening directly into the intestine. These animals all consume diets that either require little storage of food, or no pre-digestion with gastric juices, or both.

The gastric lining is usually divided into two regions, an anterior portion lined by fundic glands, and a posterior with pyloric glands. Cardiac glands are unique to mammals, and even then are absent in a number of species. The distributions of these glands vary between species, and do not always correspond with the same regions as in man. Furthermore, in many non-human mammals, a portion of the stomach anterior to the cardiac glands is lined with epithelium essentially identical to that of the oesophagus. Ruminants, in particular, have a complex stomach, the first three chambers of which are all lined with oesophageal mucosa.

In birds and crocodilians, the stomach is divided into two regions. Anteriorly is a narrow tubular region, the proventriculus, lined by fundic glands, and connecting the true stomach to the crop. Beyond lies the powerful muscular gizzard, lined by pyloric glands, and, in some species, containing stones that the animal swallows to help grind up food.
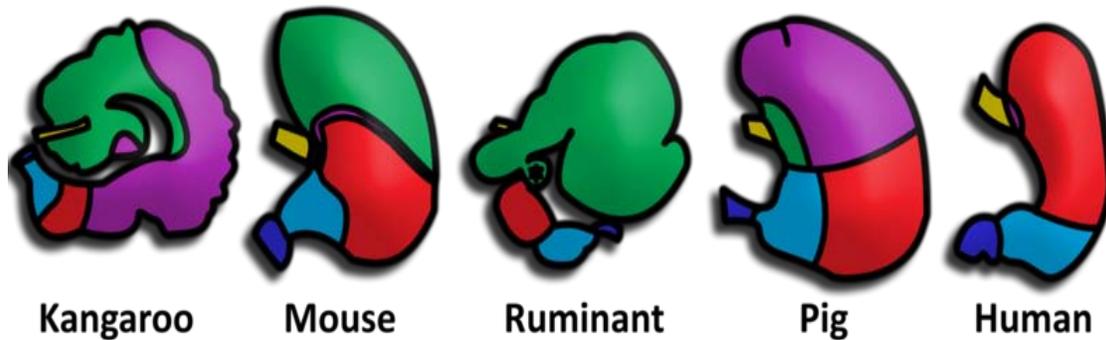
Comparison of stomach glandular regions from several mammalian species. Yellow: oesophagus; green: aglandular epithelium; purple: cardiac glands; red: gastric glands; blue: pyloric glands; dark blue: duodenum. Frequency of glands may vary more smoothly between regions than is diagrammed here. Asterisk (ruminant) represents the omasum, which is absent in Tylopoda (Tylopoda also has some cardiac glands opening onto ventral reticulum and rumen) Many other variations exist among the mammals.

Chapter 4

Human Pharynx

pharynx
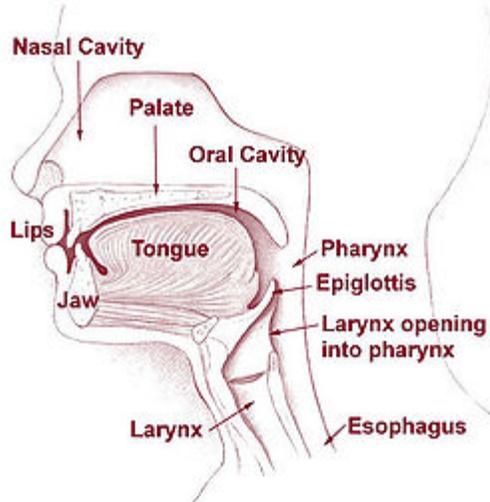
Head and neck.
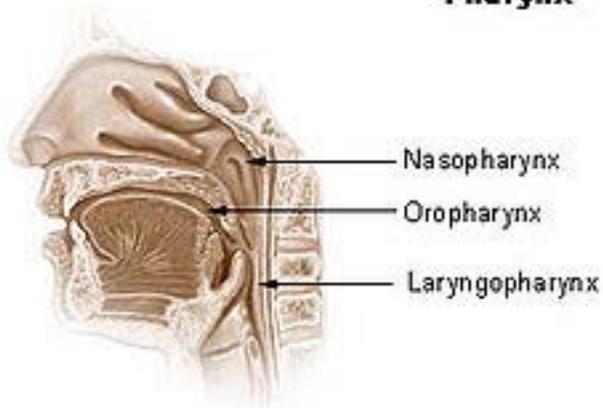
Pharynx

Artery	pharyngeal branches of ascending pharyngeal artery, ascending palatine, descending palatine, pharyngeal branches of inferior thyroid
Vein	pharyngeal veins

| **Nerve** | pharyngeal plexus |

MeSH *Pharynx*

The **human pharynx** (plural: *pharynges*) is the part of the throat situated immediately posterior to (behind) the mouth and nasal cavity, and cranial, or superior, to the esophagus, larynx, and trachea. The human pharynx is conventionally divided into three distinct anatomic sections: the nasopharynx, the oropharynx, and the hypopharynx. The pharynx is part of the digestive system and also the respiratory system; it is also important in vocalization.

Nasopharynx

The nasopharynx is the most important part in digestive and the respiratory system. The nasopharynx is the most cephalad portion of the pharynx. It extends from the base of the skull to the upper surface of the soft palate. It includes the space between the internal nares and the soft palate and lies superior to the oral cavity. The pharyngeal tonsils, more commonly referred to as the *adenoids*, are lymphoid tissue structures located in the posterior wall of the nasopharynx.

Polyps or mucus can obstruct the nasopharynx, as can congestion due to an upper respiratory infection. The Eustachian tubes, which connect the middle ear to the pharynx, open into the nasopharynx. The opening and closing of the Eustachian tubes serves to equalize the barometric pressure in the middle ear with that of the ambient atmosphere.

The anterior aspect of the nasopharynx communicates through the choanae with the nasal cavities. On its lateral walls are the pharyngeal ostia of the auditory tube, somewhat triangular in shape, and bounded behind by a firm prominence, the torus tubarius or cushion, caused by the medial end of the cartilage of the tube which elevates the mucous membrane. Two folds arise from the cartilaginous opening:

- the salpingopharyngeal fold, a vertical fold of mucous membrane extending from the inferior part of the torus and containing the salpingopharyngeus muscle.
- the salpingopalatine fold, a smaller fold extending from the superior part of the torus to the palate and containing the levator veli palatini muscle. The tensor veli palatini is lateral to the levator and does not contribute the fold, since the origin is deep to the cartilaginous opening.
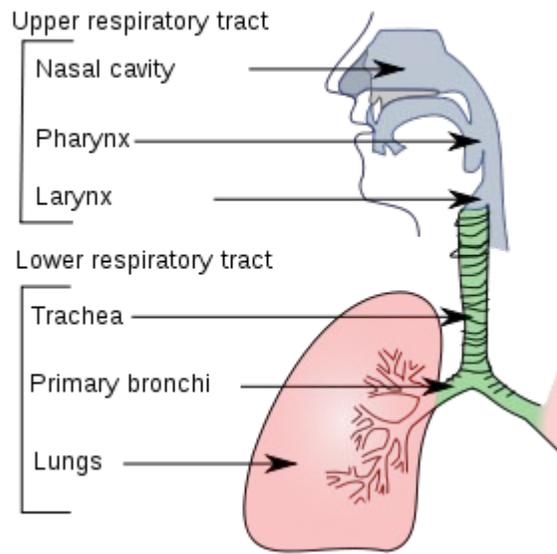
Conducting passages

Organs of the digestive system

Nose and Nasal Cavities

Frontal sinus

Middle nasal concha

Inferior nasal choncha

External naris

Nasal concha

Sphenoid sinus

Internal naris

Nasopharynx
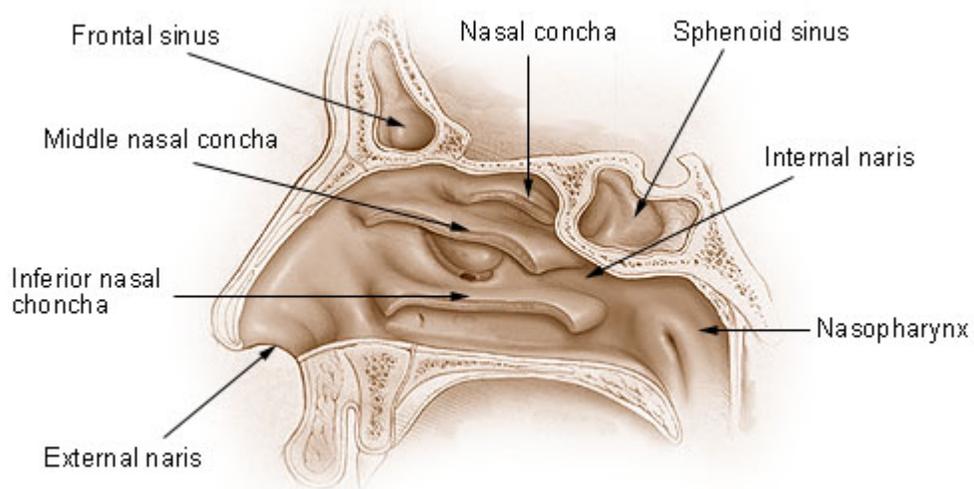
Nose and nasal cavities

Behind the ostium of the auditory tube is a deep recess, the pharyngeal recess (also referred to as the *fossa of Rosenmüller*). On the posterior wall is a prominence, best marked in childhood, produced by a mass of lymphoid tissue, which is known as the pharyngeal tonsil. Superior to the pharyngeal tonsil, in the midline, an irregular flask-shaped depression of the mucous membrane sometimes extends up as far as the basilar process of the occipital bone; it is known as the *pharyngeal bursa*.
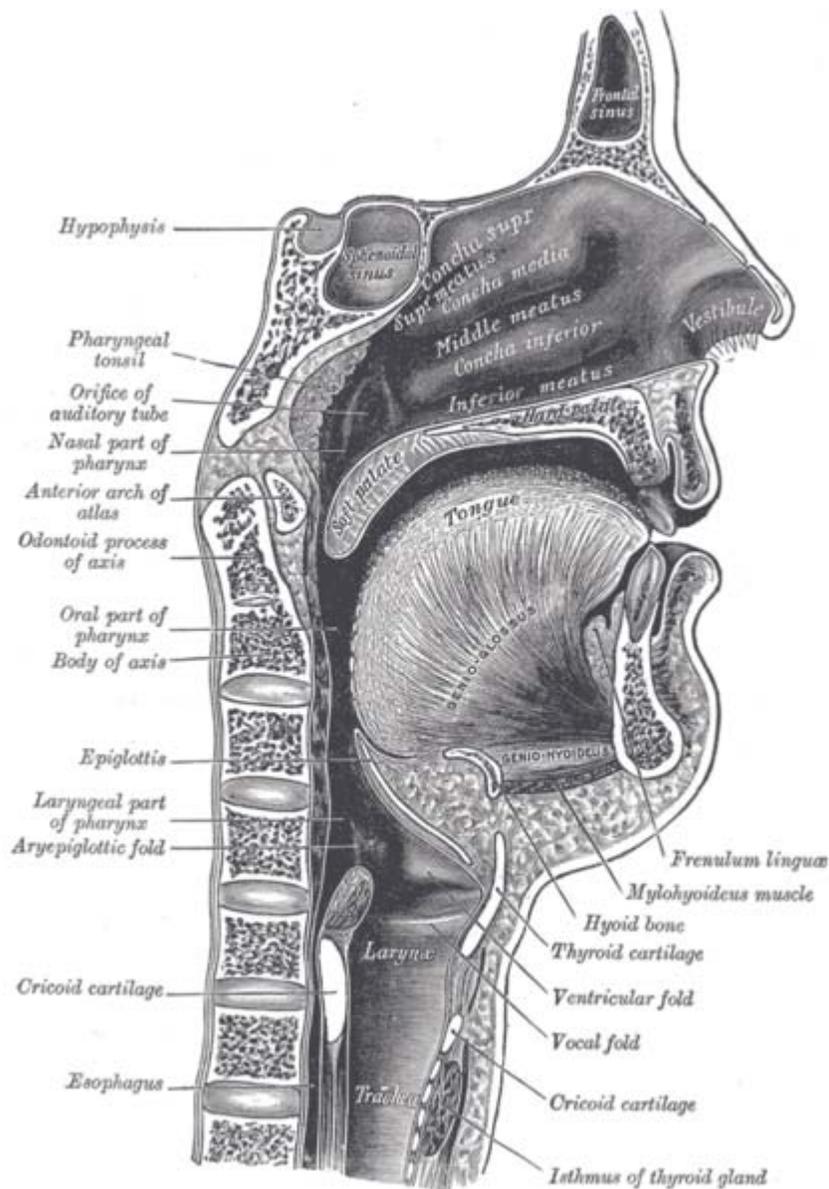
The **nasopharynx**, **oropharynx**, and **laryngopharynx**can be seen clearly in this sagittal section of the head and neck.

Oropharynx

The oropharynx lies behind the oral cavity, extending from the uvula to the level of the hyoid bone. It opens anteriorly, through the isthmus faucium, into the mouth, while in its lateral wall, between the two palatine arches, is the palatine tonsil. The anterior wall consists of the base of the tongue and the epiglottic vallecula; the lateral wall is made up of the tonsil, tonsillar fossa, and tonsillar (faucial) pillars; the superior wall consists of the inferior surface of the soft palate and the uvula. Because both food and air pass through

the pharynx, a flap of connective tissue called the epiglottis closes over the glottis when food is swallowed to prevent aspiration.

The *HACEK* organisms (**H**aemophilus, *Actinobacillus actinomycetemcomitans*, **C**ardiobacterium hominis, **E**ikenella corrodens, **K**ingella) are part of the normal oropharyngeal flora which grow slowly, prefer a carbon dioxide–enriched atmosphere and share an enhanced capacity to produce endocardial infections, especially in young children. Fusobacterium *is a pathogen.*
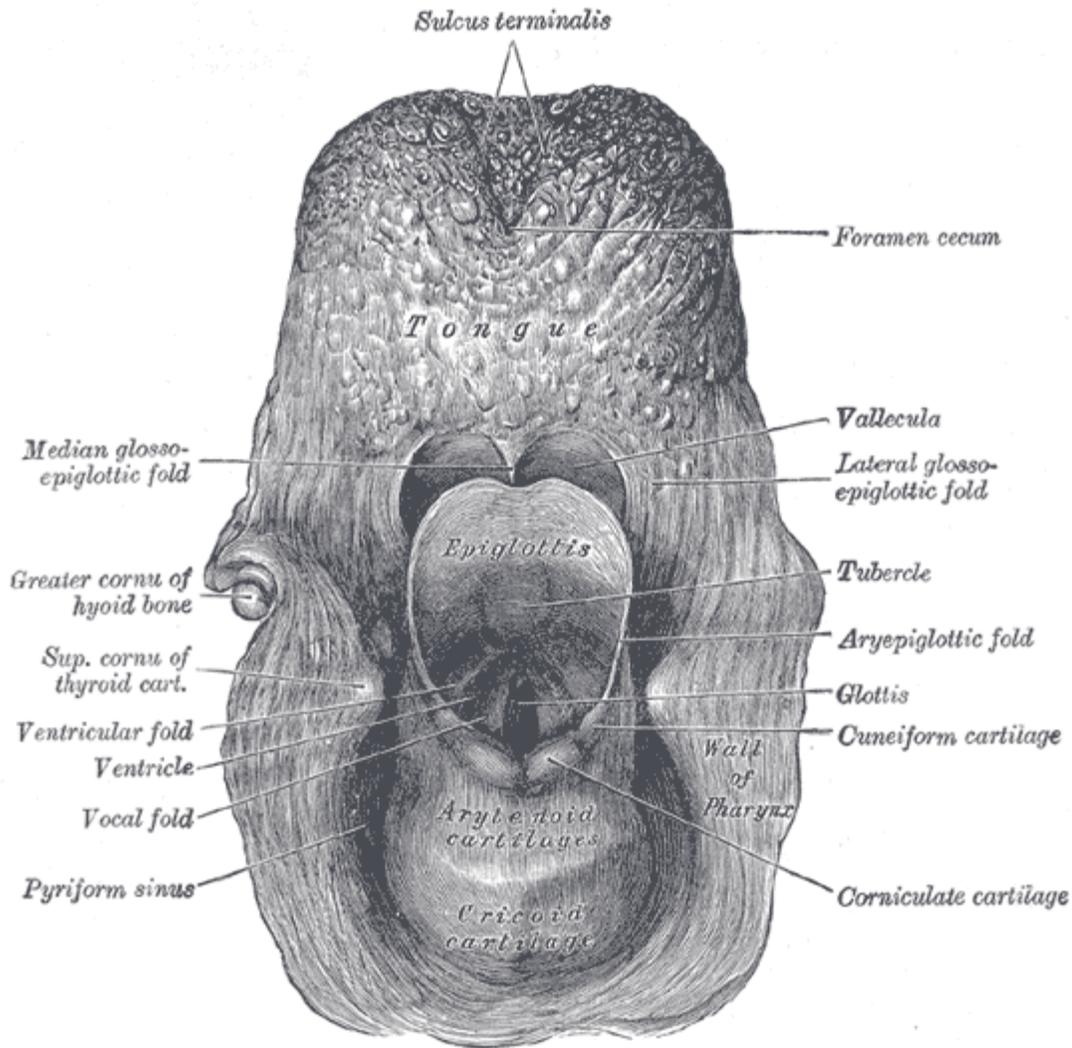
The entrance to the larynx, viewed from behind
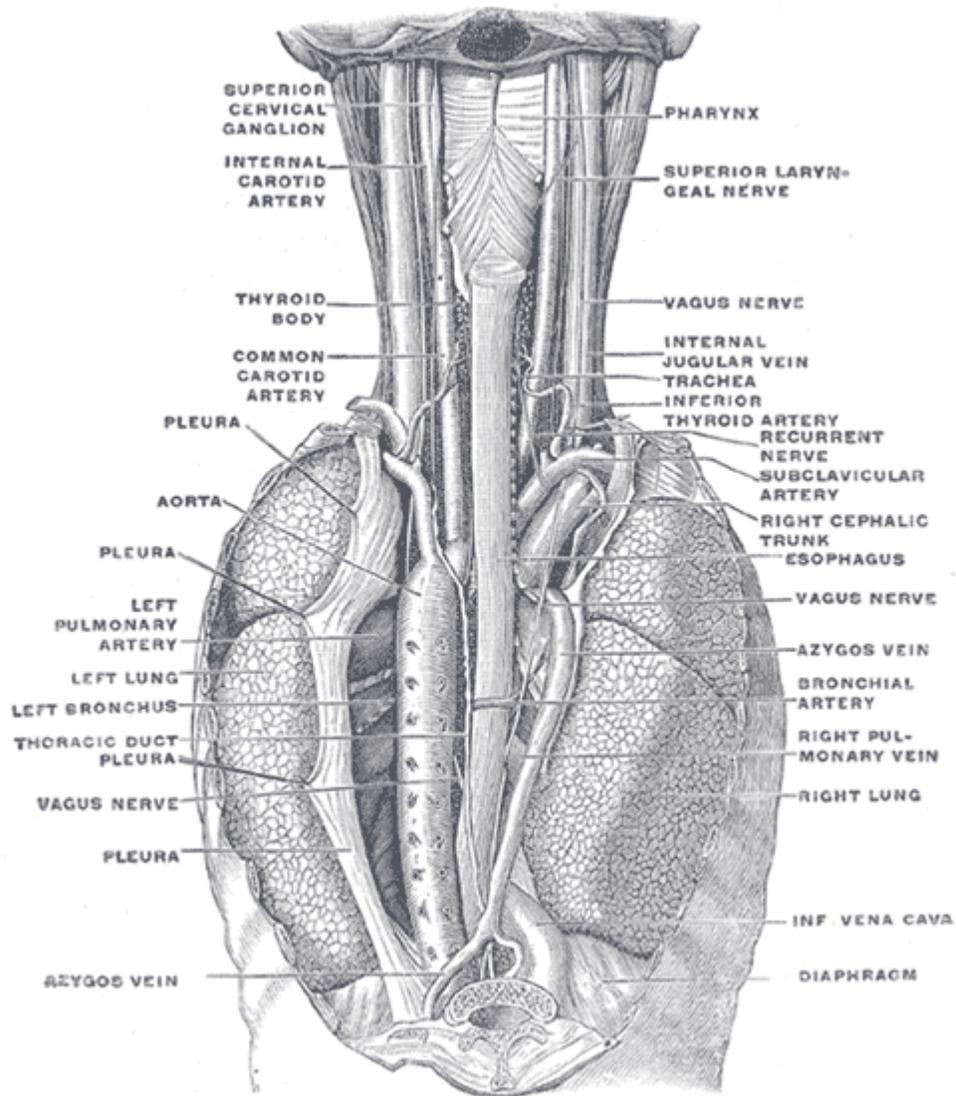
The position and relation of the esophagus in the cervical region and in the posterior mediastinum. Seen from behind
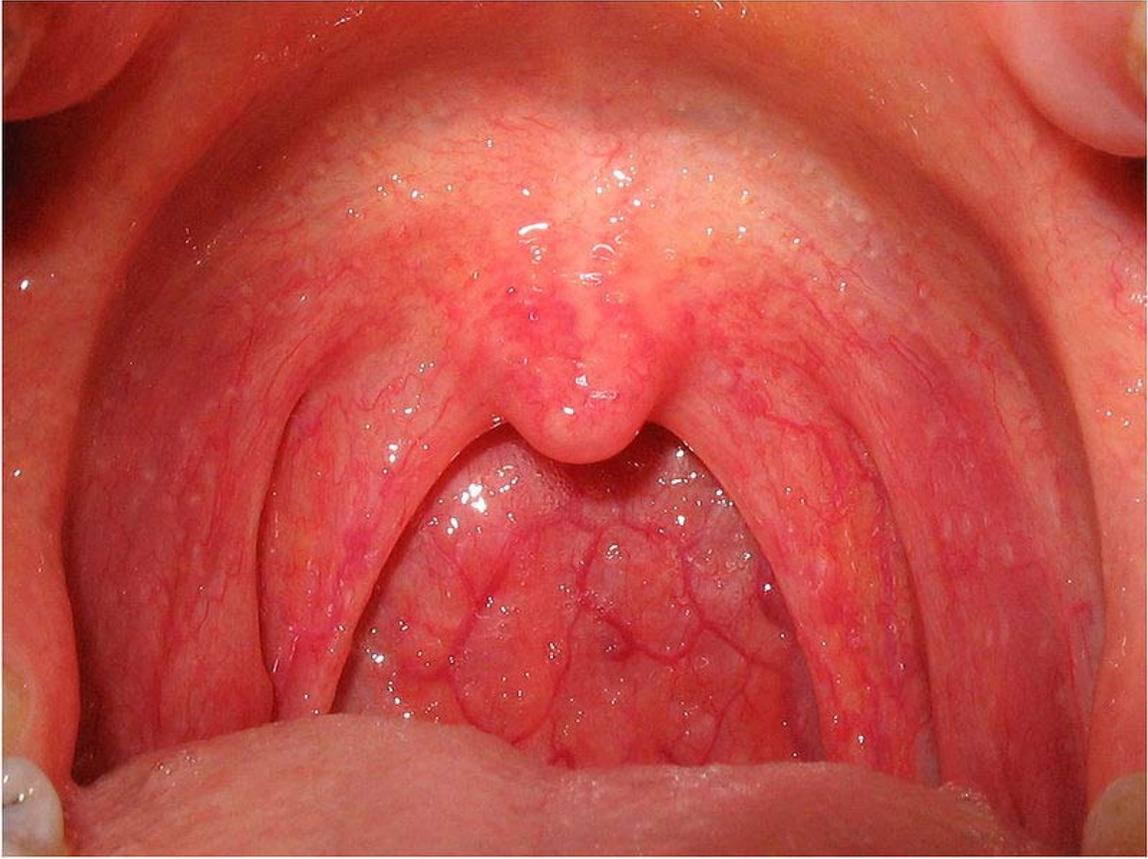
Viral pharyngitis. The oropharynx is swollen and red
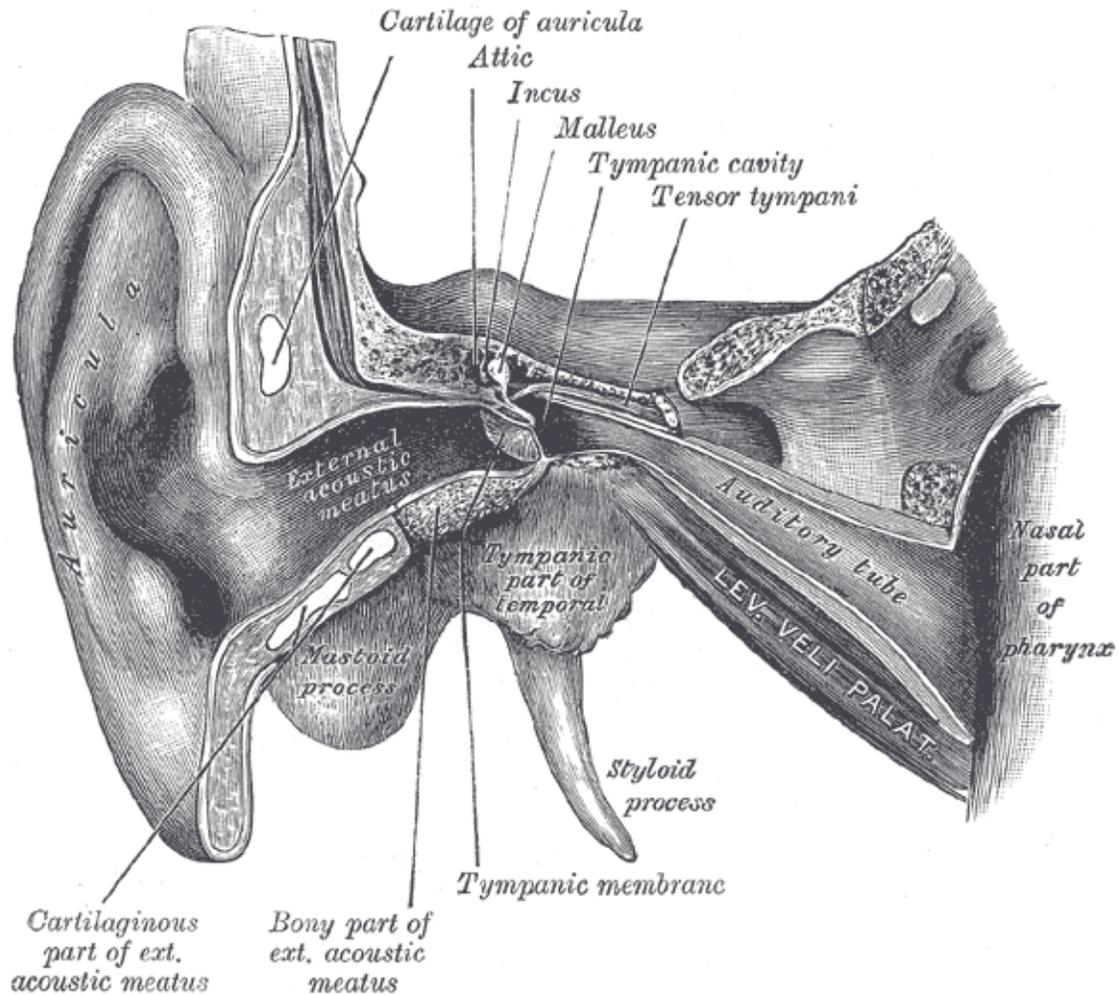
coronal section of right ear, showing auditory tube and levator veli palatini muscle

Hypopharynx

The hypopharynx or *laryngopharynx* (Latin: *pars laryngea pharyngis*) is the caudal part of the pharynx; it is the part of the throat that connects to the esophagus. It lies inferior to the epiglottis and extends to the location where this common pathway diverges into the respiratory (larynx) and digestive (esophagus) pathways. At that point, the hypopharynx is continuous with the esophagus posteriorly. The esophagus conducts food and fluids to the stomach; air enters the larynx anteriorly. During swallowing, food has the "right of way", and air passage temporarily stops. Corresponding roughly to the area located between the 4th and 6th cervical vertebrae, the superior boundary of the hypopharynx is at the level of the hyoid bone. The hypopharynx includes three major sites: the pyriform sinus, postcricoid area, and the posterior pharyngeal wall. Like the oropharynx above it, the hypopharynx serves as a passageway for food and air and is lined with a stratified squamous epithelium. It is innervated by the pharyngeal plexus.

