Chapter 1

Anatomy and physiology of major organ systems

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No area of medical science is truly self-contained; all systems interact, so as we study our chosen speciality we have to put this in a holistic context of human biology. This is as true for the clinical laboratory specialist as for any other medical professional. This introductory chapter is not aimed to be a comprehensive text on anatomy and physiology as there are numerous extremely good volumes published on this subject. However, the reader may wish to dip into these explanatory notes as a refresher or source of direction for further study. After all, students of clinical biomedical science will find they have to read around our specific substantive chapters on haematology, clinical chemistry, microbiology and especially histopathology if they do not have a grasp of anatomical systems.

1.1 The skeletal system

The obvious functions of the skeleton are to provide support, leverage and movement and protection of organs, for example the skull protects the brain, the rib cage the lungs, heart, liver and kidneys, and the pelvis the bladder. In addition, the skeletal system is a storage site for calcium and phosphate minerals and lipids (yellow marrow) and critically a site for the production of blood cells (red bone marrow).

The characteristics of bone are that they are very lightweight yet very strong — resistant to tensile and compressive forces. Interestingly, healthiness (bone density) depends on continuous stressing or loading (i.e. activity). Bones are characterized by their shape (Figure 1.1) into long bones, short bones, flat bones and irregular bones.

1.1.1 The anatomical structure of a bone

Best exemplified by long bones, the bone itself is subdivided by internal and external structures. The bone is covered by a layer of cartilage called the periosteum underneath which is a layer of dense compacted calcified compact bone: however, beneath this layer can either be a hollow chamber (medullary

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