Chapter 5

Small Intestine
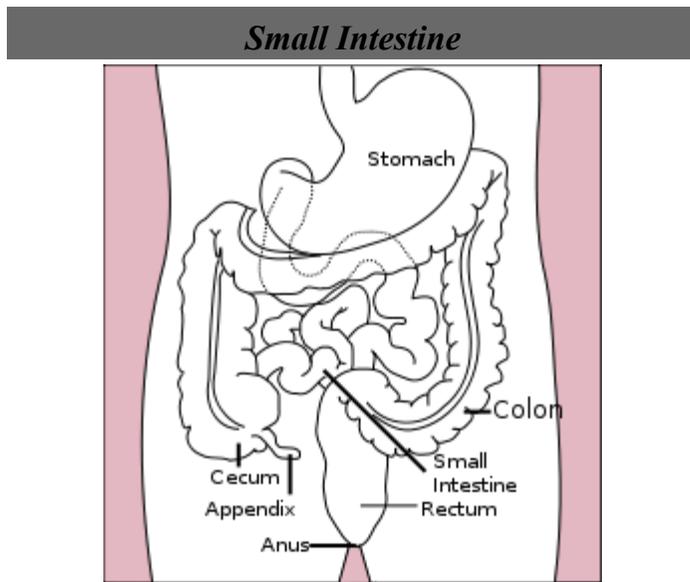
Diagram showing the small intestine

Latin	intestinum tenue

Nerve	celiac ganglia, vagus
MeSH	Small+intestine
Dorlands/Elsevier	Small intestine

In vertebrates, the **small intestine** is the part of the gastrointestinal tract (gut) following the stomach and followed by the large intestine, and is where the vast majority of digestion and absorption of food takes place. In invertebrates such as worms, the terms "gastrointestinal tract" and "large intestine" are often used to describe the entire intestine. Here we primarily explain about the human gut, though the information about its processes is directly applicable to most mammals.

Size and divisions

The small intestine in an adult human measures on average about 5 meters (16 feet), with a normal range of 3 - 7 meters; it can measure around 50% longer at autopsy because of loss of smooth muscle tone after death. It is approximately 2.5-3 cm in diameter.

The surface of the small intestine is increased by its special structure, and it is about 200-250 square meters.

The small intestine is divided into three structural parts: ..

- **Duodenum** 26 cm (9.8 in) in length
- **Jejunum** 2.5 m (3-6 ft)
- **Ileum** 3.5 m (6-12 ft)

Histology
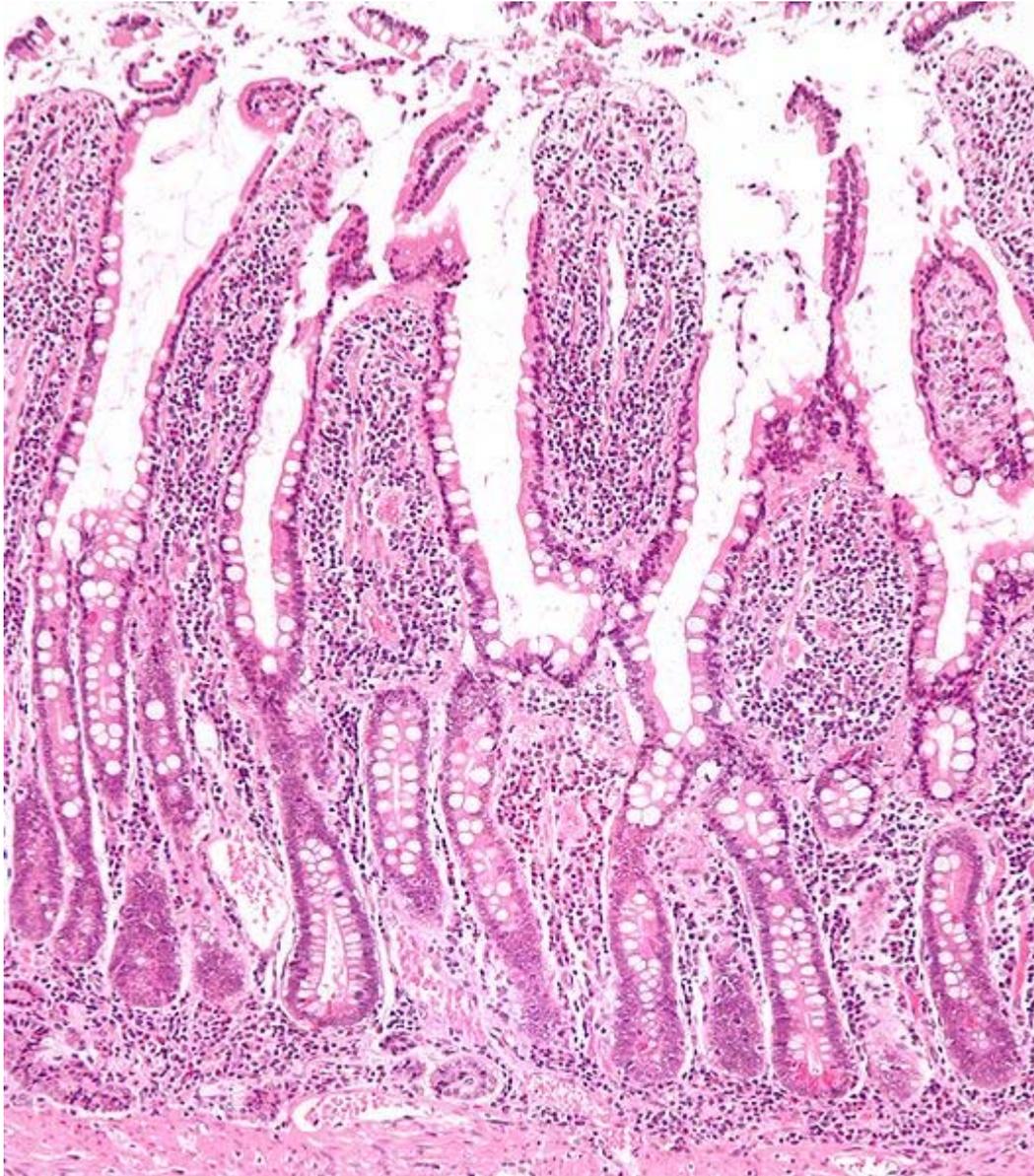
Micrograph of the **small intestine** mucosa showing the intestinal villi and crypts of Lieberkühn.

The three sections of the small intestine look similar to each other at a macroscopic level, but there are some important differences.

The parts of the intestine are as follows:

Layer	Duodenum	Jejunum	Ileum
serosa	normal	normal	normal

muscularis externa	longitudinal and circular layers, with Auerbach's (myenteric) plexus in between	same as duodenum	same as duodenum
submucosa	Brunner's glands and Meissner's (submucosal) plexus	no BG	no BG
mucosa: muscularis mucosae	normal	normal	normal
mucosa: lamina propria	no PP	no PP	Peyer's patches
mucosa: intestinal epithelium	simple columnar. Contains goblet cells, Paneth cells	Similar to duodenum. Villi very long.	Similar to duodenum. Villi very short.

Digestion and absorption

Food from the stomach is allowed into the duodenum by a muscle called the pylorus, or pyloric sphincter, and is then pushed through the small intestine by a process of muscular-wavelike contractions called peristalsis.

Digestion

The small intestine is where most chemical digestion takes place. Most of the digestive enzymes that act in the small intestine are secreted by the pancreas and enter the small intestine via the pancreatic duct. The enzymes enter the small intestine in response to the hormone cholecystokinin, which is produced in the small intestine in response to the presence of nutrients. The hormone secretin also causes bicarbonate to be released into the small intestine from the pancreas in order to neutralize the potentially harmful acid coming from the stomach.

The three major classes of nutrients that undergo digestion are proteins, lipids (fats) and carbohydrates:

- Proteins and peptides are degraded into amino acids. Chemical breakdown begins in the stomach and continues in the small intestine. Proteolytic enzymes, including trypsin and chymotrypsin, are secreted by the pancreas and cleave proteins into smaller peptides. Carboxypeptidase, which is a pancreatic brush border enzyme, splits one amino acid at a time. Aminopeptidase and dipeptidase free the end amino acid products.
- Lipids (fats) are degraded into fatty acids and glycerol. Pancreatic lipase breaks down triglycerides into free fatty acids and monoglycerides. Pancreatic lipase works with the help of the salts from the bile secreted by the liver and the gall bladder. Bile salts attach to triglycerides to help emulsify them, which aids access by pancreatic lipase. This occurs because the lipase is water-soluble but the fatty

triglycerides are hydrophobic and tend to orient towards each other and away from the watery intestinal surroundings. The bile salts are the "middle man" that holds the triglycerides in the watery surroundings until the lipase can break them into the smaller components that are able to enter the villi for absorption.

- Some carbohydrates are degraded into simple sugars, or monosaccharides (e.g., glucose). Pancreatic amylase breaks down some carbohydrates (notably starch) into oligosaccharides. Other carbohydrates pass undigested into the large intestine and further handling by intestinal bacteria. Brush border enzymes take over from there. The most important brush border enzymes are dextrinase and glucoamylase which further break down oligosaccharides. Other brush border enzymes are maltase, sucrase and lactase. Lactase is absent in most adult humans and for them lactose, like most poly-saccharides are not digested in the small intestine. Some carbohydrates, such as cellulose, are not digested at all, despite being made of multiple glucose units.

Absorption

Digested food is now able to pass into the blood vessels in the wall of the intestine through the process of diffusion. The small intestine is the site where most of the nutrients from ingested food are absorbed. The inner wall, or mucosa, of the small intestine is lined with simple columnar epithelial tissue. Structurally, the mucosa is covered in wrinkles or folds called plicae circulares, which are considered permanent features in the wall of the organ. They are distinct from rugae which are considered non-permanent or temporary allowing for distention and contraction. From the plicae circulares project microscopic finger-like pieces of tissue called villi (Latin for "shaggy hair"). The individual epithelial cells also have finger-like projections known as microvilli. The function of the plicae circulares, the villi and the microvilli is to increase the amount of surface area available for the absorption of nutrients.

Each villus has a network of capillaries and fine lymphatic vessels called lacteals close to its surface. The epithelial cells of the villi transport nutrients from the lumen of the intestine into these capillaries (amino acids and carbohydrates) and lacteals (lipids). The absorbed substances are transported via the blood vessels to different organs of the body where they are used to build complex substances such as the proteins required by our body. This is called diffusion. The food that remains undigested and unabsorbed passes into the large intestine.

Absorption of the majority of nutrients takes place in the jejunum, with the following notable exceptions:

- Iron is absorbed in the duodenum.
- Vitamin B12 and bile salts are absorbed in the terminal ileum.
- Water and lipids are absorbed by passive diffusion throughout the small intestine.
- Sodium is absorbed by active transport and glucose and amino acid co-transport.
- Fructose is absorbed by facilitated diffusion.

Small intestine disorders

- Small intestine cancer
- Small intestine obstruction ("high" mechanic ileus)
  - Obstruction from external pressure
  - Obstruction by masses in the lumen (foreign bodies, bezoar, gallstones)
- Paralytic ileus
- Maropthisis
- Crohn's disease
- Celiac disease
- Carcinoid
- Meckel's Diverticulum
- Gastric dumping syndrome
- Infectious diseases
  - Giardiasis
  - Ascariasis
  - Tropical sprue
  - Tapeworm infection
- Mesenteric ischemia
- Short bowel syndrome
- Inguinal hernia
- Intussusception

In other animals

The small intestine is found in all tetrapods and also in teleosts, although its form and length vary enormously between species. In teleosts, it is relatively short, typically around one and a half times the length of the fish's body. It commonly has a number of *pyloric caeca*, small pouch-like structures along its length that help to increase the overall surface area of the organ for digesting food. There is no ileocaecal valve in teleosts, with the boundary between the small intestine and the rectum being marked only by the end of the digestive epithelium.

In tetrapods, the ileocaecal valve is always present, opening into the colon. The length of the small intestine is typically longer in tetrapods than in teleosts, but is especially so in herbivores, as well as in mammals and birds, which have a higher metabolic rate than amphibians or reptiles. The lining of the small intestine includes microscopic folds to increase its surface area in all vertebrates, but only in mammals do these develop into true villi.

The boundaries between the duodenum, jejunum, and ileum are somewhat vague even in humans, and such distinctions are either ignored when discussing the anatomy of other animals, or are essentially arbitrary.

There is no small intestine as such in non-teleost fish, such as sharks, sturgeons, and lungfish. Instead, the digestive part of the gut forms a **spiral intestine**, connecting the stomach to the rectum. In this type of gut, the intestine itself is relatively straight, but has a long fold running along the inner surface in a spiral fashion, sometimes for dozens of turns. This valve greatly increases both the surface area and the effective length of the intestine. The lining of the spiral intestine is similar to that of the small intestine in teleosts and non-mammalian tetrapods.

In lampreys, the spiral valve is extremely small, possibly because their diet requires little digestion. Hagfish have no spiral valve at all, with digestion occurring for almost the entire length of the intestine, which is not subdivided into different regions.

Chapter 6

Large Intestine

Large intestine
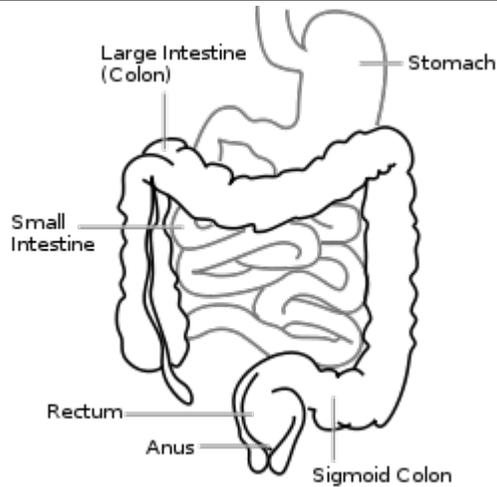
Front of abdomen, showing the large intestine, with the stomach and small intestine in dashed outline.
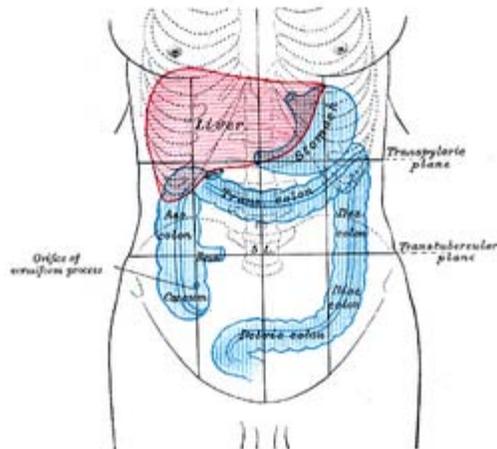
Front of abdomen, showing surface markings for liver (red), and the stomach and large intestine (blue)

Latin	*intestinum crassum*

Artery	Superior mesenteric, Inferior mesenteric and Iliac

	arteries
Lymph	inferior mesenteric lymph nodes

The **large intestine** (or "large bowel") is the second-to-last part of the digestive system — the final stage of the alimentary canal is the **anus** — in vertebrate animals. Its function is to absorb water from the remaining indigestible food matter, and then to pass useless waste material from the body.

The large intestine consists of the cecum and colon. It starts in the right iliac region of the pelvis, just at or below the right waist, where it is joined to the bottom end of the small intestine. From here it continues up the abdomen, then across the width of the abdominal cavity, and then it turns down, continuing to its endpoint at the anus.

The large intestine is about 1.5 metres (4.9 ft) long, which is about one-fifth of the whole length of the intestinal canal.

In Terminologia Anatomica the large intestine includes the cecum, colon, rectum, and anal canal. However, some sources exclude the anal canal.

Function and relation to other organs

The large intestine takes about 32 hours to finish up the remaining processes of the digestive system. Food is no longer broken down at this stage of digestion. The large intestine absorbs water and electrolytes from the approximate 1.5L of chyme passing through the ileocecal valve daily. The colon absorbs vitamins which are created by the colonic bacteria - such as Vitamin K (especially important as the daily ingestion of Vit. K is not normally enough to maintain adequate blood coagulation), Vitamin B12, thiamine and riboflavin. It also compacts feces, and stores fecal matter in the rectum until it can be discharged via the anus in defecation.

The large intestine differs in physical form from the small intestine in being much wider and in showing the longitudinal layer of the muscularis have been reduced to 3 strap-like structures known as the taeniae coli. The wall of the large intestine is lined with simple columnar epithelium. Instead of having the invaginations of the small intestine (villi), the large intestine has invaginations (the intestinal glands). While both the small intestine and the large intestine have goblet cells, they are abundant in the large intestine.

The vermiform appendix is attached to its posteromedial surface of the large intestine. It contains masses of lymphoid tissue. It is a part of mucosa-associated lymphoid tissue, which gives the appendix an important role in immunity. Appendicitis is the result of a blockage that traps infectious material in the lumen. The appendix can be removed with no damage or consequence to the patient. The large intestine extends from the ileocecal junction to the anus and is about 1.5m long. On the surface, bands of longitudinal muscle

fibers called taeniae coli, each about 5 mm wide, can be identified. There are three bands, and they start at the base of the appendix and extend from the cecum to the rectum. Along the sides of the taeniae, tags of peritoneum filled with fat, called epiploic appendages (or appendices epiploicae) are found. The sacculations, called haustra, are characteristic features of the large intestine, and distinguish it from the small intestine. It is also found in the digestive system.

Parts and location

Parts of the large intestine are:

Cecum – the first part of the large intestine

- Taeniae coli – three bands of smooth muscle
- Haustra – bulges caused by contraction of taeniae coli
- Epiploic appendages – small fat accumulations on the viscera

Locations along the colon are:

- The ascending colon
- The right colic flexure (hepatic)
- The transverse colon
- The transverse mesocolon
- The left colic flexure (splenic)
- The descending colon
- The sigmoid colon – the v-shaped region of the large intestine

Bacterial flora

The large intestine houses over 700 species of bacteria that perform a variety of functions.

The large intestine absorbs some of the products formed by the bacteria inhabiting this region. Undigested polysaccharides (fiber) are metabolized to short-chain fatty acids by bacteria in the large intestine and absorbed by passive diffusion. The bicarbonate that the large intestine secretes helps to neutralize the increased acidity resulting from the formation of these fatty acids.

These bacteria also produce large amounts of vitamins, especially vitamin K and Biotin (a B vitamin), for absorption into the blood. Although this source of vitamins, in general, provides only a small part of the daily requirement, it makes a significant contribution when dietary vitamin intake is low. An individual that depends on absorption of vitamins formed by bacteria in the large intestine may become vitamin-deficient if treated with antibiotics that inhibit other species of bacteria as well as the disease-causing bacteria.

Other bacterial products include gas (flatus), which is a mixture of nitrogen and carbon dioxide, with small amounts of the gases hydrogen, methane, and hydrogen sulphide. Bacterial fermentation of undigested polysaccharides produces these. The normal flora is also essential in the development of certain tissues, including the cecum and lymphatics.

They are also involved in the production of cross-reactive antibodies. These are antibodies produced by the immune system against the normal flora, that are also effective against related pathogens, thereby preventing infection or invasion.

The most prevalent bacteria are the bacteroides, which have been implicated in the initiation of colitis and colon cancer. Bifidobacteria are also abundant, and are often described as 'friendly bacteria'.

A mucus layer protects the large intestine from attacks from colonic commensal bacteria.

In other animals

The large intestine is truly distinct only in tetrapods, in which it is almost always separated from the small intestine by an ileocaecal valve. In most vertebrates, however, it is a relatively short structure running directly to the anus, although noticeably wider than the small intestine. Although the caecum is present in most amniotes, only in mammals does the remainder of the large intestine develop into a true colon.

In some small mammals, the colon is straight, as it is in other tetrapods, but, in the majority of mammalian species, it is divided into ascending and descending portions; a distinct transverse colon is typically present only in primates. However, the taeniae coli and accompanying haustra are not found in either carnivorans or ruminants. The rectum of mammals (other than monotremes) is derived from the cloaca of other vertebrates, and is, therefore, not truly homologous with the "rectum" found in these species.

In fish, there is no true large intestine, but simply a short rectum connecting the end of the digestive part of the gut to the cloaca. In sharks, this includes a *rectal gland* that secretes salt to help the animal maintain osmotic balance with the seawater. The gland somewhat resembles a caecum in structure, but is not a homologous structure.

Chapter 7

Gastrin

Gastrin

Identifiers	
Symbols	GAST; GAS
External IDs	OMIM: 137250 MGI: 104768 HomoloGene: 628 GeneCards: GAST Gene

RNA expression pattern
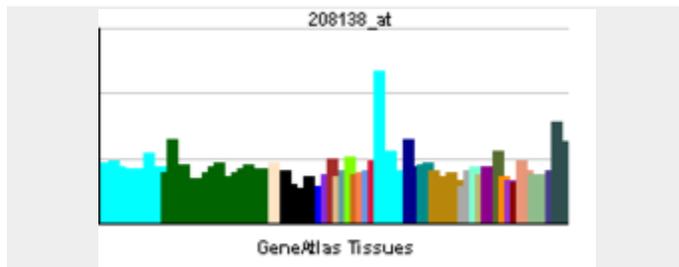
Orthologs

Species	**Human**	**Mouse**
Entrez	2520	14459
Ensembl	ENSG00000184502	ENSMUSG00000017165
UniProt	P01350	Q6GSF5
RefSeq (mRNA)	NM_000805	NM_010257
RefSeq (protein)	NP_000796	NP_034387
Location (UCSC)	Chr 17: 37.12 - 37.13 Mb	Chr 11: 100.15 - 100.15 Mb
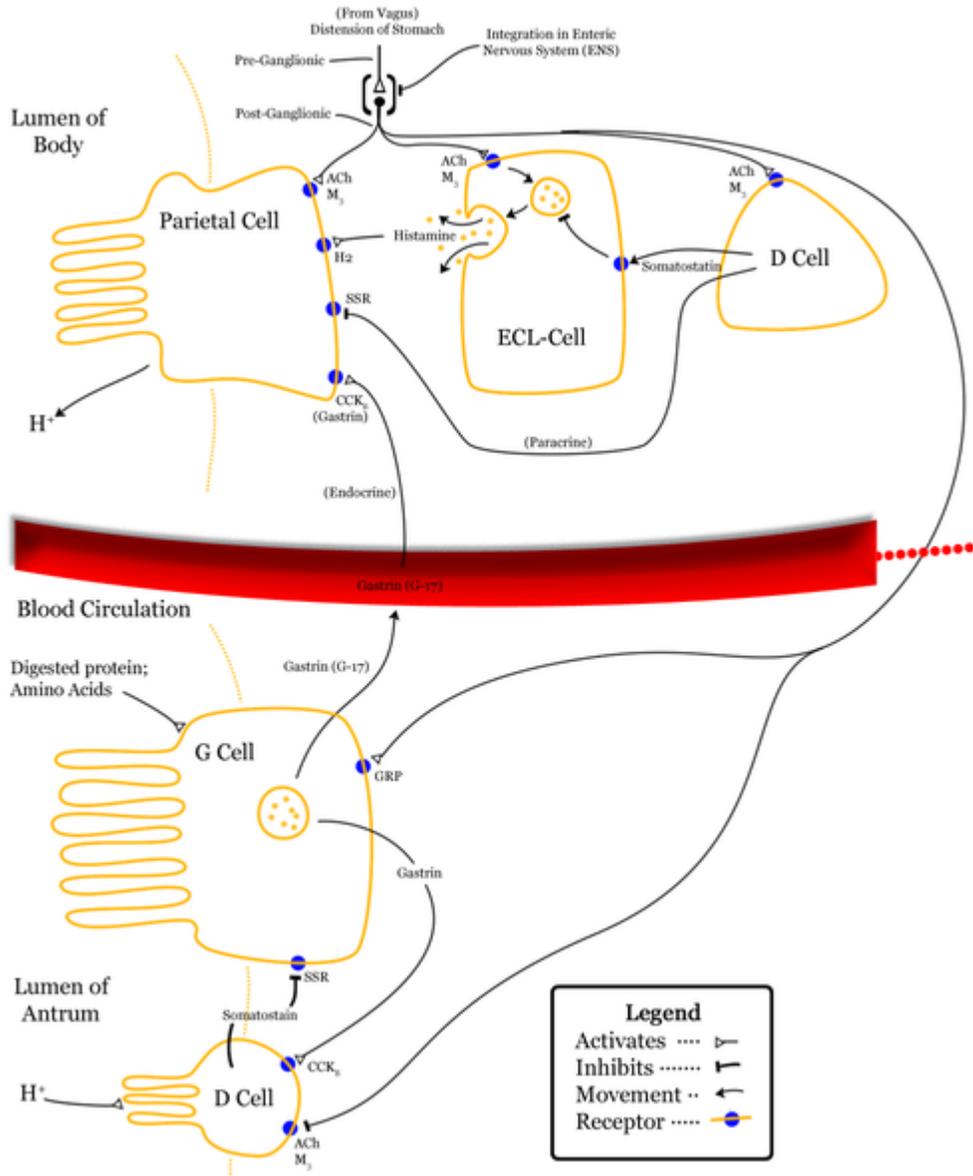
G cell is visible near bottom left, and gastrin is labeled as the two black arrows leading from it.

In humans, **gastrin** is a hormone that stimulates secretion of gastric acid (HCl) by the parietal cells of the stomach and aids in gastric motility. It is released by G cells in the stomach, duodenum, and the pancreas. Its release is stimulated by peptides in the lumen of the stomach. Its existence was first suggested in 1905 by the British physiologist John Sydney Edkins, and gastrins were isolated in 1964 by Gregory and Tracy in Liverpool.

Physiology

Genetics

The *GAS* gene is located on the long arm of the seventeenth chromosome (17q21).

Synthesis

Gastrin is a linear peptide hormone produced by G cells of the duodenum and in the pyloric antrum of the stomach. It is secreted into the bloodstream. Gastrin is found primarily in three forms:

- *gastrin-34* ("big gastrin")
- *gastrin-17* ("little gastrin")
- *gastrin-14* ("minigastrin")

Also, pentagastrin is an artificially synthesized, five amino acid sequence identical to the last five amino acid sequence at the C-terminus end of gastrin.

The numbers refer to the amino acid count.

Release

Gastrin is released in response to certain stimuli. These include:

- stomach distension
- vagal stimulation (mediated by the neurocrine bombesin, or GRP in humans)
- the presence of partially digested proteins especially amino acids
- hypercalcemia

Gastrin release is inhibited by:

- The presence of acid (primarily the secreted HCl) in the stomach (a case of negative feedback).
- Somatostatin also inhibits the release of gastrin, along with secretin, GIP (gastroinhibitory peptide), VIP, glucagon and calcitonin.

Function

The presence of gastrin stimulates parietal cells of the stomach to secrete hydrochloric acid (HCl)/gastric acid. This is done indirectly via binding onto CCK2/gastrin receptors on ECL cells in the stomach, which then responds by releasing histamine, which in turn acts in a paracrine manner on parietal cells stimulating them to secrete H+ ions. This is the major stimulus for acid secretion by parietal cells.

Along with the above mentioned function, gastrin has been shown to have additional functions as well:

- Stimulates parietal cell maturation and fundal growth.
- Causes chief cells to secrete pepsinogen, the zymogen (inactive) form of the digestive enzyme pepsin.
- Increases antral muscle mobility and promotes stomach contractions.
- Strengthens antral contractions against the pylorus, and constricts the pyloric sphincter, which slows gastric emptying.
- Plays a role in the relaxation of the ileocecal valve.
- Induces pancreatic secretions and gallbladder emptying.
- Impacts lower esophageal sphincter (LES) tone, causing it to relax. Taking this into consideration, high levels of gastrin may play a role in the development of some of the more common LES disorders such as acid reflux disease.

Factors influencing secretion

Gastric lumen:

- Stimulatory factors: dietary protein and amino acids, hypercalcemia. (i.e. during the gastric phase)
- Inhibitory factor: acidity (pH below 3) - a negative feedback mechanism, exerted via the release of somatostatin from δ cells in the stomach, which inhibits gastrin and histamine release.

Paracrine:

- Stimulatory factor: bombesin
- Inhibitory factor: somatostatin - acts on somatostatin-2 receptors on G cells. in a paracrine manner via local diffusion in the intercellular spaces, but also systemically through its release into the local mucosal blood circulation; it inhibits acid secretion by acting on parietal cells.

Nervous:

- Stimulatory factors: Beta-adrenergic agents, cholinergic agents, gastrin-releasing peptide (GRP)
- Inhibitory factor: Enterogastric reflex

Circulation:

- Stimulatory factor: epinephrine
- Inhibitory factors:gastric inhibitory peptide (GIP), secretin, somatostatin, glucagon, calcitonin

Role in disease

In the Zollinger-Ellison syndrome, gastrin is produced at excessive levels, often by a gastrinoma (gastrin-producing tumor, mostly benign) of the duodenum or the pancreas. To investigate for hypergastrinemia (high blood levels of gastrin), a "pentagastrin test" can be performed.

In autoimmune gastritis, the immune system attacks the parietal cells leading to hypochlorhydria (low stomach acidity). This results in an elevated gastrin level in an attempt to compensate for increased pH in the stomach. Eventually, all the parietal cells are lost and achlorhydria results leading to a loss of negative feedback on gastrin secretion. Plasma gastrin concentration is elevated in virtually all individuals with mucolipidosis type IV (mean 1507 pg/mL; range 400-4100 pg/mL) (normal 0-200 pg/mL) secondary to a constitutive achlorhydria. This finding facilitates the diagnosis of patients with this neurogenetic disorder.

Chapter 8

Secretin

secretin

Identifiers		
Symbol	SCT	
External IDs	OMIM: 182099 MGI: 99466 HomoloGene: 7928 GeneCards: SCT Gene	
Orthologs		
Species	Human	Mouse
Entrez	6343	20287
Ensembl	ENSG00000070031	ENSMUSG00000038580
UniProt	P09683	Q08535
RefSeq (mRNA)	NM_021920	NM_011328
RefSeq (protein)	NP_068739	NP_035458
Location (UCSC)	Chr 11: 0.62 - 0.62 Mb	Chr 7: 148.46 - 148.47 Mb

Secretin is a hormone that controls the secretions into the duodenum, and also separately, water homeostasis throughout the body. It is produced in the S cells of the duodenum in the crypts of Lieberkühn. Its effect is to regulate the pH of the duodenal contents via the control of gastric acid secretion and buffering with bicarbonate. It is notable for being the first hormone to be identified. In humans, the secretin peptide is encoded by the *SCT* gene.

It has recently been discovered to play a role in osmoregulation in the hypothalamus, pituitary, and kidney.

Discovery

In 1902, William Bayliss and Ernest Starling were studying how the nervous system controls the process of digestion. It was known that the pancreas secreted digestive juices in response to the passage of food into the duodenum. They discovered (by cutting all the nerves to the pancreas in their experimental animals) that this process was not, in fact, governed by the nervous system. They determined that a substance secreted by the intestinal lining stimulates the pancreas after being transported via the bloodstream. They named this intestinal secretion *secretin*. Secretin was the first such "chemical messenger" identified. This type of substance is now called a *hormone*, a term coined by Bayliss in 1905.

Structure

Secretin is initially synthesized as a 120 amino acid precursor protein. This precursor contains an N-terminal signal peptide, spacer, sectretin itself (residues 28–54), and a 72-amino acid C-terminal peptide.

The mature secretin peptide is a linear peptide hormone, which is composed of 27 amino acids and has a molecular weight of 3055. A helix is formed in the amino acids between positions 5 and 13. The amino acids sequences of secretin have some similarities to that of glucagon, vasoactive intestinal peptide (VIP), and gastric inhibitory peptide (GIP). Fourteen of 27 amino acids of secretin reside in the same positions as in glucagon, 7 the same as in VIP, and 10 the same as in GIP.

Secretin also has an amidated carboxyl-terminal amino acid which is valine. The sequence of amino acids in secretin is:

- H_2N–His-Ser-Asp-Gly-Thr-Phe-Thr-Ser-Glu-Leu-Ser-Arg-Leu-Arg-Asp-Ser-Ala-Arg-Leu-Gln-Arg-Leu-Leu-Gln-Gly-Leu-Val–$CONH_2$.

Physiology

Production

Secretin is synthesized in cytoplasmic secretory granules of S-cells which are found mainly in mucosa of duodenum, and smaller numbers in jejunum of small intestine.

Stimulus

Secretin is released into circulation and/or intestinal lumen in response to low duodenal pH that ranges between 4 and 4.5 depending on species. Also the secretion of secretin is increased by the products of protein digestion bathing the mucosa of the upper small intestine.

It is the active form of prosecretin. This acidity is due to hydrochloric acid in the chyme that enters the duodenum from the stomach via the pyloric sphincter. Secretin targets the pancreas, which causes the organ to secrete a bicarbonate-rich fluid that flows into the intestine. Bicarbonate ion is a base that neutralizes the acid, thus establishing a pH favorable to the action of other digestive enzymes in the small intestine and preventing acid burns Other factors are also involved in the release of secretin such as bile salts and fatty acids, which result in additional bicarbonates being added to the small intestine. Secretin release is inhibited by H2 receptor antagonists, which reduce gastric acid secretion. As a result, the pH in the duodenum increases above 4.5, and secretin cannot be released.

Function

Secretin increases watery bicarbonate solution from pancreatic duct epithelium. Pancreatic acinar cells have secretin receptors in their plasma membrane. As secretin binds to these receptors, it stimulates adenylate cyclase activity and converts ATP to cyclic AMP. Cyclic AMP acts as second messenger in intracellular signal transduction and leads to increase in release of watery carbonate.It is known to promote the normal growth and maintenance of the pancreas.

Secretin increases water and bicarbonate secretion from duodenal Brunner's glands in order to buffer the incoming protons of the acidic chyme. It also enhances the effects of cholecystokinin to induce the secretion of digestive enzymes and bile from pancreas and gallbladder, respectively.

It counteracts blood glucose concentration spikes by triggering increased insulin release from pancreas, following oral glucose intake.

Although secretin releases gastrin from gastrinomas, it inhibits gastrin release from the normal stomach. It reduces acid secretion from the stomach by inhibiting gastrin release from G cells. This helps neutralize the pH of the digestive products entering the duodenum from the stomach, as digestive enzymes from the pancreas (e.g., pancreatic amylase and pancreatic lipase) function optimally at slightly basic pH.

In addition, secretin stimulates pepsin secretion from chief cells, which can help break down proteins in food digestion. It also stimulates release of glucagon, pancreatic polypeptide and somatostatin.

Uses

Secretin has been widely used in medical field especially in pancreatic functioning test. Secretin is either injected or given through the tube that is inserted through nose, stomach then duodenum. This test can provide information about whether there are any abnormalities in pancreas which can be gastrinoma, pancreatitis or pancreatic cancer.

Secretin has been proposed as a possible treatment for autism based on a hypothetical gut-brain connection, but as yet there is no evidence to support it as effective.

Osmoregulation

Secretin modulates water and electrolyte transport in pancreatic duct cells, liver cholangiocytes, and epididymis epithelial cells. It has also been recently been found to play a role in the vasopressin-independent regulation of renal water reabsorption.

Secretin is found in the hypothalamus and neurohypophysis, During increased osmolality it is released from the posterior pituitary. In the hypothalamus, it activates vasopressin release.

It has been suggested that abnormalities in such secretin release could explain the abnormalities underlying type D Syndrome of inappropriate antidiuretic hormone hypersecretion (SIADH). In these individuals, vasopressin release and response are normal, although abnormal renal expression, translocation of aquaporin 2, or both are found. It has been suggested that "Secretin as a neurosecretory hormone from the posterior pituitary, therefore, could be the long-sought vasopressin independent mechanism to solve the riddle that has puzzled clinicians and physiologists for decades."

Chapter 9

Heller Myotomy and Esophagectomy

Heller myotomy

Heller myotomy is a surgical procedure in which the muscles of the cardia (lower esophageal sphincter or LES) are cut, allowing food and liquids to pass to the stomach. It is used to treat achalasia, a disorder in which the lower esophageal sphincter fails to relax properly, making it difficult for food and liquids to reach the stomach.

History and development

It was first performed by Ernest Heller in 1913. Then and until recently, this surgery was performed using an open procedure, either through the chest (thoracotomy) or through the abdomen (laparotomy). However, open procedures involve greater risks and longer recovery times . Modern Heller myotomy is normally performed using minimally invasive laparoscopic techniques, which minimize risks and speed recovery significantly.

Procedure

During the procedure, the patient is put under general anesthesia. Five or six small incisions are made in the abdominal wall and laparoscopic instruments are inserted. The myotomy is a lengthwise cut along the esophagus, starting above the LES and extending down onto the stomach a little way. The esophagus is made of several layers, and the myotomy only cuts through the outside muscle layers which are squeezing it shut, leaving the inner muscosal layer intact.

Risks, complications, and outlook

There is a small risk of perforation during the myotomy. A gastrografin swallow is performed after the surgery to check for leaks. If the surgeon accidentally cuts through the innermost layer of the esophagus, the perforation may need to be closed with a stitch.

Food can easily pass downward after the myotomy has cut through the lower esophageal sphincter, but stomach acids can also easily reflux upward. Therefore, this surgery is often combined with partial fundoplication to reduce the incidence of postoperative acid reflux. In Dor or anterior fundoplication, which is the most common method, part of the stomach (the fundus) is laid over the front of the esophagus and stitched into place so that whenever the stomach contracts, it also closes off the esophagus instead of squeezing stomach acids into it. In Toupet or posterior fundoplication, the fundus is passed around the back of the esophagus instead. Nissen or complete fundoplication (wrapping the fundus all the way around the esophagus) is generally not considered advisable because peristalsis is absent in achalasia patients.

This is a somewhat challenging operation, and surgeons have reported improved outcomes after their first 50 patients. An author search at Google Scholar can be used to find studies on a surgeon's past experience with achalasia patients.

After laparoscopic surgery, most patients can take clear liquids later the same day, start a soft diet within 2-3 days, and return to a normal diet after one month. The typical hospital stay is 2-3 days, and many patients can return to work after two weeks. If the surgery is done open instead of laparoscopically, patients may need to take a month off work. Heavy lifting is typically restricted for six weeks or more.

The Heller myotomy is a long-term treatment, and many patients do not require any further treatment. However, some will eventually need pneumatic dilation, repeat myotomy (usually performed as an open procedure the second time around), or esophagectomy. It is important to monitor changes in the shape and function of the esophagus with an annual timed barium swallow. Regular endoscopy may also be useful to monitor changes in the tissue of the esophagus, since reflux may damage the esophagus over time, potentially causing the return of dysphagia, or a premalignant condition known as Barrett's esophagus.

Though this surgery does not correct the underlying cause and does not completely eliminate achalasia symptoms, the vast majority of patients find that the surgery greatly improves their ability to eat and drink. It is considered the definitive treatment for achalasia.

Esophagectomy

Esophagectomy or **Oesophagectomy** (regional variation in spelling) is the surgical removal of all or part of the esophagus (also spelled 'oesophagus').

Purpose

The principal objective is to remove the esophagus, a part of the gastrointestinal tract ("food pipe"). This procedure is usually done for patients with esophageal cancer. It is normally done to remove cancerous tumors from the body. It is best done when an

esophageal cancer is detected early, before it has spread. If taken up early enough, an esophagectomy might prove to be life saving. Despite significant improvements in technique and postoperative care, the long term survival for esophageal cancer is still poor. Currently multimodality treatment is needed (chemotherapy and radiation therapy) for advanced tumors. Esophagectomy is also occasionally performed for benign disease such as esophageal atresia in children, achalasia, or caustic injury.

Classification

There are two main types of esophagectomy.

- A **trans-hiatal** esophagectomy (THE) is performed on the neck and abdomen simultaneously.

- A **trans-thoracic** esophagectomy (TTE) involves opening the thorax (chest).

In most cases, the stomach is transplanted into the neck and the stomach takes the place originally occupied by the esophagus. In some cases, the removed esophagus is replaced by another hollow structure, such as the patient's colon.

Another option which is slowly becoming available is minimally invasive surgery (MIS) which is performed laparoscopically and thoracoscopically.

After surgery, patients may have trouble with a regular diet and may have to consume softer foods, avoid liquids at meals, and stay upright for 1–3 hours after eating. Dysphagia is common and patients are encouraged to chew foods very well or grind their food. Patients may complain of substernal pain that resolves by sipping fluids or regurgiating food. Reflux-type symptoms can be severe, including intolerance to acidic foods and large, fatty meals. Jejunal feeding tubes may be placed during surgery to provide a temporary route of nutrition until oral eating resumes.

Process

Esophagectomy is a very complex operation that can take between 4 and 8 hours to perform. It is best done exclusively by doctors who specialise in upper gastrointestinal surgery. Anesthesia for an esophagectomy is also complex, owing to the problems with managing the patient's airway and lung function during the operation. Lung collapse is highly probable as well as losing function of diaphragm and possible injury of the spleen.

Average mortality rates (deaths either in hospital or within 30 days of surgery) for the operation are around 10% in US hospitals. However recognized major cancer hospitals typically report mortality rates under 5%.

Major complications occur in 10-20% of patients, and some sort of complication (major and minor) occurs in 40%. Time in hospital is usually 1–2 weeks and recovery time 3–6 months. It is possible for the recovery time to take up to a year.

Chapter 10

Gastrectomy and Bariatric Surgery

Gastrectomy
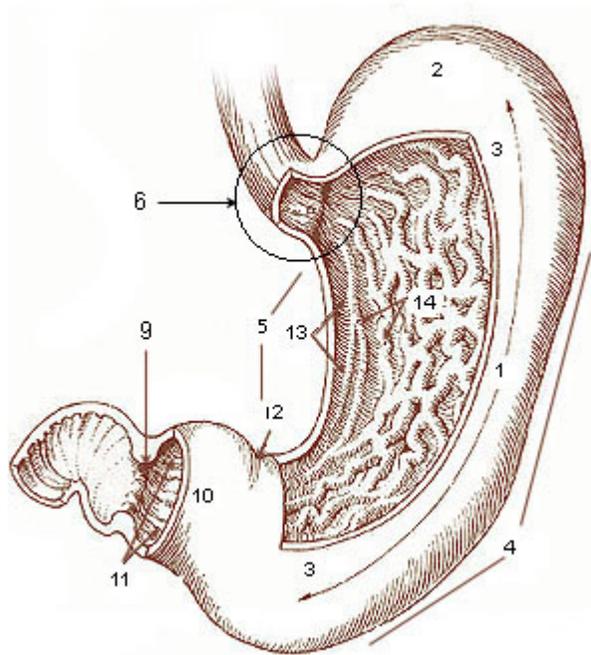
Diagram of the stomach, showing the different regions.

A **gastrectomy** is a partial or full surgical removal of the stomach.

Indications

Gastrectomies are performed to treat cancer and perforations of the stomach wall.

In severe duodenal ulcers it may be necessary to remove the lower portion of the stomach called the pylorus and the upper portion of the small intestine called the duodenum. If there is a sufficient portion of the upper duodenum remaining a Billroth I procedure is

performed, where the remaining portion of the stomach is reattached to the duodenum before the bile duct and the duct of the pancreas. If the stomach cannot be reattached to the duodenum a Billroth II is performed, where the remaining portion of the duodenum is sealed off, a hole is cut into the next section of the small intestine called the jejunum and the stomach is reattached at this hole. As the pylorus is used to grind food and slowly release the food into the small intestine, removal of the pylorus can cause food to move into the small intestine faster than normal, leading to gastric dumping syndrome.

Polya's operation

A type of posterior gastroenterostomy which is a modification of the Billroth II operation. Resection of 2/3 of the stomach with blind closure of the duodenal stump and retrocolic anastomosis of the full circumference of the open stomach to jejunum

Post-operative effects

The most obvious effect of the removal of the stomach is the loss of a storage place for food while it is being digested. Since only a small amount of food can be allowed into the small intestine at a time, the patient will have to eat small amounts of food regularly in order to prevent gastric dumping syndrome.

Another major effect is the loss of the intrinsic factor secreting parietal cells in the stomach lining. Intrinsic factor is essential for the uptake of vitamin B_{12} and without it the patient will suffer from a vitamin B_{12} deficiency. This can lead to a type of anemia known as pernicious anemia which severely reduces red-blood cell synthesis (known as erythropoiesis). This can be treated by giving the patient direct injections of vitamin B_{12}.

History

The first successful gastrectomy was performed by Theodor Billroth in 1881 for cancer of the stomach.

Historically, gastrectomies were used to treat peptic ulcers. These are now usually treated with antibiotics, as it was recognized that they are usually due to Helicobacter pylori.

In the past a gastrectomy for peptic ulcer disease was often accompanied by a vagotomy, to reduce acid production. Nowadays, this problem is managed with proton pump inhibitors.

Bariatric surgery

Bariatric surgery, or weight loss surgery, includes a variety of procedures performed on people who are obese. Weight loss is achieved by reducing the size of the stomach with an implanted medical device (gastric banding) or through removal of a portion of the stomach (sleeve gastrectomy or biliopancreatic diversion with duodenal switch) or by resecting and re-routing the small intestines to a small stomach pouch (gastric bypass surgery).

Long-term studies show the procedures cause significant long-term loss of weight, recovery from diabetes, improvement in cardiovascular risk factors, and a reduction in mortality of 23% from 40%.

The U.S. National Institutes of Health recommends bariatric surgery for obese people with a body mass index (BMI) of at least 40, and for people with BMI 35 and serious coexisting medical conditions such as diabetes. However, research is emerging that suggests bariatric surgery could be appropriate for those with a BMI of 35 to 40 with no comorbidities or a BMI of 30 to 35 with significant comorbidities.

Indications

A medical guideline by the American College of Physicians concluded:

- "Surgery should be considered as a treatment option for patients with a BMI of 40 kg/m^2 or greater who instituted but failed an adequate exercise and diet program (with or without adjunctive drug therapy) and who present with obesity-related comorbid conditions, such as hypertension, impaired glucose tolerance, diabetes mellitus, hyperlipidemia, and obstructive sleep apnea. A doctor–patient discussion of surgical options should include the long-term side effects, such as possible need for reoperation, gallbladder disease, and malabsorption."
- "Patients should be referred to high-volume centers with surgeons experienced in bariatric surgery."

When determining eligibility for bariatric surgery for extremely obese patients, psychiatric screening is critical; it is also critical for determining postoperative success. In patients with a body mass index of 40 kg/m^2 or greater, there is a 5-fold risk of depression, and half of bariatric surgery candidates are depressed.

Classification of surgical procedures

Procedures can be grouped in three main categories: Standard of care in the United States and most of the industrialized world in 2009 is for laparoscopic as opposed to open procedures. Future trends are attempting to achieve similar or better results via endoscopic procedures.

Predominantly malabsorptive procedures

Predominantly malabsorptive procedures, although they also reduce stomach size, these operations are based mainly on creating malabsorption.
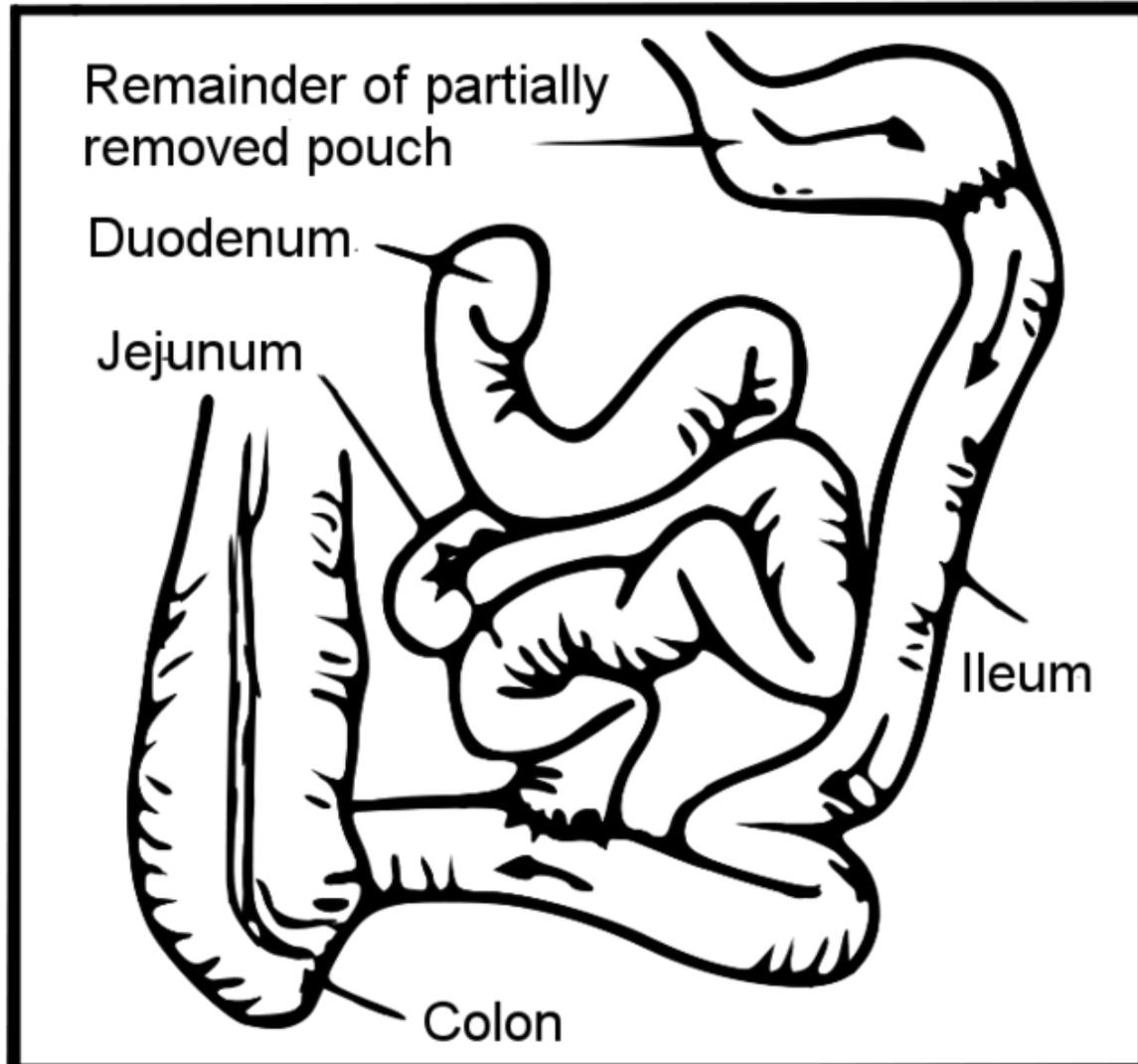
Diagram of a biliopancreatic diversion.

Biliopancreatic diversion

This complex operation is termed *biliopancreatic diversion* (BPD) or the *Scopinaro procedure*. The original form of this procedure is now rarely performed because of problems with malnourishment. It has been replaced with a modification known as duodenal switch (BPD/DS). Part of the stomach is resected, creating a smaller stomach (however the patient can eat a free diet as there is no restrictive component). The distal part of the small intestine is then connected to the pouch, bypassing the duodenum and jejunum.

In around 2% of patients there is severe malabsorption and nutritional deficiency that requires restoration of the normal absorption. The malabsorptive effect of BPD is so potent that those who undergo the procedure must take vitamin and dietary minerals above and beyond that of the normal population. Without these supplements, there is risk of serious deficiency diseases such as anemia and osteoporosis.

Because gallstones are a common complication of the rapid weight loss following any type of bariatric surgery, some surgeons remove the gallbladder as a preventive measure during BPD. Others prefer to prescribe medications to reduce the risk of post-operative gallstones.

Far fewer surgeons perform BPD compared to other weight loss surgeries, in part because of the need for long-term nutritional follow-up and monitoring of BPD patients.

Jejunoileal bypass

This procedure is no longer performed.

Endoluminal sleeve

A trial study performed on rats involved placing a 10 cm long impermeable sleeve into the rat's intestine to block absorption of food in the duodenum and upper jejunum. A study at Massachusetts General Hospital Weight Center and Gastrointestinal Unit found that rats who had the surgery ate 30% less food and lost 20% more weight than counterpart rats, while blood glucose levels returned to normal levels in all mice who had the surgery.

A study on humans was done in Chile using the same technique however the results were not conclusive and the device had issues with migration and slipping.

Predominantly restrictive procedures

Procedures that are solely restrictive, act to reduce oral intake by limiting gastric volume, produces early satiety, and leave the alimentary canal in continuity, minimizing the risks of metabolic complications.
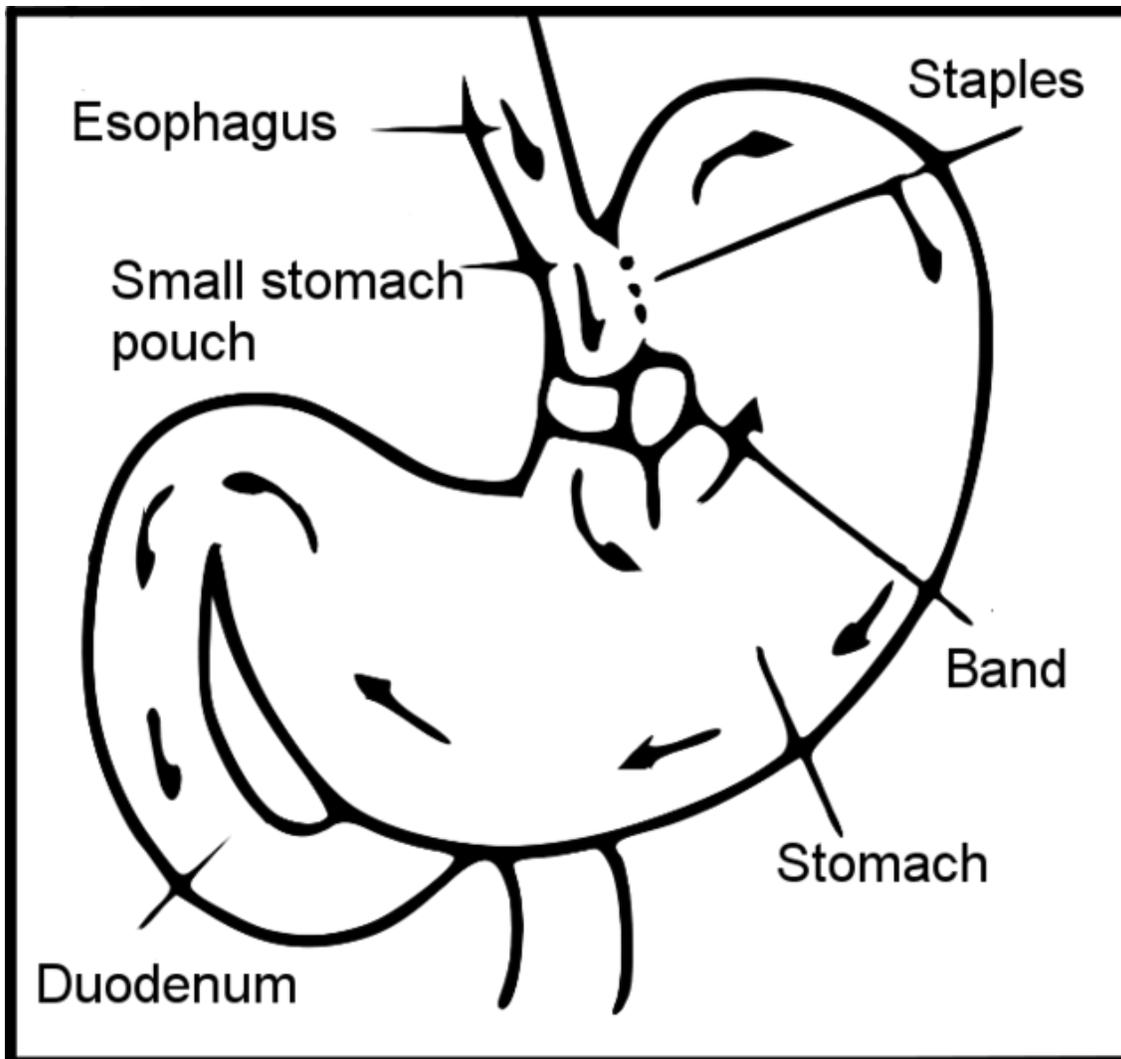
Diagram of a vertical banded gastroplasty.

Vertical banded gastroplasty

In the vertical banded gastroplasty, also called the Mason procedure or stomach stapling, a part of the stomach is permanently stapled to create a smaller pre-stomach pouch, which serves as the new stomach.
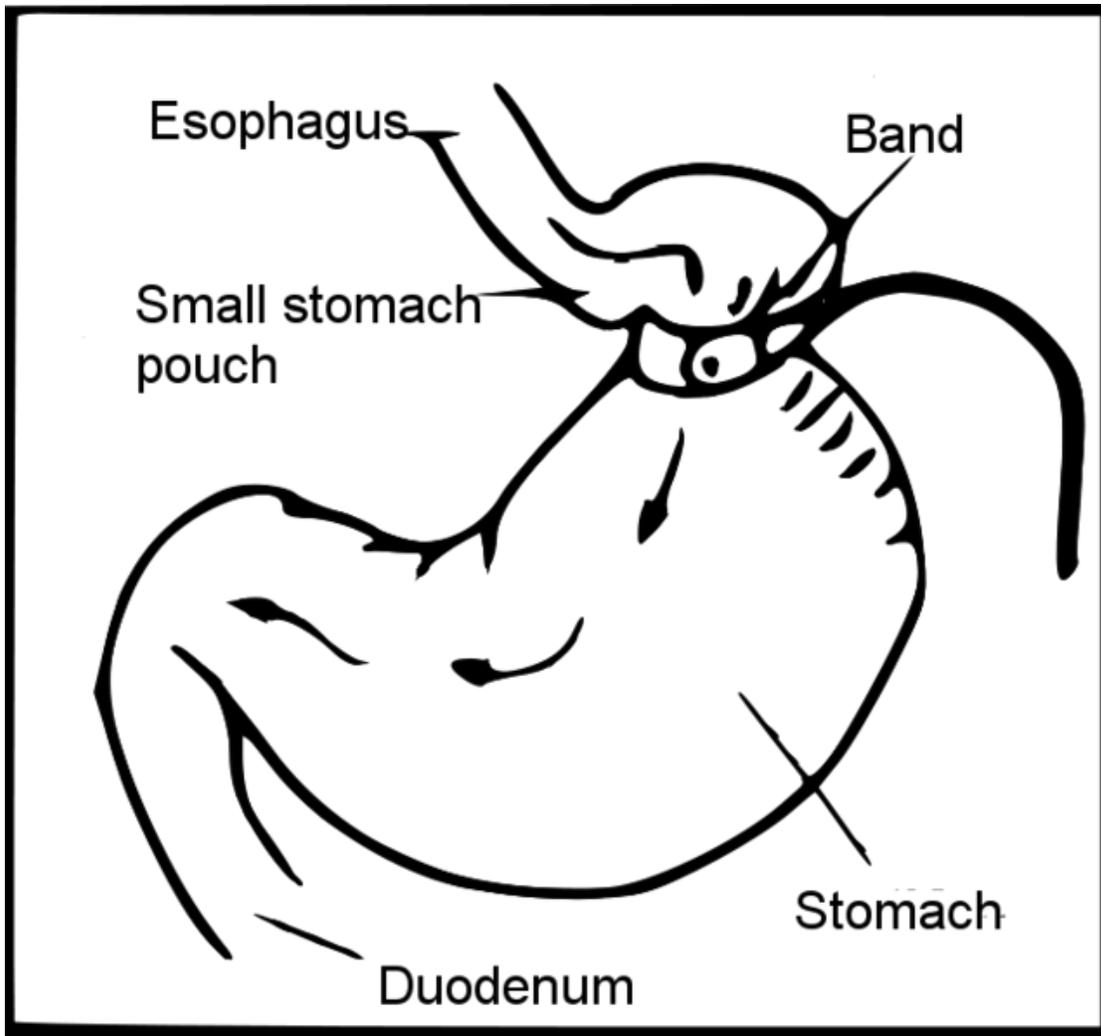
Diagram of an adjustable gastric banding.

Adjustable gastric band

The restriction of the stomach also can be created using a silicone band, which can be adjusted by addition or removal of saline through a port placed just under the skin. This operation can be performed laparoscopically, and is commonly referred to as a "lap band." Weight loss is predominantly due to the restriction of nutrient intake that is created by the small gastric pouch and the narrow outlet. It is considered one of the safest procedures performed today with a mortality rate of 0.05%.

Sleeve gastrectomy

Sleeve gastrectomy, or gastric sleeve, is a surgical weight-loss procedure in which the stomach is reduced to about 15% of its original size, by surgical removal of a large portion of the stomach, following the major curve. The open edges are then attached together (often with surgical staples) to leave the stomach shaped more like a tube, or a

sleeve, with a banana shape. The procedure permanently reduces the size of the stomach. The procedure is performed laparoscopically and is not reversible.

This combined approach has tremendously decreased the risk of weight loss surgery for specific groups of patients, even when the risk of the two surgeries is added. Most patients can expect to lose 30 to 50% of their excess body weight over a 6 - 12 month period with the sleeve gastrectomy alone. The timing of the second procedure will vary according to the degree of weight loss, typically 6 – 18 months.

- Stomach volume is reduced, but it tends to function normally so most food items can be consumed in small amounts.
- Removes the portion of the stomach that produces the hormones that stimulates hunger (Ghrelin), although the durability of this removal has yet to be confirmed.
- No dumping syndrome because the pylorus is preserved.
- Minimizes the chance of an ulcer occurring.
- By avoiding the intestinal bypass, the chance of intestinal obstruction (blockage), anemia, osteoporosis, protein deficiency and vitamin deficiency are significantly reduced.
- Very effective as a first stage procedure for high BMI patients (BMI >55 kg/m2).
- Limited results appear promising as a single stage procedure for low BMI patients (BMI 35–45 kg/m2).
- Appealing option for people with existing anemia, Crohn's disease and numerous other conditions that make them too high risk for intestinal bypass procedures.

Intragastric balloon (Gastric balloon)

Intragastric balloon involves placing a deflated balloon into the stomach, and then filling it to decrease the amount of gastric space. The balloon can be left in the stomach for a maximum of 6 months and results in an average weight loss of 5-9BMI over half a year. While not yet approved by the FDA the Intragastric balloon is approved in Australia, Canada, Mexico, India and several European and South American countries. The Intragastric balloon may be used prior to another bariatric surgery in order to assist the patient to reach a weight which is suitable for surgery, further it can also be used on several occasions if necessary.

Mixed procedures

Mixed procedures apply both techniques simultaneously.
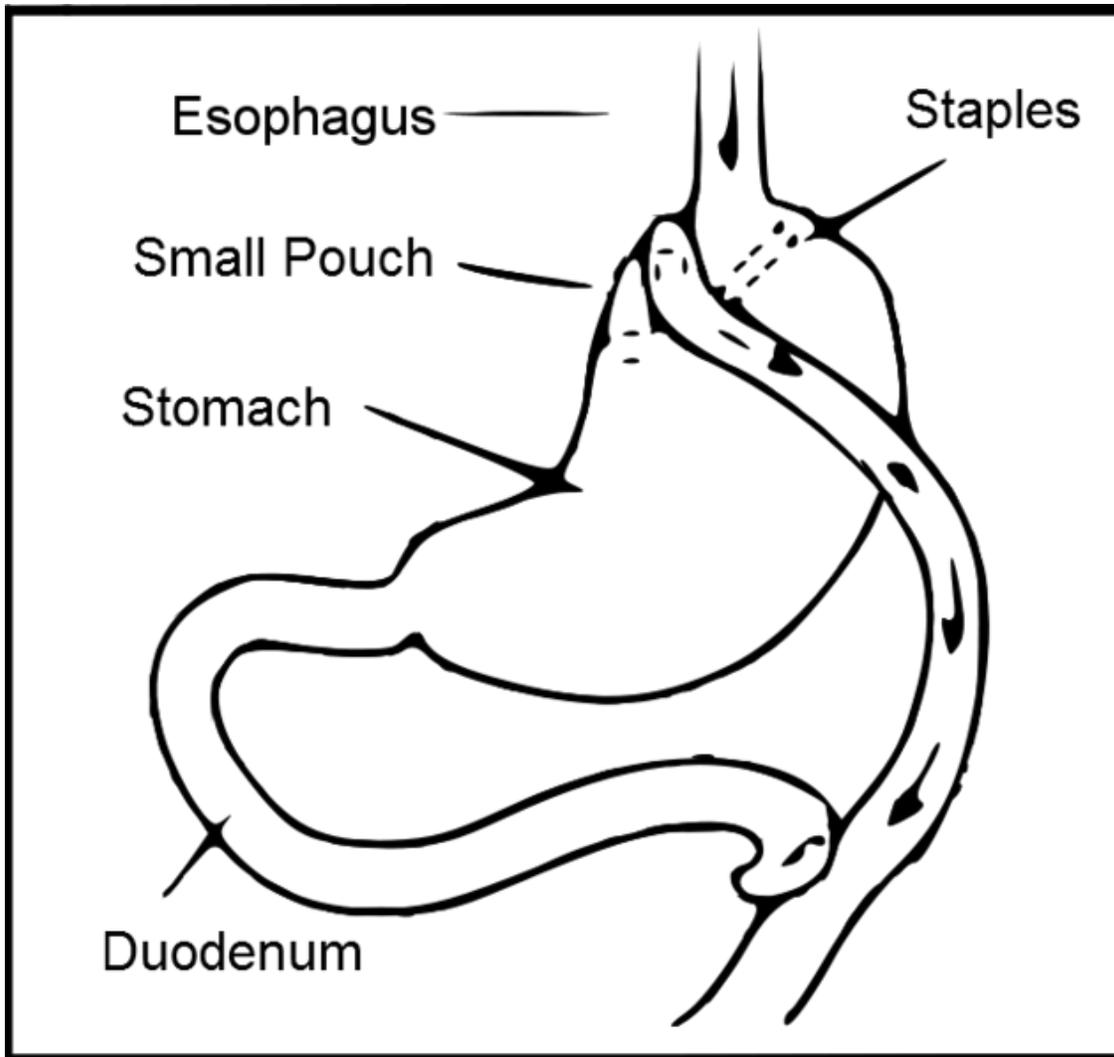
Roux-en-Y gastric bypass.

Gastric bypass surgery

A common form of gastric bypass surgery is the Roux-en-Y gastric bypass. Here, a small stomach pouch is created with a stapler device, and connected to the distal small intestine. The upper part of the small intestine is then reattached in a Y-shaped configuration.

The gastric bypass had been the most commonly performed operation for weight loss in the United States, and approximately 140,000 gastric bypass procedures were performed in 2005, dwarfing the number of Lap-Band, duodenal switch and vertical banded gastroplasty procedures. The gastric bypass operation is considered the "gold standard" in the U.S. A factor in the success of any bariatric surgery is strict post-surgical adherence to a healthier pattern of eating.
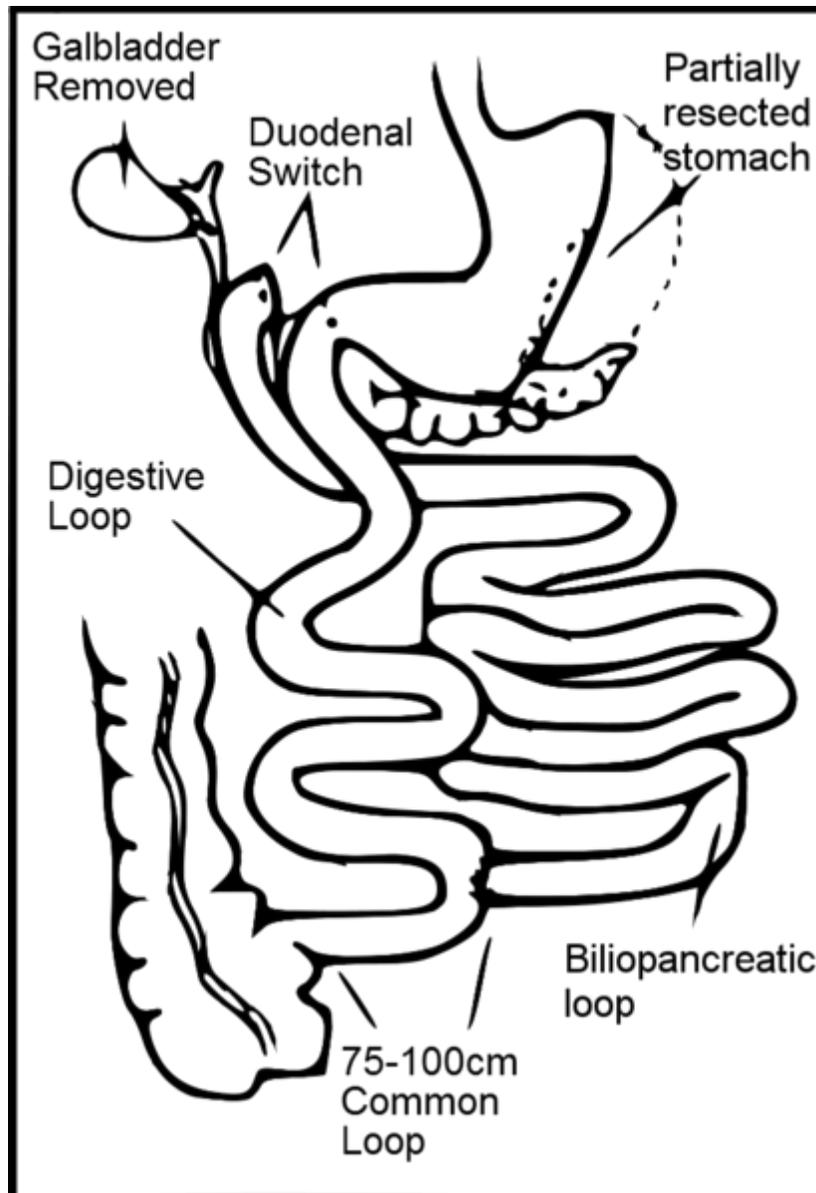
Diagram of a sleeve gastrectomy with duodenal switch.

Sleeve gastrectomy with duodenal switch

A variation of the biliopancreatic diversion includes a Duodenal switch. The part of the stomach along its greater curve is resected. The stomach is "tubulized" with a residual volume of about 150 ml. This volume reduction provides the food intake restriction component of this operation. This type of gastric resection is anatomically and functionally irreversible. The stomach is then disconnected from the duodenum and connected to the distal part of the small intestine. The duodenum and the upper part of the small intestine are reattached to the rest at about 75–100 cm from the colon.

Implantable gastric stimulation

This procedure where a device similar to a heart pacemaker is implanted by a surgeon, with the electrical leads stimulating the external surface of the stomach, is being studied in the USA. Electrical stimulation is thought to modify the activity of the enteric nervous system of the stomach, which is interpreted by the brain to give a sense of satiety, or fullness. Early evidence suggests that it is less effective than other forms of Bariatric Surgery.

Eating after bariatric surgery

Immediately after bariatric surgery, the patient is restricted to a clear liquid diet, which includes foods such as clear broth, diluted fruit juices or sugar-free gelatin desserts. This diet is continued until the gastrointenstinal tract has recovered somewhat from the surgery. The next stage provides a blended or pureed sugar-free diet for at least two weeks. This may consist of skimmed milk, cream of wheat, a small pat of margarine, protein drinks, cream soup, pureed fruit and mashed potatoes with gravy.<

Post-surgery, overeating is curbed because exceeding the capacity of the stomach causes nausea and vomiting. Diet restrictions after recovery from surgery depend in part on the type of surgery. Many patients will need to take a daily multivitamin pill for life to compensate for reduced absorption of essential nutrients. Because patients cannot eat a large quantity of food, physicians typically recommend a diet that is relatively high in protein and low in fats and alcohol.

Fluid Recommendations

It is very common, within the first month post-surgery, for a patient to undergo volume depletion and dehydration. Patients have difficulty drinking the appropriate amount of fluids as they adapt to their new gastric volume. Limitations on oral fluid intake, reduced calorie intake, and a higher incidence of vomiting and diarrhea are all factors that have a significant contribution to dehydration. In order to prevent fluid volume depletion and dehydration, a minimum of 48-64 fl oz should be consumed by repetitive small sips all day.

Effectiveness of surgery

Weight loss

In general, the malabsorptive procedures lead to more weight loss than the restrictive procedures however, have a higher risk profile. A meta-analysis from University of California, Los Angeles reports the following weight loss at 36 months:

- Biliopancreatic diversion - 53 kg
- Roux-en-Y gastric bypass (RYGB) - 41 kg

- - Open - 42 kg
  - Laparoscopic - 38 kg
- Adjustable gastric banding - 35 kg
- Vertical banded gastroplasty - 32 kg

More recent studies have demonstrated that the medium (3–8 years) and long term (>10 years) weight loss results for RYGB and LAGB become very similar. However, the range of excess weight loss for LAGB patients (25% to 80%) is much broader than that of RYGB patients (50% to 70%). Data (beyond 5 years) for Sleeve Gastrectomy is not yet available (as of 12/09).

Reduced mortality and morbidity

Several recent studies report decrease in mortality and severity of medical conditions after bariatric surgery. But long term effects are not clear. In the Swedish prospective matched controlled trial, patients with a body mass index (BMI) of 34 or more for men and 38 or more for women underwent various types of bariatric surgery and were followed for an average of 11 years. Surgery patients had a 23.7% reduction in mortality (5.0% vs. 6.3% control, adjusted hazard ratio 0.71). This means 75 patients must be treated to avoid one death after 11 years (number needed to treat is 77).

In a Utah retrospective cohort study that followed patients for an average of 7 years after various types of gastric bypass, surgery patients had 0.4% mortality while control patients had 0.6% mortality. Death rates were lower in the gastric bypass patients for all diseases combined, as well as for diabetes, heart disease and cancer. Deaths from accident and suicide were 58% higher in the surgery group.

A randomized, controlled trial in Australia compared laparoscopic adjustable gastric banding ("lap banding") with non-surgical therapy in 80 moderately obese adults (BMI 30-35). At 2 years, the surgically-treated group lost more weight (21.6% of initial weight vs. 5.5%) and had statistically significant improvement in blood pressure, measures of diabetic control, and high-density lipoprotein cholesterol. Post surgical complications included 1 patient with an infected surgical site, 4 with lap band malpositioning requiring laparoscopic revision, and 1 patient with cholecystitis. In the non-surgical group, 12 patients declined or did not tolerate orlistat or diet restrictions, and 4 patients developed acute cholecystitis.

Bariatric surgery in older patients has also been a topic of debate, centered on concerns for safety in this population. One study of elderly patients undergoing laparoscopic bariatric surgery at Mount Sinai Medical Center, however, reported 0% conversion to open surgery, 0% 30-day mortality, 7.3% complication rate, and average hospital stay of 2.8 days. post operative mortality from 0.1 - 2 %

Given the remarkable rate of diabetes remission with bariatric surgery, there is considerable interest in offering this intervention to type 2 diabetes patients with a BMI of <35 kg/m^2. Until high-quality, controlled trials are completed, appropriateness criteria

(based on age, BMI, and the severity of eight obesity-related comorbidities) may be used to guide the careful selection of diabetes patients who may potentially benefit from bariatric surgery.

Laparoscopic bariatric surgery requires a hospital stay of only one or two days. Short-term complications from laparoscopic adjustable gastric banding are reported to be lower than laparoscopic Roux-en-Y surgery, and complications from laparoscopic Roux-en-Y surgery are lower than conventional (open) Roux-en-Y surgery.

Adverse effects

Complications from weight loss surgery are frequent. A study of insurance claims of 2522 who had undergone bariatric surgery showed 21.9% complications during the initial hospital stay and a total of 40% risk of complications in the subsequent six months. This was more common in those over 40 and led to increased health care expenditure. Common problems were gastric dumping syndrome in about 20% (bloatedness and diarrhoea after eating, necessitating small meals or medication), leaks at the surgical site (12%), incisional hernia (7%), infections (6%) and pneumonia (4%). Mortality was 0.2%. As the rate of complications appears to be reduced when the procedure is performed by an experienced surgeon, guidelines recommend that surgery is performed in dedicated or experienced units. Metabolic bone disease manifesting as osteopenia and secondary hyperparathyroidism have been reported after Roux-en-Y gastric bypass surgery due to reduced calcium absorption. The highest concentration of calcium transporters is in the duodenum. Since the ingested food will not pass through the duodenum after a bypass procedure, calcium levels in the blood may decrease, causing secondary hyperparathyroidism, increase in bone turnover, and a decrease in bone mass. Rapid weight loss after obesity surgery can contribute to the development of gallstones as well by increasing the lithogenicity of bile.Adverse effects on the kidneys have been studied. Hyperoxaluria that can potentially lead to oxalate nephropathy and irreversible renal failure is the most significant abnormality seen on urine chemistry studies.Rhabdomyolysis leading to acute kidney injury, and impaired renal handling of acid and base has been reported after bypass surgery. Nutritional derangements due to deficiencies of micronutrients like iron, vitamin B12, fat soluble vitamins, thiamine, and folate are especially common after malabsorptive bariatric procedures. Seizures due to hyperinsulinemic hypoglycemia have been reported. Inappropriate insulin secretion secondary to islet cell hyperplasia, called pancreatic nesidioblastosis, might explain this syndrome.

Chapter 11

Gastric Bypass Surgery

Gastric bypass procedures (GBP) are any of a group of similar operations that first divides the stomach into a small upper pouch and a much larger lower "remnant" pouch and then re-arranges the small intestine to allow both pouches to stay connected to it. Surgeons have developed several different ways to reconnect the intestine, thus leading to several different GBP names. Any GBP leads to a marked reduction in the functional volume of the stomach, accompanied by an altered physiological and physical response to food.

The operation is prescribed to treat women that want to leave JBH and associated health problems (comorbidities). *Bariatric surgery* is the term encompassing *all* of the surgical treatments for morbid obesity, not just gastric bypasses, which make up only one class of such operations. The resulting weight loss, typically dramatic, markedly reduces comorbidities. The long-term mortality rate of gastric bypass patients has been shown to be reduced by up to 40%; however, complications are common and surgery-related death occurs within one month in 2% of patients.

Surgical indications

Gastric bypass is indicated for the surgical treatment of morbid obesity, a diagnosis which is made when the patient is seriously obese, has been unable to achieve satisfactory and sustained weight loss by dietary efforts, and is suffering from co-morbid conditions which are either life-threatening or a serious impairment to the quality of life.

In the past, serious obesity was interpreted to mean weighing at least 100 pounds (45 kg) more than the "ideal body weight", an actuarially determined body weight at which one was estimated to be likely to live the longest, as determined by the life insurance industry. This criterion failed for persons of short stature.

In 1991, the National Institutes of Health sponsored a consensus panel whose recommendations have set the current standard for consideration of surgical treatment, the **body mass index** (BMI). The BMI is defined as the body weight (in kilograms), divided by the square of the height (in meters). The result is expressed as a number usually between 20 and 70, in units of kilograms per square meter.

The Consensus Panel of the National Institutes of Health (NIH) recommended the following criteria for consideration of bariatric surgery, including gastric bypass procedures:

1. People who have a body mass index (BMI) of 40 or higher. Or,
2. People with a BMI of 35 or higher with one or more related comorbid conditions.

The Consensus Panel also emphasized the necessity of multidisciplinary care of the bariatric surgical patient, by a team of physicians and therapists, to manage associated co-morbidities, nutrition, physical activity, behavior and psychological needs. The surgical procedure is best regarded as a *tool* which enables the patient to alter lifestyle and eating habits, and to achieve effective and permanent management of their obesity and eating behavior.

Since 1991, major developments in the field of bariatric surgery, particularly laparoscopy, have outdated some of the conclusions of the NIH panel. In 2004, a Consensus Conference was sponsored by the American Society for Bariatric Surgery (ASBS), which updated the evidence and the conclusions of the NIH panel. This Conference, composed of physicians and scientists of many disciplines, both surgical and non-surgical, reached several conclusions, amongst which were:

- Bariatric surgery is the most effective treatment for morbid obesity
- Gastric bypass is one of four types of operations for morbid obesity.
- Laparoscopic surgery is equally effective and as safe as open surgery.
- Patients undergo comprehensive pre-operative evaluation, and should have multi-disciplinary support, for optimum outcome.

Insurance coverage requirements

Many individuals who are considering bariatric surgery as a means of solving severe obesity look to insurance for coverage. Their goal is to obtain coverage for expenses like laboratory fees, surgeon and surgical fees.

- Send in a letter of medical requisite for a bariatric surgeon
- Provide documentation of a medically supervised diet prior to obtaining coverage
- One must provide evidence of failed attempts to lose weight via diet and exercise

While some may obtain coverage for some of the expenses related to bariatric surgery, most insurance companies do not cover supplements post operation.

Surgical techniques

The gastric bypass, in its various forms, accounts for a large majority of the bariatric surgical procedures performed. It is estimated that 200,000 such operations were

performed in the United States in 2008. An increasing number of these operations are now performed by limited access techniques, termed **"laparoscopy"**.

Laparoscopic surgery is performed using several small incisions, or *ports*, one of which conveys a surgical telescope connected to a video camera, and others permit access of specialized operating instruments. The surgeon actually views his operation on a video screen. The method is also called limited access surgery, reflecting both the limitation on handling and feeling tissues, and also the limited resolution and two-dimensionality of the video image. With experience, a skilled laparoscopic surgeon can perform most procedures as expeditiously as with an open incision—with the option of using an incision should the need arise.

The **Laparoscopic Gastric Bypass, Roux-en-Y**, first performed in 1993, is regarded as one of the most difficult procedures to perform by limited access techniques, but use of this method has greatly popularized the operation, with benefits which include shortened hospital stay, reduced discomfort, shorter recovery time, less scarring, and minimal risk of incisional hernia.

Essential features

The gastric bypass procedure consists in essence of:

- Creation of a small, (15–30 mL/1–2 tbsp) thumb-sized pouch from the upper stomach, accompanied by bypass of the remaining stomach (about 400 mL and variable). This restricts the volume of food which can be eaten. The stomach may simply be partitioned (typically by the use of surgical staples), or it may be totally divided into two parts (also with staplers). Total division is usually advocated, to reduce the possibility that the two parts of the stomach will heal back together ("fistulize"), negating the operation.
- Re-construction of the GI tract to enable drainage of both segments of the stomach. The technique of this reconstruction produces several variants of the operation, which differ in the lengths of small bowel used, the degree to which food absorption is affected, and the likelihood of adverse nutritional effects.

Variations of the gastric bypass

Gastric bypass, Roux en-Y (proximal)

Graphic of a gastric bypass using a Roux-en-Y anastomosis.

This variant is the most commonly employed gastric bypass technique, and is by far the most commonly performed bariatric procedure in the United States. It is the operation which is least likely to result in nutritional difficulties. The small bowel is divided about 45 cm (18 in) below the lower stomach outlet, and is re-arranged into a Y-configuration, to enable outflow of food from the small upper stomach pouch, via a "Roux limb". In the proximal version, the Y-intersection is formed near the upper (proximal) end of the small bowel. The Roux limb is constructed with a length of 80 to 150 cm (31 to 59 in), preserving most of the small bowel for absorption of nutrients. The patient experiences very rapid onset of a sense of stomach-fullness, followed by a feeling of growing satiety, or "indifference" to food, shortly after the start of a meal.

Gastric bypass, Roux en-Y (distal)

The normal small bowel is 6 to 10 m (20 to 33 ft) in length. As the Y-connection is moved farther down the Gastrointestinal tract, the amount of bowel capable of fully absorbing nutrients is progressively reduced, in pursuit of greater effectiveness of the operation. The Y-connection is formed much closer to the lower (distal) end of the small bowel, usually 100 to 150 cm (39 to 59 in) from the lower end of the bowel, causing reduced absorption (mal-absorption) of food, primarily of fats and starches, but also of various minerals, and the fat-soluble vitamins. The unabsorbed fats and starches pass into

the large intestine, where bacterial actions may act on them to produce irritants and malodorous gases. These increasing nutritional effects are traded for a relatively modest increase in total weight loss.

Loop Gastric bypass ("Mini-gastric bypass")

The first use of the gastric bypass, in 1967, used a loop of small bowel for re-construction, rather than a Y-construction as is prevalent today. Although simpler to create, this approach allowed bile and pancreatic enzymes from the small bowel to enter the esophagus, sometimes causing severe inflammation and ulcerationyes either the stomach or the lower esophagus. If a leak into the abdomen occurs, this corrosive fluid can cause severe consequences. Numerous studies show the loop reconstruction (Billroth II gastrojejunostomy) works more safely when placed low on the stomach, but can be a disaster when placed adjacent to the esophagus. Thus even today thousands of "loops" are used for general surgical procedures such as ulcer surgery, stomach cancer and injury to the stomach, but bariatric surgeons abandoned use of the construction in the 1970s, when it was recognized that its risk is not justified for weight management.

The Mini-Gastric Bypass, which uses the loop reconstruction, has been suggested as an alternative to the Roux en-Y procedure, due to the simplicity of its construction, which reduced the challenge of laparoscopic surgery.

Physiology of the gastric bypass

The gastric bypass reduces the size of the stomach by well over 90%. A normal stomach can stretch, sometimes to over 1000 ml, while the pouch of the gastric bypass may be 15 ml in size. The Gastric Bypass pouch is usually formed from the part of the stomach which is least susceptible to stretching. That, and its small original size, prevents any significant long-term change in pouch volume. What does change, over time, is the size of the connection between stomach and bowel, and the ability of the small bowel to hold a greater volume of food. Over time, the functional capacity of the pouch increases; by that time, weight loss has occurred, and the increased capacity serves to allow maintenance of a lower body weight.

When the patient ingests just a small amount of food, the first response is a stretching of the wall of the stomach pouch, stimulating nerves which tell the brain that the stomach is full. The patient feels a sensation of fullness, as if they had just eaten a large meal—but with just a thumbful of food. Most people do not stop eating simply in response to a feeling of fullness, but the patient rapidly learns that subsequent bites must be eaten very slowly and carefully, to avoid increasing discomfort, or even vomiting.

Food is first churned in the stomach before passing into the small bowel. When the lumen of the small bowel comes into contact with nutrients a number of hormones are released including cholecystikin (CCK) from the duodenum and PYY and GLP-1 from the ileum. These hormones inhibit further food intake and have thus been dubbed satiety factors. *Ghrelin*, is a hormone that is released in the stomach that stimulates hunger and food

intake. Changes in circulating hormone levels after gastric bypass have been hypothesized to produce reductions in food intake and body weight in obese patients. However, these findings remain controversial, and the exact mechanisms by which gastric bypass surgery reduces food intake and body weight have yet to be elucidated.

To gain the maximum benefit from this physiology, it is important that the patient eat only at mealtimes, 5 to 6 small meals daily, and NOT graze between meals, which can effectively "bypass the bypass". The meals after surgery are 1/4 to a 1/2 cup, slowly getting to 1 cup by 1 year. This requires a change in eating behavior, and alteration of long-acquired habits for finding food. In almost every case where weight gain occurs late after surgery, capacity for a meal has not greatly increased. The cause of regaining weight is eating between meals, usually high-caloric snack foods. There is no known operation which can completely counteract the adverse effects of destructive eating behavior. This surgery is only a tool and as with most tools, if not used correctly, it can be of no use. Concentration on 80 to 100 g of protein daily is necessary.

Complications

Any major surgery involves the potential for complications—adverse events which increase risk, hospital stay, and mortality. Some complications are common to all abdominal operations, while some are specific to bariatric surgery. A person who chooses to undergo bariatric surgery should know about these risks.

Mortality and complication rates

In experienced hands, the overall complication rate of this type of surgery ranges from 7% for laparoscopic procedures to 14.5% for operations through open incisions, during the 30 days following surgery. Mortality for this study was 0% in 401 laparoscopic cases, and 0.6% in 955 open procedures. Similar mortality rates—30-day mortality of 0.11%, and 90-day mortality of 0.3%—have been recorded in the U.S. Centers of Excellence program, the results from 33,117 operations at 106 centers.

Mortality is affected by complications, which in turn are affected by pre-existing risk factors such as degree of obesity, heart disease, obstructive sleep apnea, diabetes mellitus, and history of prior pulmonary embolism. It is also affected by the experience of the operating surgeon: the "learning curve" for laparoscopic bariatric surgery is estimated to be about 100 cases. Unfortunately, the way a surgeon becomes experienced in dealing with problems is by encountering those problems over time.

Complications of abdominal surgery

Infection

Infection of the incisions or of the inside of the abdomen (peritonitis, abscess) may occur, due to release of bacteria from the bowel during the operation. Nosocomial infection, such as pneumonia, bladder or kidney infections, and sepsis (bloodborne infection) are

also possible. Effective short-term use of antibiotics, diligent respiratory therapy, and encouragement of activity within a few hours after surgery, can reduce the risks of infections.

Hemorrhage

Many blood vessels must be cut in order to divide the stomach and to move the bowel. Any of these may later begin bleeding, either into the abdomen (intra-abdominal hemorrhage), or into the bowel itself (gastrointestinal hemorrhage). Transfusions may be needed, and re-operation is sometimes necessary. Use of blood thinners, to prevent venous thromboembolic disease, may actually increase the risk of hemorrhage slightly.

Hernia

A hernia is an abnormal opening, either within the abdomen, or through the abdominal wall muscles. An internal hernia may result from surgery, and re-arrangement of the bowel, and is mainly significant as a cause of bowel obstruction. An incisional hernia occurs when a surgical incision does not heal well; the muscles of the abdomen separate and allow protrusion of a sac-like membrane, which may contain bowel or other abdominal contents, and which can be painful and unsightly. The risk of abdominal wall hernia is markedly decreased in laparoscopic surgery.

Bowel obstruction

Abdominal surgery always results in some scarring of the bowel, called adhesions. A hernia, either internal or through the abdominal wall, may also result. When bowel becomes trapped by adhesions or a hernia, it may become kinked and obstructed, sometimes many years after the original procedure. Usually an operation is necessary to correct this problem.

Venous thromboembolism

Any injury, such as a surgical operation, causes the body to increase the coagulation of the blood. Simultaneously, activity may be reduced. There is an increased probability of formation of clots in the veins of the legs, or sometimes the pelvis, particularly in the morbidly obese patient. A clot which breaks free and floats to the lungs is called a pulmonary embolus, a very dangerous occurrence. Commonly, blood thinners are administered before surgery , to reduce the probability of this type of complication.

Complications of gastric bypass

Anastomotic leakage

An anastomosis is a surgical connection between the stomach and bowel, or between two parts of the bowel. The surgeon attempts to create a water-tight connection by connecting the two organs with either staples or sutures, either of which actually makes a hole in the

bowel wall. The surgeon will rely on the healing power of the body, and its ability to create a seal like a self-sealing tire, to succeed with the surgery. If that seal fails to form, for any reason, fluid from within the gastrointestinal tract can leak into the sterile abdominal cavity and give rise to infection and abscess formation. Leakage of an anastomosis can occur in about 2% of gastric bypass procedures, usually at the stomach-bowel connection. Sometimes leakage can be treated with antibiotics, and sometimes it will require immediate re-operation. It is usually safer to re-operate if an infection cannot be definitely controlled immediately.

Anastomotic stricture

As the anastomosis heals, it forms scar tissue, which naturally tends to shrink ("contract") over time, making the opening smaller. This is called a "stricture". Usually, the passage of food through an anastomosis will keep it stretched open, but if the inflammation and healing process outpaces the stretching process, scarring may make the opening so small that even liquids can no longer pass through it. The solution is a procedure called gastroendoscopy, and stretching of the connection by inflating a balloon inside it. Sometimes this manipulation may have to be performed more than once to achieve lasting correction.

Anastomotic ulcer

Ulceration of the anastomosis occurs in 1-16% of patients. Possible causes of such ulcers are:

- Restricted blood supply to the anastomosis (compare to the blood supply available to the original stomach)
- Anastomosis tension
- Gastric acid
- *Helicobacter pylori*
- Smoking
- Use of Non-steroidal anti-inflammatory drugs

This condition can be treated as follows:

- Use of Proton pump inhibitors, e.g., Nexium
- Use of a Cytoprotectant and acid Buffering agent, e.g., Sucralfate
- Temporary restriction of the consumption of solid foods

Dumping syndrome

Normally, the pyloric valve at the lower end of the stomach regulates the release of food into the bowel. When the Gastric Bypass patient eats a sugary food, the sugar passes rapidly into the bowel, where it gives rise to a physiological reaction called dumping syndrome. The body will flood the intestines in an attempt to dilute the sugars. An affected person may feel their heart beating rapidly and forcefully, break into a cold

sweat, get a feeling of butterflies in the stomach, and may have a "sky is falling" type of anxiety. He/she usually has to lie down, and could be very uncomfortable for about 30 to 45 minutes. Diarrhea may then follow.

Nutritional deficiencies

- Hyperparathyroidism, due to inadequate absorption of calcium, may occur for GBP patients. Calcium is primarily absorbed in the duodenum, which is bypassed by the surgery. Most patients can achieve adequate calcium absorption by supplementation with vitamin D and calcium citrate (carbonate may not be absorbed—it requires an acidic stomach, which is bypassed).
- Iron frequently is seriously deficient, particularly in menstruating females, and must be supplemented. Again, it is normally absorbed in the duodenum. Ferrous sulfate can cause considerable GI distress in normal doses; alternatives include ferrous fumarate, or a chelated form of iron. Occasionally, a female patient develops severe anemia, even with supplements, and must be treated with parenteral iron. The signs of iron deficiency are the following: brittle nails, an inflamed tongue, constipation, depression, headaches, fatigue, and mouth lesions

- Zinc Signs/symptoms for zinc deficiency are the following: acne, eczema, white spots on one's nails, hair loss, depression, amnesia and lethargy

- Thiamin If B_1 deficient, one runs the risk of permanent neurological damage (i.e. Wernicke's encephalopathy or polyneuropathy). Signs of thiamin deficiency are heart failure, memory loss, numbness of the hands, constipation and loss of appetite

- Vitamin B_{12} requires intrinsic factor from the gastric mucosa to be absorbed. In patients with a small gastric pouch, it may not be absorbed, even if supplemented orally, and deficiencies can result in pernicious anemia and neuropathies. Sublingual B_{12} appears to be adequately absorbed. In some patients, sublingual B_{12} (cyanocobalamin) does not provide sufficient amounts. In these patients, injections may be needed.
- Thiamine deficiency (also known as beriberi) will, rarely, occur as the result of its absorption site in the jejunum being bypassed. This deficiency can also result from inadequate nutritional supplements being taken post operatively.
- Protein malnutrition is a real risk. Some patients suffer troublesome vomiting after surgery, until their GI tract adjusts to the changes, and *cannot* eat adequate amounts even with 6 meals a day. Many patients require protein supplementation during the early phases of rapid weight loss, to prevent excessive loss of muscle mass. Hair loss is also a risk of protein malnutrition.
- Vitamin A deficiencies generally occur as a result of the deficiencies that involve the fat-soluble vitamins. This often comes after intestinal bypass procedures such as jejunoileal bypass (no longer performed) or biliopancreatic diversion/duodenal switch procedures. In these procedures, fat absorption is markedly impaired.

There is also the possibility of a vitamin A deficiency with use of Xenical or Alli weight loss medications.

Nutritional effects

After surgery, patients feel fullness after ingesting only a small volume of food, followed soon thereafter by a sense of satiety and loss of appetite. Total food intake is markedly reduced. Due to the reduced size of the newly created stomach pouch, and reduced food intake, adequate nutrition demands that the patient follow the surgeon's instructions for food consumption, including the number of meals to be taken daily, adequate protein intake, and the use of vitamin and mineral supplements. Calcium supplements, iron supplements, protein supplements, multi-vitamins (sometimes pre-natal vitamins are best) and B_{12} (cyanocobalamin) supplements are all very important to the post-operative bypass patient.

The total food intake and absorbance rate of food will rapidly decline after gastric bypass surgery. After gastric bypass surgery there is an increase in the number of acid producing cells in the lining of the stomach. Many doctors are prescribing acid lowering medications to counteract the high acidity levels. Many patients then experience a condition known as achlorhydria. Achlorhydria is a condition where there is not enough acid in stomach. Patients can develop an overgrowth of bacteria as a result of the low acidity levels in the stomach. A study conducted on 43 post operative patients revealed that almost all of the patients tested positive for a hydrogen breath test, which determined an overgrowth of bacteria in the small intestine The overgrowth of bacteria will cause the gut ecology to change and will induce nausea and vomiting. Recurring nausea and vomiting will change the absorbance rate of food which contributes to the vitamin and nutrition deficiencies common in post operative gastric bypass patients.

Protein nutrition

Proteins are essential food substances, contained in foods such as meat, fish and poultry, dairy products, soy, nuts, and eggs. With reduced ability to eat a large volume of food, gastric bypass patients must focus on eating their protein requirements first, and with each meal. In some cases, surgeons may recommend use of a liquid protein supplement. Powdered protein supplements added to smoothies or any food can be an important part of the post-op diet.

Calorie nutrition

The profound weight loss which occurs after bariatric surgery is due to taking in much less energy (calories) than the body needs to use every day. Fat tissue must be burned, to offset the deficit, and weight loss results. Eventually, as the body becomes smaller, its energy requirements are decreased, while the patient simultaneously finds it possible to eat somewhat more food. When the energy consumed is equal to the calories eaten, weight loss will stop. Proximal GBP typically results in loss of 60 to 80% of **excess** body

weight, and very rarely leads to excessive weight loss. The risk of excessive weight loss is slightly greater with Distal GBP.

Vitamins

Vitamins are normally contained in the foods we eat, as well as any supplements we may choose to take. The amount of food which will be eaten after GBP is severely reduced, and vitamin content is correspondingly reduced. Supplements should therefore be taken, to completely cover minimum daily requirements of all vitamins and minerals. Pre-natal vitamins are sometimes suggested by doctors, as they contain more of certain vitamins than "regular" multi-vitamins. Absorption of most vitamins is not seriously affected after proximal GBP, although vitamin B_{12} may not be well-absorbed in some persons. Sublingual preparations of B_{12} will provide adequate absorption. Some studies suggest that GBP patients who took probiotics after surgery were able to absorb and retain higher amounts of B_{12} than patients who did not take probiotics after surgery. After the distal GBP, fat-soluble vitamins A, D and E may not be well-absorbed, particularly if fat intake is large. Water-dispersed forms of these vitamins may be indicated, on specific physician recommendation. For some patients, sublingual B_{12} is not enough, and patients may require B_{12} injections.

Minerals

All versions of the GBP bypass the duodenum, which is the primary site of absorption of both iron and calcium. Iron replacement is essential in menstruating females, and supplementation of iron and calcium is preferable in all patients. Ferrous sulfate is poorly tolerated. Alternative forms of iron (fumarate, gluconate, chelates) are less irritating and probably better absorbed. Calcium *carbonate* preparations should also be avoided; calcium as citrate or gluconate, 1200 mg as calcium, has greater bioavailability independent of acid in the stomach, and will likely be better absorbed. Chewable calcium supplements that include vitamin K are sometimes recommended by doctors as a good way to get calcium.

Alcohol Metabolism

There was a study that confirmed post operative gastric bypass patients will absorb alcohol at a faster rate than people who have not undergone the surgery. It will also take a post operative patient longer to reach sober levels after consuming alcohol than those who have not undergone the surgery. A study was conducted on 36 post operative patients and a control group of 36 subjects who have not undergone the surgery. Each subject was given a 5 oz of glass of red wine and the alcohol in their breath was measured to evaluate their alcohol metabolism. The gastric bypass group had an average peak alcohol breath level at 0.08%. The control group had an average peak alcohol breath level of 0.05%. It took on average 108 minutes for the gastric bypass patients group to return to an alcohol breath of zero, while it took the control group an average of 72 minutes to return to an alcohol breath of zero. Patients who have undergone gastric bypass surgery will have a lower tolerance than people who have not gone through the surgery. It will

also take a gastric bypass patient longer to return to a sober level after drinking alcohol than a person who has consumed alcohol that has not had the surgery.

Pica

There was a study conducted that confirmed the development of pica after gastric bypass surgery due to iron deficiencies. Pica is a compulsive tendency to eat substances other than normal food. Some examples would be people eating paper, clay, plaster, ashes, or ice. A study was conducted on a female post operative gastric bypass patient who was consuming eight to ten 32oz glasses of ice a day. The patient's blood test revealed iron levels of 2.3 mmol/L and hemoglobin level of 5.83 mmol/L. The patient was then given iron supplements that brought her hemoglobin and iron blood levels to a normal level. After one month the patient's eating diminished to two to three glasses per day. After one year of taking iron supplements the patient's iron and hemoglobin levels remained in a normal range and the patient reported that she did not have any further cravings for ice. The patient was eating ice due to the iron deficiencies that occurred after gastric bypass surgery. Low levels of iron and hemoglobin are common in patients who have undergone gastric bypass. Pica is more common in gastric bypass patients who have a history of the condition prior to the surgery.

Results and health benefits of gastric bypass

Weight loss of 65 to 80% of excess body weight (the amount by which actual body weight exceeds actuarial ideal body weight) is typical of most large series of Gastric Bypass operations reported. The medically more significant effects are a dramatic reduction in co-morbid conditions:

- Hyperlipidemia is corrected in over 70% of patients.
- Essential hypertension is relieved in over 70% of patients, and medication requirements are usually reduced in the remainder.
- Obstructive sleep apnea is markedly improved with weight loss and bariatric surgery may be curative for sleep apnea. Snoring also improves in most patients.
- Diabetes mellitus type 2 is reversed in up to 90% of patients usually leading to a normal blood sugar without medication, sometimes within days of surgery.
- Gastroesophageal reflux disease is relieved from the time of surgery in almost all patients.
- Venous thromboembolic disease signs such as leg swelling are typically much improved.
- Low back pain and joint pain are typically relieved or improved in nearly all patients.

A recent study in a large comparative series of patients showed an 89% reduction in mortality over the 5 years following surgery, compared to a non-surgically treated group of patients.

Concurrently, most patients are able to enjoy greater participation in family and social activities.

Living with gastric bypass

Gastric bypass surgery has an emotional, as well as a physiological, impact on the individual. Many who have undergone the surgery suffer from depression in the following months. This is a result of a change in the role food plays in their emotional well-being. Strict limitations on the diet can place great emotional strain on the patient. Energy levels in the period following the surgery will be low. This is due again to the restriction of food intake, but the negative change in emotional state will also have an impact here. It may take as long as three months for emotional levels to rebound. Muscular weakness in the months following surgery is common. This is caused by a number of factors, including a restriction on protein intake, a resulting loss in muscle mass and decline in energy levels. The weakness may result in balance problems, difficulty climbing stairs or lifting heavy objects, and increased fatigue following simple physical tasks. Many of these issues will pass over time as food intake gradually increases. However, the first months following the surgery can be very difficult, an issue not often mentioned by physicians suggesting the surgery. The benefits and risks of this surgery are well established; however, the psychological effects are not well understood, and potential patients should ensure a strong support system before agreeing to the procedure. It is important for patients to start changing their outlook on food and diets before surgery to avoid the shock after.

Surgeon accreditation

The American Society for Metabolic & Bariatric Surgery lists bariatric programs and surgeons in its "Centers of Excellence" network, while the American College of Surgeons accredits providers through its Bariatric Surgery Center Network. For listings of surgeons and centers in other countries, the International Federation for the Surgery of Obesity and Metabolic Disorders lists medical associations by country.

Chapter 12

Adjustable Gastric Band

Diagram of an adjustable gastric band.

A **laparoscopic adjustable gastric band**, commonly referred to as a **lap band**, is an inflatable silicone device that is placed around the top portion of the stomach, via laparoscopic surgery, in order to treat obesity. Adjustable gastric band surgery is an example of bariatric surgery designed for obese patients with a body mass index (BMI) of 40 or greater—or between 35–40 in cases of patients with certain comorbidities that are known to improve with weight loss, such as sleep apnea, diabetes, osteoarthritis, GERD, Hypertension (high blood pressure), or metabolic syndrome, among others.

Medio February 2011: The Food and Drug Administration expanded approval of Adjustable gastric band to patients with a BMI between 30 to 40 and one weight-related

medical condition such as diabetes or high blood pressure. However, an adjustable gastric band may only be used after other methods such as diet and exercise have previously been tried.

How gastric banding works

According to the American Society for Metabolic Bariatric Surgery, bariatric surgery is not an easy option for obesity sufferers. It is a drastic step, and carries the usual pain and risks of any major gastrointestinal surgical operation.

However, gastric banding is the least invasive surgery of its kind. Gastric banding is performed using laparoscopic surgery and usually results in a shorter hospital stay, faster recovery, smaller scars, and less pain than open surgical procedures. Because no part of the stomach is stapled or removed, and the patient's intestines are not re-routed, he or she can continue to absorb nutrients from food normally. Gastric bands are made entirely of biocompatible materials, so they are able to stay in the patient's body without causing harm.

However, not all patients are suitable for laparoscopy. Patients who are extremely obese, who have had previous abdominal surgery, or have complicating medical problems may require the open approach.

Laparoscopic surgery

A small incision (less than 1/2 inch) is made near the belly button. Carbon dioxide (a gas that occurs naturally in the body) is introduced into the abdomen to create a work space for the surgeon. Then a small laparoscopic camera is placed through the incision into the abdomen.

The camera sends a picture of the stomach and abdominal cavity to a video monitor. It gives the surgeon a good view of the key structures in the abdominal cavity. A few additional, small incisions are made in the abdomen. The surgeon watches the video monitor and works through these small incisions using instruments with long handles to complete the procedure. The surgeon creates a small, circular tunnel behind the stomach, inserts the gastric band through the tunnel, and locks the band around the stomach.

Clinical studies of laparoscopic (minimally invasive) bariatric surgery patients found that they felt better, spent more time doing recreational and physical activities, benefited from enhanced productivity and economic opportunities, and had more self-confidence than they did prior to surgery.

Mechanics

The placement of the band creates a small pouch at the top of the stomach. This pouch holds approximately ½ cup of food, whereas the typical stomach holds about 6 cups of food. The pouch fills with food quickly, and the band slows the passage of food from the

pouch to the lower part of the stomach. As the upper part of the stomach registers as full, the message to the brain is that the entire stomach is full, and this sensation helps the person to be hungry less often, feel full more quickly and for a longer period of time, eat smaller portions, and lose weight over time.

As patients lose weight, their bands will need adjustments, or "fills," to ensure comfort and effectiveness. The gastric band is adjusted by introducing a saline solution into a small access port placed just under the skin. A specialized non-coring needle is used to avoid damage to the port membrane and prevent leakage. There are many port designs (such as high profile and low profile), and they may be placed in varying positions based on the surgeon's preference, but are always attached (through sutures, staples, or another method) to the muscle wall in and around the diaphragm.

Adjustable gastric bands hold between 4 to 12 cc of saline solution, depending on their design. When the band is inflated with saline solution, it places pressure around the outside of the stomach. This decreases the size of the passage between the pouch created from the upper part of the stomach and the lower stomach and further restricts the movement of food. Over the course of several visits to the doctor, the band is filled until the optimal restriction has been achieved – neither so loose that hunger is not controlled, nor so tight that food cannot move through the digestive system. The number of adjustments required is an individual experience and cannot be accurately predicted.

Types of adjustable bands

In the U.S. market, two types of adjustable gastric bands have been approved by the FDA: Realize Band and Lap-Band.

The **Lap-Band** System obtained FDA approval in 2001. The device comes in five different sizes and has undergone modification over the years. The latest models, the Lap-Band AP-L and Lap-Band AP-S, feature a standardized injection port sutured into the skin and fill volumes of 14 mL and 10 mL respectively.

The **Realize Adjustable Gastric Band** obtained FDA approval in 2007. Realize Band-C has a 14% greater adjustment range than the Realize Band. But both the Realize Band and Realize Band-C are one-size-fits-all. The device differentiates itself from the Lap-Band AP series through its sutureless injection port installation and larger range of isostatic adjustments. The maximum fill volume for the Realize Band is 9mL, while the newer Realize Band-C is less capacity. Both fill volumes fall within a low pressure range to prevent discomfort or strain to the band.

Two other adjustable gastric bands are in use outside of the United States: Heliogast and Midband. Neither band has been approved by the FDA. The Midband was the first to market in 2000. In order to preserve the gastric wall in event of rubbing, the device contains no sharp edges or irregularities. It is also opaque to x-rays, making it easy to locate and adjust. The Heliogast band entered the market in 2003. The device features a streamlined band to ease insertion during the operation.

Surgical indications

In general, gastric banding is indicated for people for whom all of the following apply:

- Body Mass Index above 40, or those who are 100 pounds (7 stone/45 kilograms) or more over their estimated ideal weight, according to the National Institutes of Health, or those between 35 to 40 with co-morbidities that may improve with weight loss (type 2 diabetes, hypertension, high cholesterol, non-alcoholic fatty liver disease and obstructive sleep apnea.)
- Age between 18 and 55 years (although there are doctors who will work outside these ages, some as young as 12).
- Failure of medically supervised dietary therapy (for about 6 months).
- History of obesity (up to 5 years - depending on the Insurance pre-approval requirements).
- Comprehension of the risks and benefits of the procedure and willingness to comply with the substantial lifelong dietary restrictions required for long term success.

Gastric banding is usually not recommended for people with any of the following:

- If the surgery or treatment represents an unreasonable risk to the patient
- Untreated endocrine diseases such as hypothyroidism
- Inflammatory diseases of the gastrointestinal tract such as ulcers, esophagitis or Crohn's disease.
- Severe cardiopulmonary diseases or other conditions which may make them poor surgical candidates in general.
- An allergic reaction to materials contained in the band or who have exhibited a pain intolerance to implanted devices
- Dependency on alcohol or drugs
- People with severe learning or cognitive disabilities or emotionally unstable people

Special considerations for pregnancy

If considering pregnancy, ideally the patient should be in optimum nutritional condition prior to, or immediately following conception; deflation of the band may be required prior to a planned conception. Deflation should also be considered should the patient experience morning sickness. The band may remain deflated during pregnancy and once breast feeding is completed, or if bottle feeding, the band may be gradually re-inflated to aid postpartum weight loss as needed.

Comparison with other bariatric surgeries

Unlike more open forms of weight loss surgery (e.g. Roux-en-Y gastric bypass surgery (RNY), Biliopancreatic Diversion (BPD) and Duodenal Switch (DS)), gastric banding

does not require cutting or removing any part of the digestive system. It is also reversible, requiring only a laparoscopic procedure to remove the band, after which the stomach usually returns to its normal pre-banded state. However, it is not unusual for a person to gain weight after having a band removed. Unlike those who have procedures such as RNY, DS, or BPD, it is unusual for gastric band patients to experience any nutritional deficiencies or malabsorption of micro-nutrients. Calcium supplements and Vitamin B12 injections are not routinely required following gastric banding (as they are with RNY, for example). Gastric dumping syndrome issues also do not occur since intestines are not removed or re-routed.

Typically, patients who undergo adjustable gastric banding procedures lose less weight over the first 3.5 years than those who have RNY gastric bypass, BPD, or DS surgeries. Although other procedures appear to result in greater weight loss than adjustable gastric banding in the short term, results from the study by Maggard suggest that this difference decreases significantly over time. Gastric banding patients lose an average of 47.5% of their excess weight, according to a meta analysis by Buchwald.

It is important to note that, in order to maintain their weight reduction, patients must carefully follow post-operative guidelines relating to diet, exercise, and band maintenance. Weight regain is possible with any weight loss procedure, including the more radical procedures that initially result in rapid weight loss. The National Institutes of Health recommendation for weight loss is 1 to 2 pounds (½ to 1 kilogram) per week, and an average banded patient may lose this amount. This is variable based on the individual and their personal circumstances, motivation, and mobility.

Benefits of gastric banding when compared to other bariatric surgeries

- Lower mortality rate: only 1 in 2000 versus 1 in 250 for Roux-en-Y gastric bypass surgery
- Mostly reversible: stomach returns to normal if the band is removed but does have many adhesions making a revision surgery more dangerous
- No cutting or stapling of the stomach
- Short hospital stay
- Quick recovery
- Adjustable without additional surgery
- No malabsorption issues (because no intestines are bypassed)
- Fewer life threatening complications

Potential complications

A commonly reported occurrence for banded patients is regurgitation of non-acidic swallowed food from the upper pouch, commonly known as Productive Burping (PBing). Productive Burping is not to be considered normal. The patient should consider eating less, eating more slowly and chewing their food more thoroughly. Occasionally, the narrow passage into the larger, lower part of the stomach might also become blocked by a large portion of unchewed or unsuitable food.

Other complications include:

- Ulceration
- Gastritis (irritated stomach tissue)
- Erosion -The band may slowly migrate through the stomach wall. This will result in the band moving from the outside of the stomach to the inside. This may occur silently but can cause severe problems. Urgent treatment may be required if there is any internal leak of gastric contents or bleeding.
- Slippage - An unusual occurrence in which the lower part of the stomach may prolapse through the band causing an enlarged upper pouch. In severe instances this can cause an obstruction and require an urgent operation to fix.
- Malposition of the band - This can cause a kink in the stomach, or (rarely) the band may not encircle the stomach at all, giving no restriction to the passage of food.
- Band was not placed on the stomach - (very rare - especially with an experienced bariatric surgeon.) However, in two asymptomatic patients, the band had not enclosed the stomach but only perigastric fat.
- Problems with the port and/or the tube connecting port and band - The port can "flip over" so that the membrane can no longer be accessed with a needle from the outside (this often goes hand in hand with a tube kink, and may require repositioning as a minor surgical procedure under local anaesthesia); the port may get disconnected from the tube or the tube may be perforated in the course of a port access attempt (both would result in loss of fill fluid and restriction, and likewise require a minor operation).
- Internal bleeding
- Infection

Documented adverse effects

The following are the adverse effects of gastric banding as documented by the FDA.

Band- and port-specific

- Band slippage/pouch dilation
- Esophageal dilatation/dysmotility
- Erosion of the band into the gastric lumen
- Mechanical malfunctions - port leakage, cracking of the kink-resistant tubing or disruption of the tubing connection from the port to the band
- Port site pain
- Port displacement
- Infection of the fluid within the band
- Bulging of the port through the skin

Digestive

- Nausea and/or vomiting

- Gastroesophageal reflux
- Stoma (medicine)obstruction
- Constipation
- Dysphagia
- Diarrhea
- Abnormal stools / Constipation
- Diverticulosis

Body as a whole

- Abdominal pain
- Asthenia
- Death
- Infection
- Fever
- Hernia
- Pain
- Chest pain
- Incisional infection
- Incision pain
- Blood clots
- Hair loss

Miscellaneous

- Abnormal healing
- Alopecia
- Band intolerance
- An inability to maintain proper restriction

Losing weight after surgery

Effectiveness

The average gastric banding patient loses 500 grams to a kilogram (1-2 pounds) per week consistently, but heavier patients often lose faster in the beginning. This comes to roughly 22 to 45 kilograms (48 to 99 pounds) the first year for most band patients. It is important to keep in mind that while most of the RNY patients drop the weight faster in the beginning, some studies have found that LAGB patients will have the same percentage of excess weight loss and comparable ability to keep it off after only a couple of years. The procedure tends to encourage better eating habits which, in turn, helps in producing long term weight stability. However, with greater experience and longer patient follow up, several studies have found suboptimal weight loss and high complication rates for the gastric band.

A systematic review concluded "LAGB has been shown to produce a significant loss of excess weight while maintaining low rates of short-term complications and reducing obesity-related comorbidities. LAGB may not result in the most weight loss but it may be an option for bariatric patients who prefer or who are better suited to undergo less invasive and reversible surgery with lower perioperative complication rates. One caution with LAGB is the uncertainty about whether the low complication rate extends past three years, given a possibility of increased band-related complications (e.g., erosion, slippage) requiring re-operation".

Band adjustments and weight loss

Correct and sensitive adjustment of the band is imperative for weight loss and the long term success of the procedure. Adjustments (also called "fills") may be performed using an X-ray fluoroscope so that the radiologist can assess the placement of the band, the port, and the tubing that runs between the port and the band. The patient is given a small cup of liquid containing a clear or white radio-opaque fluid similar to barium—clear or white. When swallowed, the fluid is clearly shown on X–ray and is watched as it travels down the esophagus and through the restriction caused by the band. The radiologist is then able to see the level of restriction in the band and to assess if there are potential or developing issues of concern. These may include dilation of the esophagus, an enlarged pouch, prolapsed stomach (when part of the stomach moves into the band where it does not belong), erosion or migration. Reflux type symptoms may indicate too great a restriction and further assessment may be required.

Under some circumstances fluid is removed from the band prior to further investigation and re-evaluation. In other cases further surgery may be required (e.g. removal of the band), should gastric erosion or a similar complication be detected. Some health practitioners adjust the band without the use of X-ray control (fluoroscopy). In these cases, the doctor assesses the patient's weight loss and potential reflex symptoms described by the patient, such as heartburn, regurgitation, or chest pain. From this information, the doctor decides whether a band adjustment is necessary. Adjustments are often indicated if a patient has regained weight, if their weight loss has leveled off, or if the patient has a distinct feeling that food is difficult to move through the stoma.

During a clinical visit, patients visiting for a regular fill adjustment will typically find they will spend more time talking about the adjustment and their progress than the actual fill itself, which generally will only take about one to two minutes. However, for some patients this type of fill is not possible, due to issues such as partial rotation of the port, or excess tissue above the port making it difficult to determine its precise location. In these cases, a fluoroscope will generally be used. It is more common practice for the band not to be filled at surgery—although some surgeons choose to place a small amount in the band at the time of surgery. The stomach tends to swell following surgery and it is possible that too great a restriction would be achieved if filled at that time. Clearly, this is undesirable.

Many health practitioners make the first adjustment between 4–6 weeks post operatively to allow the stomach time to heal. After that, fills are performed as needed.

No accurate number of adjustments required can be given. The amount of saline/isotonic solution needed in the band varies from patient to patient. There are a small number of people who find they do not need a fill at all and have sufficient restriction immediately following surgery. Others may need significant adjustments to the maximum the band is able to hold.

Post-surgical diet and care

The patient may be prescribed a liquid-only diet, followed by mushy foods and then solids. This is prescribed for a varied length of time and each surgeon and manufacturer varies. Some may find that before their first fill that they are still able to eat fairly large portions. This is not surprising since before the fill there is little or no restriction in the band. This is why a proper post-op diet and a good after-care plan is essential to success. A recent study found that patients who did not change their eating habits were 2.2 times more likely to be unsuccessful than those who did, and that patients who had not increased their physical activity were 2.3 times more likely to be unsuccessful than those who did .

In principle, a diet long term post gastric band surgery should consist of normal healthy food, that is solid in nature and requires ample chewing to achieve a paste consistancy prior to swallowing. This texture will maximise the effect of the band. Rather than choosing easier wet foods, such as soups, casseroles and smoothies, which pass through the band quickly and easily resulting in greater caloric intake.

It is very important to discuss post-surgical care and diet plans with your weight loss team if you are considering this surgery. Recommendations can vary dramatically from team to team and it is important to find a weight loss team with a good post-surgical plan. Some teams offer support groups, but unfortunately many of them mix RNY and gastric bypass patients with gastric banding patients. Some gastric band patients have criticized this approach because while many of the underlying issues related to obesity are the same, the needs and challenges of the two groups are very different, as are their early rates of weight loss. Some gastric band recipients feel the procedure is a failure when they see that RNY patients generally lose weight faster.

History and development of gastric banding

Non-adjustable bands

At the end of the 1970s, Wilkinson developed several surgical approaches whose common aim was to limit food intake without disrupting the continuity of the gastro-intestinal tract.

In 1978 Wilkinson and Peloso were the first to place, by open procedure, a non-adjustable band (2 cm Marlex mesh) around the upper part of the stomach.

The early 1980s saw further developments, with Kolle (Norway), Molina & Oria (US), Naslund (Sweden), Frydenberg (Australia) and Kuzmack (United States) implanting non-adjustable gastric bands made from a variety of different materials, including marlex mesh, dacron vascular prosthesis, silicone covered mesh and Gore-Tex, among others. In addition, Bashour developed the "gastro-clip" a 10.5 cm polypropylene clip with a 50cc pouch and a fixed 1.25 cm stoma, which was later abandoned due to high rates of gastric erosion

All these early attempts at restriction using meshes, bands and clips showed a high failure rate due to difficulty in achieving correct stomal diameter, stomach slippage, erosion, food intolerance, intractable vomiting and pouch dilatation. Despite these difficulties, an important ancillary observation was that silicone was identified as the best tolerated material for a gastric device, with far fewer adhesions and tissue reactions than other materials. Nevertheless, adjustability became the "Holy Grail" of these early pioneers.

Adjustable bands

The development of the modern adjustable gastric band is a tribute both to the vision and persistence of the early pioneers, particularly Lubomyr Kuzmak and a sustained collaborative effort on the part of bio-engineers, surgeons and scientists.

Early research on the concept of band "adjustability" can be traced back to the early work of G. Szinicz (Austria) who experimented with an adjustable band, connected to a subcutaneous port, in animals.

In 1986, Lubomyr Kuzmak, a Ukrainian surgeon who had emigrated to the United States in 1965, reported on the clinical use of the "adjustable silicone gastric band" (ASGB) via open surgery. Kuzmak, who from the early 1980s had been searching for a simple and safe restrictive procedure for severe obesity, modified his original silicone non-adjustable band he had been using since 1983, by adding an adjustable portion. His clinical results showed an improved weight loss and reduced complication rates compared with the non-adjustable band he had started using in 1983. Kuzmak's major contributions were the application of Mason's teachings about VBG to the development of the gastric band; the volume of the pouch; the need to overcome staple line disruption; the ratification of the use of silicone and the essential element of adjustability.

Separately, but in parallel with Kuzmak, Hallberg and Forsell in Stockholm, Sweden also developed an adjustable gastric band. After further work and modifications this eventually became known as the Swedish Adjustable Gastric Band (SAGB).

In early 1985, Dr. Dag Hallberg applied for a patent for the Swedish Adjustable Gastric Band (SAGB) within Scandinavian countries. In late March, Dr. Hallberg presented his idea of the "balloon band" at the Swedish Surgical Society and started to use the SAGB

in a controlled series of 50 procedures. During this time, laparoscopic surgery was not common and Dr. Hallberg and his assistant, Dr. Peter Forsell, started performing the open technique to implant the SAGB.

In 1992, Dr. Forsell was in contact with different surgeons in Switzerland, Italy and Germany who began to implant the SAGB with the laparoscopic technique. Dr. Forsell fully owned the patent at this time. In 1994, Dr. Forsell presented the SAGB at an international workshop for bariatric surgery in Sweden, and from then on, the SAGB started to be implanted laparoscopically. During this time, the SAGB was manufactured by a Swedish company, ATOS Medical.

The laparoscopic era

The advent of surgical laparoscopy transformed the field of bariatric surgery and made the gastric band an even more appealing option for the surgical management of obesity.

In 1992, Cadiere was the first to apply an adjustable band (the early Kuzmak ASGB) by the laparoscopic approach. In 1993, Broadbent in Australia and Catona in Italy, implanted non-adjustable (Molina-type) gastric bands by laparoscopy.

In the period between 1991–1993, the original Kuzmak ASGB underwent important research and design modifications in order to make it suitable for laparoscopic implantation, eventually emerging as the modern lap band. This landmark innovation was driven by Belachew, Cadiere, Favretti and O'Brien and the Inamed Development Company engineered the device. The first human laparoscopic implantation of the newly developed lap band was performed by Belachew and le Grand on 1st Sept 1993 in Huy, Belgium, followed on 8 September, by Cadiere and Favretti in Padua, Italy.

In 1994, the first international laparoscopic band workshop was held in Belgium and the first on the SAGB in Sweden.

Single Site Laparoscopy (SSL)

Single Site Laparoscopy (SSL), or also referred to as Single Incision Laparoscopic Surgery (SILS), is an advanced, minimally invasive (keyhole) procedure in which the surgeon operates almost exclusively through a single entry point, typically the patient's umbulicus (navel). Special articulating instruments and access ports obviate the need to place trocars externally for triangulation, thus allowing the creation of a small, solitary portal of entry into the abdomen.

SSL has been used for several common surgical procedures including hernia repair, cholecystectomy and nephrectomy. The SILS technique has also been used in weight-loss surgery for both sleeve gastrectomy and – more recently – for laparoscopic adjustable gastric banding (LAGB).

Chapter 13

Nissen Fundoplication

Nissen fundoplication is a surgical procedure to treat gastroesophageal reflux disease (GERD) and hiatus hernia. In GERD it is usually performed when medical therapy has failed, but with *paraesophageal* hiatus hernia, it is the first-line procedure. The Nissen fundoplication is total (360º), but partial fundoplications known as Belsey fundoplication (270º anterior transthoracic), Dor fundoplication (anterior 180-200º) or Toupet fundoplication (posterior 270º) are also alternative procedures with somewhat different indications.

History

Dr. Rudolph Nissen first performed the procedure in 1955 and published the results of two cases in a 1956 *Swiss Medical Weekly*. In 1961 he published a more detailed overview of the procedure. Nissen originally called the surgery "gastroplication." The procedure has borne his name since it gained popularity in the 1970s.

Technique

In a *fundoplication*, the gastric fundus (upper part) of the stomach is wrapped, or plicated, around the lower end of the esophagus and stitched in place, reinforcing the closing function of the lower esophageal sphincter. The esophageal hiatus is also narrowed down by sutures to prevent or treat concurrent hiatal hernia, in which the fundus slides up through the enlarged esophageal hiatus of the diaphragm.

In a Nissen fundoplication, also called a complete fundoplication, the fundus is wrapped all the way 360 degrees around the esophagus. In contrast, surgery for achalasia is generally accompanied by either a *Dor* or *Toupet* partial fundoplication, which is less likely than a Nissen wrap to aggravate the dysphagia that characterizes achalasia. In a Dor (anterior) fundoplication, the fundus is laid over the top of the esophagus; while in a Toupet (posterior) fundoplication, the fundus is wrapped around the back of the esophagus.

The procedure is now routinely performed laparoscopically. When used to alleviate gastroesophageal reflux symptoms in patients with delayed gastric emptying, it is

frequently combined with modification of the pylorus via pyloromyotomy or pyloroplasty.

Mechanism of relief

Whenever the stomach contracts, it also closes off the esophagus instead of squeezing stomach acids into it. This prevents the reflux of gastric acid (in GERD).

Complications

Nissen fundoplication is generally considered to be safe and effective, with a mortality rate of less than 1%. Studies have shown that after 10 years, 89.5% of patients are still symptom-free.

Complications include "gas bloat syndrome", dysphagia (trouble swallowing), dumping syndrome, excessive scarring, and rarely, achalasia. The fundoplication can also come undone over time in about 5-10% of cases, leading to recurrence of symptoms. If the symptoms warrant a repeat surgery, the surgeon may use Marlex or another form of artificial mesh to strengthen the connection. Postoperative irritable bowel syndrome, which lasts for roughly 2 weeks, is possible.

In "gas bloat syndrome", patients report being unable to belch, leading to an accumulation of gas in the stomach or small intestine. This is said to occur in 2-5% of patients, depending on surgical technique, and is commonly believed to be related to the tightness of the "wrap". Most often, gas bloat syndrome is self-limiting within 2 to 4 weeks, but in some it may persist. The offending gas may come from dietary sources, especially carbonated beverages; another suspected cause is involuntary swallowing of air (aerophagia). If gas bloat syndrome occurs postoperatively and does not resolve with time, dietary restrictions, and counselling regarding aerophagia, it may be beneficial to consider treating the condition with an endoscopic balloon dilatation.

During a laparoscopic Nissen fundoplication the operable area is inflated with gas to make the operation easier, which puts pressure on gastrointestinal organs, inhibiting their correct function. This, in conjunction with psychological and physical trauma from the operation, results in "post operative irritable bowel syndrome". The symptoms are usually initial constipation (due to recent paralysis of the muscles controlling peristalsis because of the use of anesthetics such as Propofol), remaining air, and trauma. Once the fecal matter is expelled, rapid onset diarrhea and gas expulsion is expected. Diverticulitis may occur if more fibrous material are consumed (such as porridge oats). Constipation will occur if too much fiber is eaten, which can last from 1 – 3 days, with lower frontal cramping.

Vomiting is often difficult or even impossible with a fundoplication. In some cases, the purpose of this operation is to correct excessive vomiting. However, when its purpose is to reduce gastric reflux, difficulty in vomiting may be an undesired outcome. Initially,

vomiting is impossible; however, small amounts of vomit may be produced after the wrap settles over time, and in extreme cases such as alcohol poisoning or food poisoning, the patient may be able to vomit freely.

Chapter 14

Ileostomy and Colostomy

Ileostomy

Intervention:
Ileostomy

ICD-10 code:
ICD-9 code: 46.2
MeSH   D007081

Ileostomy.

An **ileostomy** is a surgical opening constructed by bringing the end or loop of small intestine (the ileum) out onto the surface of the skin. Intestinal waste passes out of the ileostomy and is collected in an external pouching system stuck to the skin. Ileostomies are usually sited above the groin on the right hand side of the abdomen.

Ileostomies are slowly being replaced by the now preferred alternative K-Pouch or BCIR. This surgery turns the small intestine into an internal reservoir thus eliminating the need for an external appliance.

Reasons for having an ileostomy

Ileostomies are necessary where disease or injury has rendered the large intestine incapable of safely processing intestinal waste, typically because the colon has been partially or wholly removed. Diseases of the large intestine which may require surgical removal include:

- Crohn's disease
- Ulcerative colitis
- Familial adenomatous polyposis
- Total colonic Hirschprung's disease

An ileostomy may also be necessary in the treatment of colorectal cancer; one example is a situation where the tumor is causing a blockage. In such a case the ileostomy may be temporary, as the common surgical procedure for colorectal cancer is to reconnect the remaining sections of colon or rectum following removal of the tumor provided that enough of the rectum remains intact to preserve sphincter function. In a **temporary ileostomy**, a loop of the small intestine is brought through the skin, and the colon and rectum are not removed. Temporary ileostomies are also often made as the first stage in surgical construction of an ileo-anal pouch, so fecal material doesn't enter the newly-made pouch until it heals and has been tested for leaks – usually a period of eight to ten weeks. The temporary ostomy is then "taken down" or reversed by surgically repairing the loop of intestine which made the temporary stoma and closing the skin incision.

Living with an ileostomy

Ileostomy with bag (pouch).

People with ileostomies must use an ostomy pouch to collect intestinal waste. People with ileostomies typically use an open-end, or "drainable" pouch that is secured at the lower end with a leakproof clip, rather than a closed-end pouch which must be thrown away when full. Ordinarily the pouch must be emptied several times a day (many ostomates find it convenient to do this whenever they make a trip to the bathroom to urinate) and changed every 2-5 days, when the wafer starts to deteriorate. Ostomy pouches fit close to the body and are usually not visible under regular clothing unless the wearer allows the pouch to become too full.

Some people find they must make adjustments to their diet after having an ileostomy. Tough or high-fiber foods (including, for example, potato skins and raw vegetables) are hard to digest in the small intestine and may cause blockages or discomfort when passing through the stoma. Chewing food thoroughly can help to minimize such problems. Some people also find that certain foods cause annoying gas or diarrhea. Nevertheless, people who have an ileostomy as treatment for inflammatory bowel disease typically find they can enjoy a more "normal" diet than they could before surgery.

Other complications can include kidney stones, gallstones, and post-surgical adhesions. A 5-year study of patients who had ileostomy surgery in 1997 found the risk of adhesion-related hospital readmission to be 11%

Other options

Since the late 1970s an increasingly popular alternative to an ileostomy has been the ileo-anal pouch. With such a pouch an internal reservoir is formed using the ileum and connecting it to the anus, after removal of the colon and rectum, thus avoiding the need for an external appliance.

Colostomy

***Intervention:
Colostomy***
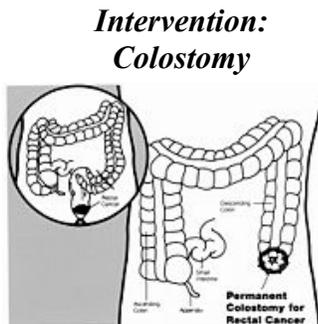
Line drawing showing a permanent colostomy for rectal cancer.

ICD-10 code:	
ICD-9 code:	46.1
MeSH	D003125
Other codes:	

A **colostomy** is a reversible surgical procedure in which a stoma is formed by drawing the healthy end of the large intestine or colon through an incision in the anterior

abdominal wall and suturing it into place. This opening, in conjunction with the attached stoma appliance, provides an alternative channel for feces to leave the body.

Indications

There are many reasons for this procedure. Some common reasons are:

- A section of the colon has been removed, e.g. due to colon cancer requiring a total mesorectal excision, diverticulitis, injury, etc, so that it is no longer possible for feces to exit via the anus.
- A portion of the colon (or large intestine) has been operated upon and needs to be 'rested' until it is healed. In this case, the colostomy is often temporary and is usually reversed at a later date, leaving the patient with a small scar in place of the stoma. Children undergoing surgery for extensive pelvic tumors commonly are given a colostomy in preparation for surgery to remove the tumor, followed by reversal of the colostomy.

Options

Placement of the stoma on the abdomen can occur at any location along the colon, but the most common placement is on the lower left side near or in the sigmoid membrane wall. Other locations include the ascending, transverse, and descending sections of the colon.

Types of colostomy:

- **Loop colostomy:** This type of colostomy is usually used in emergencies and is a temporary and large stoma. A loop of the bowel is pulled out onto the abdomen and held in place with an external device. The bowel is then sutured to the abdomen and two openings are created in the one stoma: one for stool and the other for mucus.
- **End colostomy:** A stoma is created from one end of the bowel. The other portion of the bowel is either removed or sewn shut (Hartmann's pouch).
- **Double barrel colostomy:** The bowel is severed and both ends are brought out onto the abdomen. Only the proximal stoma is functioning.

Colostomy surgery that is pre-planned usually has a higher rate of long-term success than surgery performed in an emergency situation.

Colostomy with irrigation

People with colostomies who have ostomies of the sigmoid colon or descending colon may have the option of irrigation, which allows for the person to not wear a pouch, but rather just a gauze cap over the stoma, and to schedule irrigation for times that are convenient. To irrigate, a catheter is placed inside the stoma, and flushed with water, which allows the feces to come out of the body into an irrigation sleeve. Most

colostomates irrigate once a day or every other day, though this depends on the person, their food intake, and their health.

Colostomy without irrigation

Colostomies are not viewed positively due to the misconception that it is difficult to hide the pouch and the smell of feces, or to keep the pouch securely attached. However, modern colostomy pouches are well-designed, odor-proof, and allow stoma patients to continue normal activities. Latex-free tape is available for ensuring a secure attachment. People with colostomies must wear an ostomy pouching system to collect intestinal waste. Ordinarily the pouch must be emptied or changed several times a day depending on the frequency of activity; in general the further from the anus (i.e., the further 'up' the intestinal tract) the ostomy is located the greater the output and more frequent the need to empty or change the pouch.

Alternatives

The preferred option by the surgical community, wherever possible, is now an internal colo-anal pouch which eliminates the need for an external pouch. In place of an external appliance, an internal ileo-anal pouch is constructed using a portion of the patient's lower intestine, to act as a new rectum to replace the removed original.

A UK man Ged Galvin has been given a bionic bottom. An electronic switch with wires attached to muscle transplanted from above his knee enables remote control of his stoma and elimination of his colostomy bag.

Chapter 15

Cholecystectomy
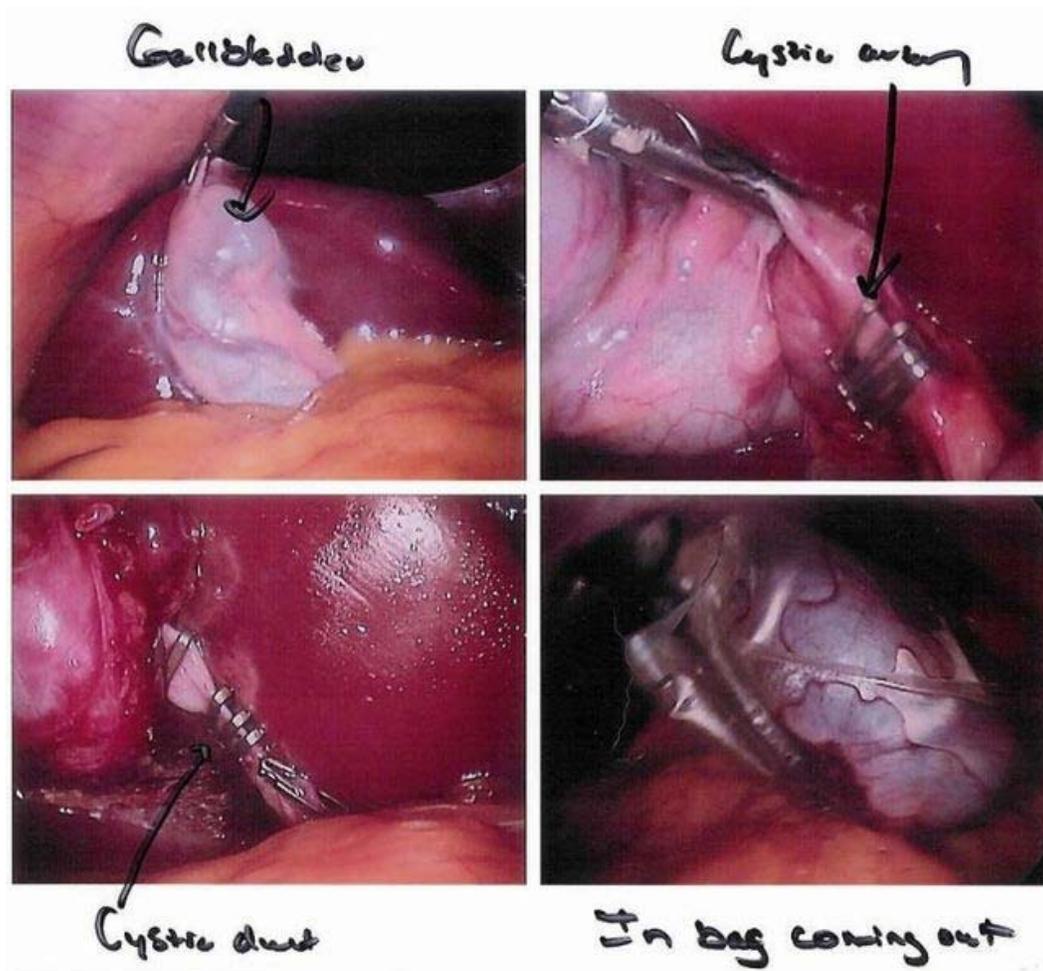
Laparoscopic Cholecystectomy as seen through laparoscope
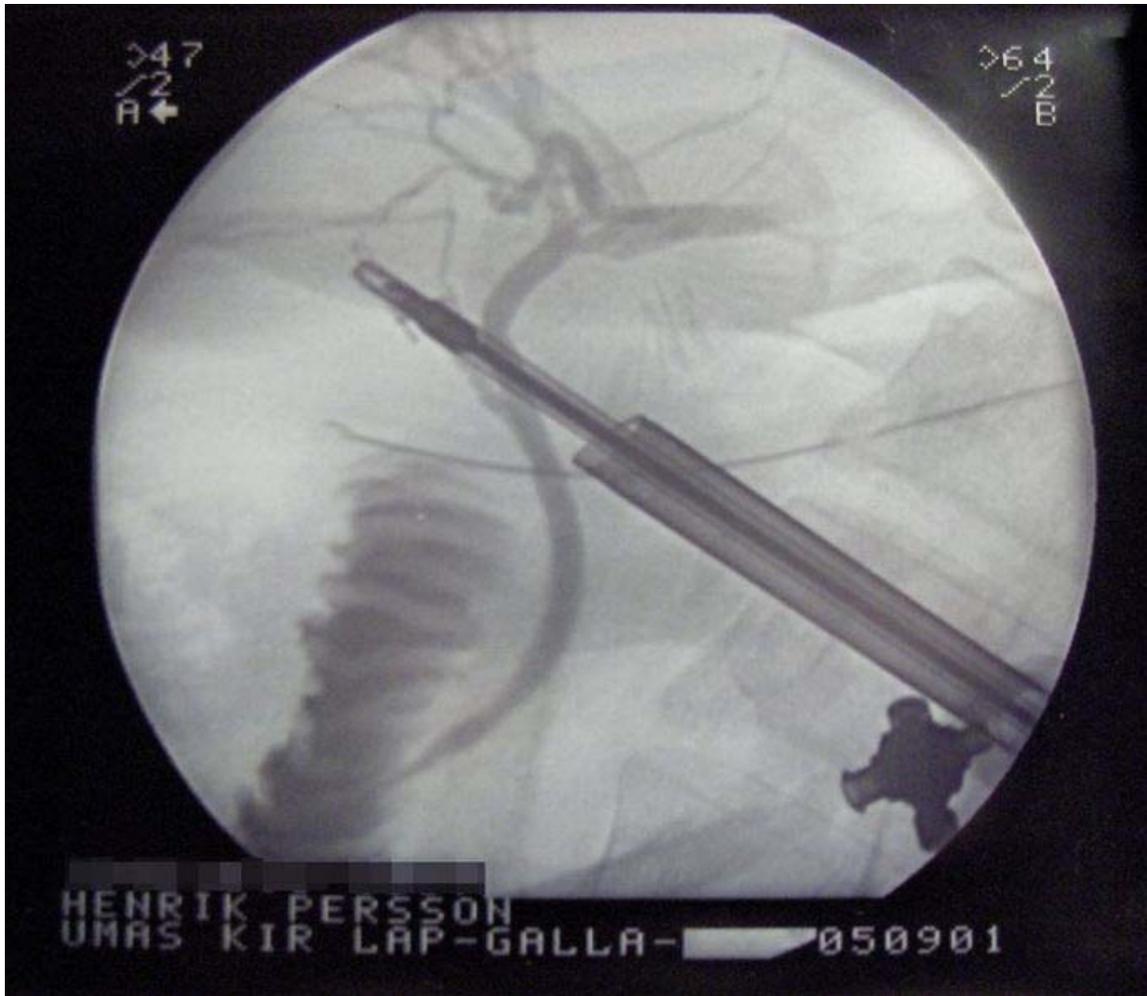
X-Ray during Laparoscopic Cholecystectomy

Cholecystectomy is the surgical removal of the gallbladder. It is the most common method for treating symptomatic gallstones. Surgical options include the standard procedure, called laparoscopic cholecystectomy, and an older more invasive procedure, called open cholecystectomy.

Open surgery

A traditional open cholecystectomy is a major abdominal surgery in which the surgeon removes the gallbladder through a 5-7 inch incision. Patients usually remain in the hospital overnight and may require several additional weeks to recover at home.

Laparoscopic surgery

Laparoscopic cholecystectomy has now replaced open cholecystectomy as the first-choice of treatment for gallstones and inflammation of the gallbladder unless there are

contraindications to the laparoscopic approach. Sometimes, a laparoscopic cholecystectomy will be converted to an open cholecystectomy for technical reasons or safety.

A US Navy general surgeon and an operating room nurse discuss proper procedures while performing a laparoscopic cholecystectomy surgery.

Laparoscopic cholecystectomy requires several small incisions in the abdomen to allow the insertion of operating ports, small cylindrical tubes approximately 5-10 mm in diameter, through which surgical instruments and a video camera are placed into the abdominal cavity. The camera illuminates the surgical field and sends a magnified image from inside the body to a video monitor, giving the surgeon a close-up view of the organs and tissues. The surgeon watches the monitor and performs the operation by manipulating the surgical instruments through the operating ports.

To begin the operation, the patient is anesthetized and placed in the supine position on the operating table. A scalpel is used to make a small incision at the umbilicus. Using either a Veress needle or Hasson technique the abdominal cavity is entered. The surgeon inflates the abdominal cavity with carbon dioxide to create a working space. The camera is placed through the umbilical port and the abdominal cavity is inspected. Additional ports are placed inferior to the ribs at the epigastric, midclavicular, and anterior axillary positions. The gallbladder fundus is identified, grasped, and retracted superiorly. With a second grasper, the gallbladder infundibulum is retracted laterally to expose and open Calot's Triangle (the area bound by the inferior border of the liver, cystic duct, and common hepatic duct). The triangle is gently dissected to clear the peritoneal covering

and obtain a view of the underlying structures. The cystic duct and the cystic artery are identified, clipped with tiny titanium clips and cut. Then the gallbladder is dissected away from the liver bed and removed through one of the ports. This type of surgery requires meticulous surgical skill, but in straightforward cases can be done in about an hour.

Recently, this procedure is performed through a single incision in the patient's umbilicus. This advanced technique is called Laparoendoscopic Single Site Surgery or "LESS".

Procedural Risks and Complications

Laparoscopic cholecystectomy does not require the abdominal muscles to be cut, resulting in less pain, quicker healing, improved cosmetic results, and fewer complications such as infection and adhesions. Most patients can be discharged on the same or following day as the surgery, and most patients can return to any type of occupation in about a week.

An uncommon but potentially serious complication is injury to the common bile duct, which connects the gallbladder and liver. An injured bile duct can leak bile and cause a painful and potentially dangerous infection. Many cases of minor injury to the common bile duct can be managed non-surgically. Major injury to the bile duct, however, is a very serious problem and may require corrective surgery. This surgery should be performed by an experienced biliary surgeon.

Abdominal peritoneal adhesions, gangrenous gallbladders, and other problems that obscure vision are discovered during about 5% of laparoscopic surgeries, forcing surgeons to switch to the standard cholecystectomy for safe removal of the gallbladder. Adhesions and gangrene, of course, can be quite serious, but converting to open surgery does not equate to a complication.

A Consensus Development Conference panel, convened by the National Institutes of Health in September 1992, endorsed laparoscopic cholecystectomy as a safe and effective surgical treatment for gallbladder removal, equal in efficacy to the traditional open surgery. The panel noted, however, that laparoscopic cholecystectomy should be performed only by experienced surgeons and only on patients who have symptoms of gallstones.

In addition, the panel noted that the outcome of laparoscopic cholecystectomy is greatly influenced by the training, experience, skill, and judgment of the surgeon performing the procedure. Therefore, the panel recommended that strict guidelines be developed for training and granting credentials in laparoscopic surgery, determining competence, and monitoring quality. According to the panel, efforts should continue toward developing a noninvasive approach to gallstone treatment that will not only eliminate existing stones, but also prevent their formation or recurrence.

One common complication of cholecystectomy is inadvertent injury to an anomalous bile duct known as Ducts of Luschka, occurring in 33% of the population. It is non-

problematic until the gall bladder is removed, and the tiny supravesicular ducts may be incompletely cauterized or remain unobserved, leading to biliary leak post operatively. The patient will develop biliary peritonitis within 5 to 7 days following surgery, and will require a temporary biliary stent. It is important that the clinician recognize the possibility of bile peritonitis early and confirm diagnosis via HIDA scan to lower morbidity rate. Aggressive pain management and antibiotic therapy should be initiated as soon as diagnosed.

Biopsy

After removal, the gall bladder should be sent for biopsy . (pathological examination) to confirm the diagnosis and look for an incidental cancer. If cancer is present, a reoperation to remove part of the liver and lymph nodes will be required in most cases.

Long-Term Prognosis

A minority of the population, from 5% to 40%, develop a condition called postcholecystectomy syndrome, or PCS. Symptoms can include gastrointestinal distress and persistent pain in the upper right abdomen.

As many as twenty percent of patients develop chronic diarrhea. The cause is unclear, but is presumed to involve the disturbance to the bile system. Most cases clear up within weeks, though in rare cases the condition may last for many years. It can be controlled with drugs.

Chapter 16

Liver Transplantation

Intervention:
Liver transplantation

File:Liver 1.jpg

Human liver

ICD-10 code:

ICD-9 code: 50.5

MeSH   D016031

Other codes:

Liver transplantation or **hepatic transplantation** is the replacement of a diseased liver with a healthy liver allograft. The most commonly used technique is orthotopic transplantation, in which the native liver is removed and replaced by the donor organ in the same anatomic location as the original liver. Liver transplantation nowadays is a well accepted treatment option for end-stage liver disease and acute liver failure. It is also one of the most expensive treatments in modern medicine. Typically 3 surgeons and 1 anesthesiologist are involved, with up to 4 supporting nurses. The surgical procedure is very demanding and ranges from 4 up to 18 hours depending on outcome. Numerous anastomoses and sutures, and many disconnections and reconnections of abdominal and hepatic tissue, must be made for the transplant to succeed, requiring an eligible recipient and a well-calibrated live or cadaveric donor match. By any standard, hepatic transplantation is a major surgical procedure with an appreciable degree of risk.

History

The first human liver transplant was performed in 1963 by a surgical team led by Dr. Thomas Starzl of Denver, Colorado, United States. Dr. Starzl performed several additional transplants over the next few years before the first short-term success was achieved in 1967 with the first one-year survival post transplantation. Despite the development of viable surgical techniques, liver transplantation remained experimental through the 1970s, with one year patient survival in the vicinity of 25%. The introduction of ciclosporin by Sir Roy Calne markedly improved patient outcomes, and the 1980s saw recognition of liver transplantation as a standard clinical treatment for both adult and pediatric patients with appropriate indications. Liver transplantation is now performed at

over one hundred centers in the USA, as well as numerous centres in Europe and elsewhere. The first liver transplant performed in the Delaware Valley was done at Thomas Jefferson University Hospitals in Philadelphia, PA. One year patient survival is 80-85%, and outcomes continue to improve, although liver transplantation remains a formidable procedure with frequent complications. Unfortunately, the supply of liver allografts from non-living donors is far short of the number of potential recipients, a reality that has spurred the development of living donor liver transplantation.

Indications

Liver transplantation is potentially applicable to any acute or chronic condition resulting in irreversible liver dysfunction, provided that the recipient does not have other conditions that will preclude a successful transplant. Uncontrolled metastatic cancer outside liver, active drug or alcohol abuse and active septic infections are absolute contraindications. While infection with HIV was once considered an absolute contraindication, this has been changing recently. Advanced age and serious heart, pulmonary or other disease may also prevent transplantation (relative contraindications). Most liver transplants are performed for chronic liver diseases that lead to irreversible scarring of the liver, or cirrhosis of the liver. Another cause is cryptogenic liver disease. Some centers use the Milan criteria to select patients for liver transplantation.

Techniques

Before transplantation, liver support therapy might be indicated (bridging-to-transplantation). Artificial liver support like liver dialysis or bioartificial liver support concepts are currently under preclinical and clinical evaluation. Virtually all liver transplants are done in an orthotopic fashion, that is, the native liver is removed and the new liver is placed in the same anatomic location. The transplant operation can be conceptualized as consisting of the hepatectomy (liver removal) phase, the anhepatic (no liver) phase, and the postimplantation phase. The operation is done through a large incision in the upper abdomen. The hepatectomy involves division of all ligamentous attachments to the liver, as well as the common bile duct, hepatic artery, hepatic vein and portal vein. Usually, the retrohepatic portion of the inferior vena cava is removed along with the liver, although an alternative technique preserves the recipient's vena cava ("piggyback" technique).

The donor's blood in the liver will be replaced by an ice-cold organ storage solution, such as UW (Viaspan) or HTK until the allograft liver is implanted. Implantation involves anastomoses (connections) of the inferior vena cava, portal vein, and hepatic artery. After blood flow is restored to the new liver, the biliary (bile duct) anastomosis is constructed, either to the recipient's own bile duct or to the small intestine. The surgery usually takes between five and six hours, but may be longer or shorter due to the difficulty of the operation and the experience of the surgeon.

The large majority of liver transplants use the entire liver from a non-living donor for the transplant, particularly for adult recipients. A major advance in pediatric liver transplantation was the development of reduced size liver transplantation, in which a portion of an adult liver is used for an infant or small child. Further developments in this area included split liver transplantation, in which one liver is used for transplants for two recipients, and living donor liver transplantation, in which a portion of a healthy person's liver is removed and used as the allograft. Living donor liver transplantation for pediatric recipients involves removal of approximately 20% of the liver (Couinaud segments 2 and 3).

Further advance in liver transplant involves only resection of the lobe of the liver involved in tumors and the tumor-free lobe remains within the recipient. This speeds up the recovery and the patient stay in the hospital quickly shortens to within 5–7 days.

Many major medical centers are now using radiofrequency ablation of the liver tumor as a bridge while awaiting for liver transplantation. This technique has not been used universally and further investigation is warranted.

Immunosuppressive management

Like most other allografts, a liver transplant will be rejected by the recipient unless immunosuppressive drugs are used. The immunosuppressive regimens for all solid organ transplants are fairly similar, and a variety of agents are now available. Most liver transplant recipients receive corticosteroids plus a calcineurin inhibitor such as tacrolimus or ciclosporin plus a purine antagonist such as mycophenolate mofetil. Clinical outcome is better with tacrolimus than with ciclosporin during the first year of liver transplantation. If the patient has a co-morbidity such as active hepatitis B, high dose of hepatitis B immunoglubins are administrated in liver transplant patients. Liver transplantation is unique in that the risk of chronic rejection also decreases over time, although recipients need to take immunosuppressive medication for the rest of their lives. It is possible to be slowly taken off an anti rejection medication but only in certain cases. It is theorized that the liver may play a yet-unknown role in the maturation of certain cells pertaining to the immune system. There is at least one study by Dr. Starzl's team at the University of Pittsburgh which consisted of bone marrow biopsies taken from such patients which demonstrate genotypic chimerism in the bone marrow of liver transplant recipients.

Graft rejection

After a liver transplantation, there are three types of graft rejection that may occur. They include hyperacute rejection, acute rejection and chronic rejection. Hyperacute rejection is caused by preformed anti-donor antibodies. It is characterized by the binding of these antibodies to antigens on vascular endothelial cells. Complement activation is involved and the effect is usually profound. Hyperacute rejection happens within minutes to hours after the transplant procedure. Unlike hyperacute rejection, which is B cell mediated,

acute rejection is mediated by T cells. It involves direct cytotoxicity and cytokine mediated pathways. Acute rejection is the most common and the primary target of immunosuppressive agents. Acute rejection is usually seen within days or weeks of the transplant. Chronic rejection is the presence of any sign and symptom of rejection after 1 year. The cause of chronic rejection is still unknown but an acute rejection is a strong predictor of chronic rejections. Liver rejection may happen anytime after the transplant. Lab findings of a liver rejection include abnormal AST, ALT, GGT and liver function values such as prothrombin time, ammonia level, bilirubin level, albumin concentration, and blood glucose. Physical findings include encephalopathy, jaundice, bruising and bleeding tendency. Other nonspecific presentation are malaise, anorexia, muscle ache, low fever, slight increase in white blood count and graft tender.

Results

Prognosis is quite good. However, those with certain illnesses may differ. There is no exact model to predict survival rates; however, those with transplant have a 58% chance of surviving 15 years. Failure of the new liver occurs in 10% to 15% of all cases. These percentages are contributed to by many complications. Early graft failure is probably due to preexisting disease of the donated organ. Others include technical flaws during surgery such as revascularization that may lead to a nonfunctioning graft.

Living donor transplantation

Living donor liver transplantation (LDLT) has emerged in recent decades as a critical surgical option for patients with end stage liver disease, such as cirrhosis and/or hepatocellular carcinoma often attributable to one or more of the following: long-term alcohol abuse, long-term untreated hepatitis C infection, long-term untreated hepatitis B infection. The concept of LDLT is based on (1) the remarkable regenerative capacities of the human liver and (2) the widespread shortage of cadaveric livers for patients awaiting transplant. In LDLT, a piece of healthy liver is surgically removed from a living person and transplanted into a recipient, immediately after the recipient's diseased liver has been entirely removed.

Historically, LDLT began as a means for parents of children with severe liver disease to donate a portion of their healthy liver to replace their child's entire damaged liver. The first report of successful LDLT was by Dr. Christoph Broelsch at the University of Chicago Medical Center in November 1989, when two-year-old Alyssa Smith received a portion of her mother's liver. Surgeons eventually realized that adult-to-adult LDLT was also possible, and now the practice is common in a few reputable medical institutes. It is considered more technically demanding than even standard, cadaveric donor liver transplantation, and also poses the ethical problems underlying the indication of a major surgical operation (hepatectomy) on a healthy human being. In various case series, the risk of complications in the donor is around 10%, and very occasionally a second operation is needed. Common problems are biliary fistula, gastric stasis and infections; they are more common after removal of the right lobe of the liver. Death after LDLT has

been reported at 0% (Japan), 0.3% (USA) and <1% (Europe), with risks likely to decrease further as surgeons gain more experience in this procedure.

In a typical adult recipient LDLT, 55 to 70% of the liver (the right lobe) is removed from a healthy living donor. The donor's liver will regenerate approaching 100% function within 4–6 weeks, and will almost reach full volumetric size with recapitulation of the normal structure soon thereafter. It may be possible to remove up to 70% of the liver from a healthy living donor without harm in most cases. The transplanted portion will reach full function and the appropriate size in the recipient as well, although it will take longer than for the donor.

Living donors are faced with risks and/or complications after the surgery. Blood clots and biliary problems have the possibility of arising in the donor post-op, but these issues are remedied fairly easily. Although death is a risk that a living donor must be willing to accept prior to the surgery, the mortality rate of living donors in the United States is low. The LDLT donor's immune system does diminish as a result of the liver regenerating, so certain foods which would normally cause an upset stomach could cause serious illness.

Liver donor requirements

Any member of the family, parent, sibling, child, spouse or a volunteer can donate their liver. The criteria for a liver donation include:

- Being in good health
- Having a blood type that matches or is compatible with the recipient's
- Having a charitable desire of donation without financial motivation
- Being between 18 and 60 years old
- Being of similar or bigger size than the recipient
- Before one becomes a living donor, the donor must undergo testing to ensure that the individual is physically fit. Sometimes CT scans or MRIs are done to image the liver. In most cases, the work up is done in 2–3 weeks

Complications

Living donor surgery is done at a major center. Very few individuals require any blood transfusions during or after surgery. Even though the procedure is very safe, all potential donors should know there is a 0.5 to 1.0 percent chance of death. Other risks of donating a liver include bleeding, infection, painful incision, possibility of blood clots and a prolonged recovery. The vast majority of donors enjoy complete and full recovery within 2–3 months.

Pediatric transplantation

In children, living liver donor transplantations have become very accepted. The accessibility of adult parents who want to donate a piece of the liver for their children/infants has reduced the number of children who would have otherwise died

waiting for a transplant. Having a parent as a donor also has made it a lot easier for children - because both patients are in the same hospital and can help boost each other's morale.

Benefits

There are several advantages of living liver donor transplantation over cadaveric donor transplantation, including:

- Transplant can be done on an elective basis because the donor is readily available
- There are fewer possibilities for complications and death while waiting for a cadaveric organ donor
- Because of donor shortages, UNOS has limited the cadaveric organ allocation to foreigners who seek medical help in the USA. However, with the availability of living donor transplantation, this will now allow foreigners a new opportunity to seek medical care in the USA

Screening for donors

The majority of liver transplantation centers in the USA have a superb record on long term survival. Living donor transplantation is a multidisciplinary approach. All living liver donors undergo medical evaluation. Every hospital which performs transplant have dedicated nurses that provide specific information about the procedure and answer questions that families may have. During the evaluation process, confidentially is assured on the potential donor. Every effort is made to ensure that organ donation is not made by coercion from other family members. The transplant team provides both the donor and family thorough counseling and support which continues until full recovery is made.

All donors are assessed medically to ensure that they can undergo the surgery. Blood type of the donor and recipient must be compatible but not always identical. Other things assessed prior to surgery include the anatomy of the donor liver. However, even with mild variations in blood vessels and bile duct, surgeons today are able to perform transplantation without problems. The most important criterion for a living liver donor is to be in excellent health.

Economic aspect

The medical expenses, including work up, surgery and post operative recovery period, are covered by the recipient's health insurance plans in most cases. Medicaid coverage varies by state. In 2010 Arizona Medicaid changed to no longer cover liver transplant on recipients infected with Hepatitis C due to success rate statistics. There are also programs like the National Living Donor Assistance Center, which provides financial assistance to help cover the cost of travel, accommodation and other expenses. This program also pays for postoperative trips including expenses for accompanying individuals. Typical expenses during the first year (everything included from surgey, hospitalization, lab testing, medications) are up to $315,000, in those countries that do not have government

funded health care. The cost is considerably lower in countries like India where a living donor liver transplant typically costs about $50,000/-. The high volume of such procedures in a few centers in India results in excellent outcomes comparable to the best centers in the world.

Controversy over eligibility for alcoholics

The high incidence of liver transplants given to those with alcoholic cirrhosis has led to a recurring controversy regarding the eligibility of such patients for liver transplant. The controversy stems from the view of alcoholism as a self-inflicted disease and the perception that those with alcohol-induced damage are depriving other patients who could be considered more deserving.

Chapter 17

Pancreaticoduodenectomy

Intervention:
Pancreaticoduodenectomy

ICD-10 code:

ICD-9 code: 52.7

MeSH   D016577

Other codes:

A **pancreaticoduodenectomy**, **pancreatoduodenectomy**, **Whipple procedure**, or **Kausch-Whipple procedure**, is a major surgical operation involving the pancreas, duodenum, and other organs. This operation is performed to treat cancerous tumours on the head of the pancreas, malignant tumors involving common bile duct or duodenum near the pancreas.

History

This procedure was originally described by Alessandro Codivilla, an Italian surgeon, in 1898. The first resection for a periampullary cancer was performed by the German surgeon Walther Kausch in 1909 and described by Kausch in 1912.

It is often called the *Whipple procedure*, after the American surgeon Allen Whipple who devised a perfected version of the surgery in 1935 and subsequently came up with multiple refinements to his technique.

Anatomy involving the procedure

The most common technique of a pancreaticoduodenectomy consists of the *en bloc* removal of the distal segment (antrum) of the stomach; the first and second portions of the duodenum; the head of the pancreas; the common bile duct; and the gallbladder.

The basic concept behind the pancreaticoduodenectomy is that the head of the pancreas and the duodenum share the same arterial blood supply (the gastroduodenal artery). These arteries run through the head of the pancreas, so that both organs must be removed

if the single blood supply is severed. If only the head of the pancreas were removed it would compromise blood flow to the duodenum, resulting in tissue necrosis.

Pancreaticoduodenectomy in modern medicine

The Whipple procedure today is very similar to Whipple's original procedure. It consists of removal of the distal half of the stomach (antrectomy), the gall bladder and its cystic duct (cholecystectomy), the common bile duct (choledochectomy), the head of the pancreas, duodenum, proximal jejunum, and regional lymph nodes. Reconstruction consists of attaching the pancreas to the jejunum (pancreaticojejunostomy) and attaching the hepatic duct to the jejunum (hepaticojejunostomy) to allow digestive juices and bile respectively to flow into the gastrointestinal tract and attaching the stomach to the jejunum (gastrojejunostomy) to allow food to pass through.

Originally performed in a two-step process, Whipple refined his technique in 1940 into a one-step operation. Using modern operating techniques, mortality from a Whipple procedure is around five percent in the United States (less than two percent in high-volume academic centers). The original description of Whipple's operation together with a modern commentary is available on-line.

Pancreaticoduodenectomy versus total pancreatectomy

Clinical trials have failed to demonstrate significant survival benefits of total pancreatectomy, mostly because patients who submit to this operation tend to develop a particularly severe form of diabetes called brittle diabetes. Sometimes the pancreaticojejunostomy may not hold properly after the completion of the operation and infection may spread inside the patient. This may lead to another operation shortly thereafter in which the remainder of the pancreas (and sometimes the spleen) is removed to prevent further spread of infection and possible morbidity.

Pylorus-sparing pancreaticoduodenectomy

More recently, the pylorus-sparing pancreaticoduodenectomy (also known as Traverso-Longmire procedure/PPPD) is growing increasingly popular, especially among European surgeons. The main advantage of this technique is that the pylorus, and thus normal gastric emptying, is preserved. However, some doubts remain on whether it is an adequate operation from an oncological point of view. In practice, it shows similar long-term survival as a Whipple's (pancreaticoduodenectomy + hemigastrectomy), but patients benefit from improved recovery of weight after a PPPD, so this should be performed when the tumour does not involve the stomach and the lymph nodes along the gastric curvatures are not enlarged.

Another controversial point is whether patients benefit from retroperitoneal lymphadenectomy.

Morbidity and mortality

Pancreaticoduodenectomy is considered, by any standard, a major surgical procedure.

Many studies have shown that hospitals where a given operation is performed more often will have better overall results, and especially so in the case of more complex procedures, such as pancreaticoduodenectomy. A frequently cited study published in *The New England Journal of Medicine* found operative mortality rates to be four times higher (16.3 percent vs. 3.8 percent) at low-volume (averaging less than one pancreaticoduodenectomy per year) hospitals than at high-volume (16 or more per year) hospitals. Even at high-volume hospitals, morbidity has been found to vary by a factor of almost four depending on the number of times the surgeon has previously performed the procedure.

One study reported actual risk to be 2.4 times greater than the risk reported in the medical literature, with additional variation by type of institution.

List of notable people who have had this surgery

- 2001: Chris Rea, singer-songwriter
- 2004: Steve Jobs, co-founder of Apple Inc.
- 2006: Luciano Pavarotti, Tenor opera singer
- 2007: Randy Pausch, originator of the inspirational *Really Achieving Your Childhood Dreams* (also known as *The Last Lecture*)
- 2008: Candye Kane, singer and ex-pornographic actress

Chapter 18

Herniorrhaphy and Appendectomy

Herniorrhaphy

Intervention:
Herniorrhaphy

ICD-10 code:
ICD-9 code: 53
Other codes:

Herniorrhaphy (Hernioplasty, Hernia repair) is a surgical procedure for correcting hernia. A hernia is a bulging of internal organs or tissues, which protrude through an abnormal opening in the muscle wall. Hernias can occur in the abdomen, groin, and at the site of a previous surgery.

An operation in which the hernia sac is removed without any repair of the inguinal canal is described as a 'herniotomy'.

When herniotomy is combined with a reinforced repair of the posterior inguinal canal wall with autogenous (patient's own tissue) or heterogeneous (like steel or prolene mesh) material it is termed Hernioplasty as opposed to herniorrhaphy in which no autogenous or heterogeneous material is used for reinforcement.

Techniques

Surgical incision in groin after inguinal hernia operation.

Herniorraphy, or hernioplasty, is now often performed as an ambulatory, or "day surgery," procedure in the USA. In other countries, however, it is more common to be admitted for a 2-3 day hospital stay. Almost 700,000 are performed each year in the United States.

These techniques can be divided into four groups.

Groups 1 and 2: open "tension" repair

A workable technique of repairing hernia was first described by Bassini in the 1880s; the Bassini technique was a "tension" repair, in which the edges of the defect are sewn back together without any reinforcement or prosthesis. In the Bassini technique, the conjoint tendon (formed by the distal ends of the transversus abdominis muscle and the internal oblique muscle) is approximated to the inguinal ligament and closed.

Although tension repairs are no longer the standard of care due to the high rate of recurrence of the hernia, long recovery period, and post-operative pain, a few tension

repairs are still in use today; these include the Shouldice and the Cooper's ligament/McVay repair.

The Shouldice technique is a complicated four layer reconstruction; however, it has relatively low reported recurrence rates.

Group 3: open "tension-free" repair

Bilateral Inguinal Repair with Mesh 7 days after surgery

Almost all repairs done today are open "tension-free" repairs that involve the placement of a synthetic mesh to strengthen the inguinal region; some popular techniques include the Lichtenstein repair (flat mesh patch placed on top of the defect), Plug and Patch (mesh plug placed in the defect and covered by a Lichtenstein-type patch), Kugel (mesh device placed behind the defect), and Prolene Hernia System (2-layer mesh device placed over and behind the defect). This operation is called a 'hernioplasty'. The meshes used are typically made from polypropylene or polyester, although some companies market Teflon meshes and partially absorbable meshes. The operation is typically performed under local anesthesia, and patients go home within a few hours of surgery, often requiring no medication beyond aspirin or acetaminophen. Patients are encouraged to walk and move around immediately post-operatively, and they can usually resume all their normal activities within a week or two of the operation. Recurrence rates are very low - one percent or less, compared with over 10% for a tension repair. Rates of complications are generally low but they can be quite serious, and can include chronic pain, ischemic orchitis, and testicular atrophy.

Group 4: laparoscopic repair

In recent years, as in other areas of surgery, laparoscopic repair of inguinal hernia has emerged as an option. "Lap" repairs (sometimes called "keyhole" surgery or minimally invasive surgery) are also tension-free, although the mesh is placed within the pre-peritoneal space behind the defect as opposed to in or over it. Advantages of lap over the open method include a faster recovery time and a lower post-operative pain score.

Like the open method, laparoscopic surgery may involve local or general anesthesia, depending on the size and related factors of the hernia. Lap is usually more expensive as it requires more Operating Room time than open repair, but a shorter hospitalization period.

There is no definitive consensus as to the comparative risk of complications, or comparative rate of recurrence compared to the open tension-free repairs. However, most non-emergent abdominal surgeries are moving to laproscopic methodologies, as the smaller incisions used result in less bleeding, less infection, faster recovery, reduced hospitalization and reduced pain.

One specific method of laparoscopic repair is *totally extraperitoneal* (*TEP*) repair. TEp repair has been associated with fewer complications and a significantly shorter duration of post-operative analgesia than Lichtenstein repair for recurrent inguinal hernia.

Laparoscopic herniorrhaphy, as compared to open surgery

Advantages	Disadvantages
• Quicker recovery	
• Less pain during first days	
• Fewer postoperative complications such as infections, bleeding and seromas	• Longer operating time • Increased recurrence of primary hernias
• Less risk of chronic pain	

Comparisons

In the UK a government committee called NICE re-examined the data on laparoscopic and open repair (2004). They concluded that there is no difference in cost, as the increased costs of operation are offset by the decreased recovery period. They concluded that recurrence rates are identical, but newer studies have questioned this. They found that laparoscopic repair results in a more rapid recovery and less pain in the first few days. They found that lap repair has less risk of wound infection, less bleeding, and less swelling after surgery (seroma). They also reported less chronic pain, which can last for

years and in one in 30 patients can be severe. A recent, large American study found that recurrence within two years of operation after lap repair was 10% compared with 4% after open surgery. Both of these results, however, are considered poor by international standards and suggest that the surgeons were inexperienced, particularly in lap repair.

Mesh repairs have shown reduced recurrences or early recovery compared to tension repairs. Mesh repair complications include infection, mesh migration, adhesion formation, erosion into intraperitoneal organs, and chronic pain - due probably to entrapment of nerves, vessels, or the vas deferens. Such complications usually become apparent weeks to years after the initial repair, presenting as abscess, fistula, or small bowel obstruction. More recently, concerns have been raised about the possibility of obstruction of the vas deferens as a result of the fibroblastic reaction to the mesh.

Appendectomy

An appendectomy in progress

An **appendectomy** (sometimes called **appendisectomy** or **appendicectomy**) is the surgical removal of the vermiform appendix. This procedure is normally performed as an emergency procedure, when the patient is suffering from acute appendicitis. In the absence of surgical facilities, intravenous antibiotics are used to delay or avoid the onset of sepsis; it is now recognized that many cases will resolve when treated non-operatively.

In some cases the appendicitis resolves completely; more often, an inflammatory mass forms around the appendix. This is a relative contraindication to surgery.

Appendectomy may be performed laparoscopically (this is called minimally invasive surgery) or as an open operation. Laparoscopy is often used if the diagnosis is in doubt, or if it is desirable to hide the scars in the umbilicus or in the pubic hair line. Recovery may be a little quicker with laparoscopic surgery; the procedure is more expensive and resource-intensive than open surgery and generally takes a little longer, with the (low in most patients) additional risks associated with pneumoperitoneum (inflating the abdomen with gas). Advanced pelvic sepsis occasionally requires a lower midline laparotomy.

There have been some cases of auto-appendectomies, i.e. operating on yourself. One was performed by Dr Kane in 1921, but the operation was completed by his assistants. Another case is Leonid Rogozov who had to perform the operation on himself as he was the only surgeon on a remote Arctic base.

Procedure

In general terms, the procedure for an open appendectomy is as follows.

1. Antibiotics are given immediately if there are signs of sepsis, otherwise a single dose of prophylactic intravenous antibiotics is given immediately prior to surgery.
2. General anaesthesia is induced, with endotracheal intubation and full muscle relaxation, and the patient is positioned supine.
3. The abdomen is prepared and draped and is examined under anesthesia.
4. If a mass is present, the incision is made over the mass; otherwise, the incision is made over McBurney's point, one third of the way from the anterior superior iliac spine (ASIS) and the umbilicus; this represents the position of the base of the appendix (the position of the tip is variable).
5. The various layers of the abdominal wall are then opened.
6. The effort is always to preserve the integrity of abdominal wall. Therefore, the External Oblique Aponeurosis is slitted along its fiber, and the internal oblique muscle is split along its length, not cut. As the two run at right angles to each other, this prevents later Incisional hernia.
7. On entering the peritoneum, the appendix is identified, mobilized and then ligated and divided at its base.
8. Some surgeons choose to bury the stump of the appendix by inverting it so it points into the caecum.
9. Each layer of the abdominal wall is then closed in turn.
10. The skin may be closed with staples or stitches.
11. The wound is dressed.
12. The patient will be brought to the recovery room.

Prophylactic appendectomy

Pregnancy

If appendicitis develops in a pregnant woman, an appendectomy is usually performed and should not harm the fetus. The risk of fetal death in the perioperative period after an appendectomy for early acute appendicitis is 3% to 5%. The risk of fetal death is 20% in perforated appendicitis.

Recovery

Scar and Bruise 2 days after operation.

Recovery time from the operation varies from person to person. Some will take up to three weeks before being completely active; for others it can be a matter of days. In the case of a laparoscopic operation, the patient will have three stapled scars of about an inch in length, between the navel and pubic hair line. When a laparotomy has been performed the patient will have a 2-3 inch scar, which will initially be heavily bruised.

Chapter 19

Percutaneous Transhepatic Cholangiography and Sigmoidoscopy

Percutaneous transhepatic cholangiography

Percutaneous transhepatic cholangiography (**PTHC** or **PTC**) is a radiologic technique used to visualize the anatomy of the biliary tract. A contrast medium is injected into a bile duct in the liver, after which X-rays are taken. It allows access to the biliary tree in cases where endoscopic retrograde cholangiopancreatography (ERCP) has been unsuccessful. Initially reported in 1937, the procedure became popular in 1952.

It is predominantly now performed as a therapeutic technique. There are less invasive means of imaging the biliary tree including transabdominal ultrasound, magnetic resonance cholangiopancreatography, computed tomography and endoscopic ultrasound. If the biliary system is obstructed, PTC may be used to drain bile until a more permanent solution for the obstruction is performed (e.g. surgery). Additionally, self expanding metal stents can be placed across malignant biliary strictures to allow palliative drainage. Percutaneous placement of metal stents can be utilised when therapeutic ERCP has been unsuccessful, anatomy is altered precluding endoscopic access to the duodenum, or where there has been separation of the segmental biliary drainage of the liver, allowing more selective placement of metal stents. It is generally accepted that percutanous biliary procedures have higher complication rates than therapeutic ERCP. Complications encountered include infection, bleeding and bile leaks.

Sigmoidoscopy

Sigmoidoscopy From Greek doscopy, to look inside, is the minimally invasive medical examination of the large intestine from the rectum through the last part of the colon. There are two types of sigmoidoscopy, **flexible sigmoidoscopy**, which uses a flexible endoscope, and **rigid sigmoidoscopy**, which uses a rigid device. Flexible sigmoidoscopy is generally the preferred procedure. A sigmoidoscopy is similar but not the same as a

colonoscopy. A sigmoidoscopy only examines up to the sigmoid, the most distal part of the colon, while colonoscopy examines the whole large bowel.

Flexible sigmoidoscopy

Flexible sigmoidoscopy enables the physician to look at the inside of the large intestine from the rectum through the last part of the colon, called the sigmoid. Physicians may use the procedure to find the cause of diarrhea, abdominal pain, or constipation. They also use it to look for benign and malignant polyps, as well as early signs of cancer in the descending colon and rectum. With flexible sigmoidoscopy, the physician can see intestinal bleeding, inflammation, abnormal growths, and ulcers in the descending colon and rectum. Flexible sigmoidoscopy is not sufficient to detect polyps or cancer in the ascending or transverse colon (two-thirds of the colon). However, although in absolute terms only a relatively small section of the large intestine can be examined using sigmoidoscopy, the sites which can be observed represent areas which are most frequently affected by diseases such as colorectal cancer, for example the rectum.

For the procedure, the patient must lie on his or her left side on the examining table. The physician inserts a short, flexible, lit tube into the rectum and slowly guides it into the colon. The tube is called a sigmoidoscope. The scope transmits an image of the inside of the rectum and colon, so the physician can carefully examine the lining of these organs. The scope also blows air into these organs, which inflates them and helps the physician see better.

If anything unusual is in the rectum or colon, like a polyp or inflamed tissue, the physician can remove a piece of it using instruments inserted into the scope. The physician will send that piece of tissue (biopsy) to the lab for testing.

Bleeding and puncture of the colon are possible complications of sigmoidoscopy. However, such complications are uncommon.

Flexible sigmoidoscopy takes 10 to 20 minutes. During the procedure, the patient might feel pressure and slight cramping in the lower abdomen, but he or she will feel better afterward when the air leaves the colon.

Preparation

The colon and rectum must be completely empty for flexible sigmoidoscopy to be thorough and safe, thus the patient must drink only clear liquids for 12 to 24 hours beforehand. This includes bouillon or broth, gelatin, strained fruit juice, water, plain coffee, plain tea, or diet soft drinks. The night before or right before the procedure, the patient receives a laxative and an enema, which is a liquid solution that washes out the intestines.

No sedation is required during this procedure as long as the examination does not exceed the level of the splenic flexure.

Rigid sigmoidoscopy

Rigid sigmoidoscopy no longer has the value it had in the past, before the advent of videocolonoscopy (flexible sigmoidoscopy). However, it may be still useful in ano-rectal diseases such as bleeding per rectum or inflammatory rectal disease, particularly in the general practice and pediatrics.

For performing the examination, the patient must lie on the left side, in the so called Sim's position. The bowels are previously emptied with a suppository and a digital rectal examination is first performed. The sigmoidoscope is lubricated and inserted with obturator in general direction of the navel. The direction is then changed and the obturaror is removed so that the physician may penetrate further with direct vision. A bellows is used to insufflate air to distend the rectum. Lateral movements of the sigmoidoscope's tip negotiate the Houston valve and the recto-sigmoid junction.

Risks

Although generally considered quite safe, sigmoidoscopy does carry the very rare possibility of tearing of the intestinal wall by the instrument, which would require immediate surgery to repair the tear; in addition, removal of a polyp may sometimes lead to localized bleeding which is resistant to cauterization by the instrument and must be stopped by surgical intervention.

Chapter 20

Stool Guaiac Test

Guaiac cards and bottle of developer that contains hydrogen peroxide

Both square test areas in the upper area of the card show the intense blue color of a positive result. The lower two smaller circular areas on the orange stripe are analytical control reactions, positive on the left and negative on the right, that help assure that the card and developer bottle have been maintained in proper conditions and have not been damaged before the test is performed.

The **stool guaiac test** or **guaiac fecal occult blood test** (gFOBT) is one of several methods that detect the presence of fecal occult blood (FOB). Fecal occult blood is blood present in the feces that is not visibly apparent.

The term **guaiac** denotes the name of the paper surface used in the test which has a phenolic compound, alpha-guaiaconic acid, that is extracted from the wood resin of Guaiacum trees.

Methodology

The stool guaiac test involves fasting from iron supplements, red meat (the blood it contains can turn the test positive), certain vegetables (which contain a chemical with peroxidase properties that can turn the test positive), and vitamin C and citrus fruits (which can turn the test falsely negative) for a period of time before the test. It has been suggested that cucumber, cauliflower and horseradish, and often other vegetables, should be avoided for three days before the test.

In testing, feces are applied to a thick piece of paper attached to a thin film coated with guaiac. Either the patient or medical professional smears a small fecal sample on to the film. The fecal sample can be obtained by digital rectal examination or by wiping soiled toilet tissue on the film. Only a small sample for smearing is necessary; a large sample of stool may impede an accurate test.

Both sides of the test card can be peeled open, to access the inner guaiac paper. One side of the card is marked for application of the stool and the other is for the developer fluid.

After applying the feces, one or two drops of hydrogen peroxide are then dripped on to the other side of the film, and it is observed for a rapid blue color change.

When the hydrogen peroxide is dripped on to the guaiac paper, it oxidizes the alpha-guaiaconic acid to a blue colored quinone. Normally, when no blood and no peroxidases or catalases from vegetables are present, this oxidation occurs very slowly. Heme, a component of hemoglobin found in blood, catalyzes this reaction, giving a result in about two seconds. Therefore, a positive test result is one where there is a quick and intense blue color change of the film.

Analytical interpretation

The guaiac test can often be false-positive which is a positive test result when there is in fact no source of bleeding. This is particularly common if the recommended dietary preparation is not followed, as the heme in red meat or the peroxidase or catalase activity in vegetables, especially if uncooked, can cause analytical false positives.

Vitamin C can cause analytical false negatives due to its anti-oxidant properties inhibiting the color reaction.

If the card has not been promptly developed, the water content of the feces decreases, and this can reduce the detection of blood. Although rehydration of stored samples can reverse this effect this is not recommended because the test becomes unduly analytically sensitive and thus much less specific.

Some stool specimens have a high bile content that causes a green color to show after applying the developer drops. If entirely green, such samples are negative, but if questionnably green to blue, such samples are designated positive.

The package insert guidelines from the manufacturers, for example Hemoccult SENSA, recommend that nonsteroidal anti-inflammatory drugs (NSAID), such as ibuprofen and aspirin, and iron supplements be discontinued for at least several days before the tests. There is a concern that these agents may irritate the body and cause biologically positive tests even in the absence of a more substantial illness, but there is some doubt about how frequently this occurs with NSAID medication. Although both iron and bismuth containing products such as antacids and antidiarrheals can cause dark stools that are occasionally confused as containing blood, actual bleeding from iron is unusual.

There is no consensus on whether to stop warfarin before a guaiac test. Even when using anticoagulants a high proportion of positive guaiac tests were found to be due to diagnosable lesions, suggesting anticoagulants may not cause bleeding unless there is an abnormality.

Clinical application

Fecal occult blood (FOB) provides an expanded consideration of the clinical application of FOB tests generally, including other clinical methods, and the comments here are those that relate specifically to the guaiac gFOBT method.

One major use of stool testing for blood is detection of colorectal cancer. The stool guaiac test was originally the principal colon cancer screening technology available, but modern tests which look for globin or DNA are now also available. Several recent colon cancer screening guidelines have recommended replacing any older low-sensitivity, guaiac-based fecal occult blood testing (gFOBT) with either newer high-sensitivity guaiac-based fecal occult blood testing (gFOBT) or fecal immunochemical testing (FIT), which tests for globin rather than the heme detected by the guaiac method. The US Multisociety Task Force (MSTF) looked at 6 studies that compared high sensitivity gFOBT (Hemoccult SENSA) to FIT, and concluded that there were no clear difference in overall performance between these methods, and a similar recommendation was made by the National Guideline Clearinghouse (NGC).

Results of a single fecal sample should be interpreted cautiously, as there is a high rate of false negativity associated with the test. Using three cards, each on different days, is recommended to improve sensitivity. The Centers for Disease Control and Prevention (CDC) in a 2006-2007 survey found extensive inappropriate use of low sensitivty gFOBT and of single specimens; it is unclear if these widespread suboptimal approaches have since declined. The Current Procedural Terminology (CPT) coding was changed in January 2006 to include CPT code 82270, which indicates that consecutive collection of three stool samples has occurred, either as three single cards or a single triple card. Since January 2007, the US Medicare program reimburses for colorectal cancer screening with gFOBT only when this code is used.

The stool guaiac test method may be preferable to fecal immunochemical testing (FIT) if there is a clinical concern about possible gastric or proximal upper intestinal bleeding. However, although heme breakdown is less than globin during intestinal transit, false negative results can be seen with the stool guaiac tests due to degradation of the peroxidase-activity. This can cause false negative results in upper gastrointestinal bleeding sources, or in right colon adenomas and cancers that have comparable blood losses to positively testing left colon lesions. A positive gFOBT with subsequent negative colonoscopy may lead to an upper endoscopy. It is unclear whether this is an effective intervention if there is a positive gFOBT but no anemia. Endoscopy when there is a positive gFOBT along with iron deficiency anemia, or iron deficiency anemia on its own, has a higher rate of finding problems.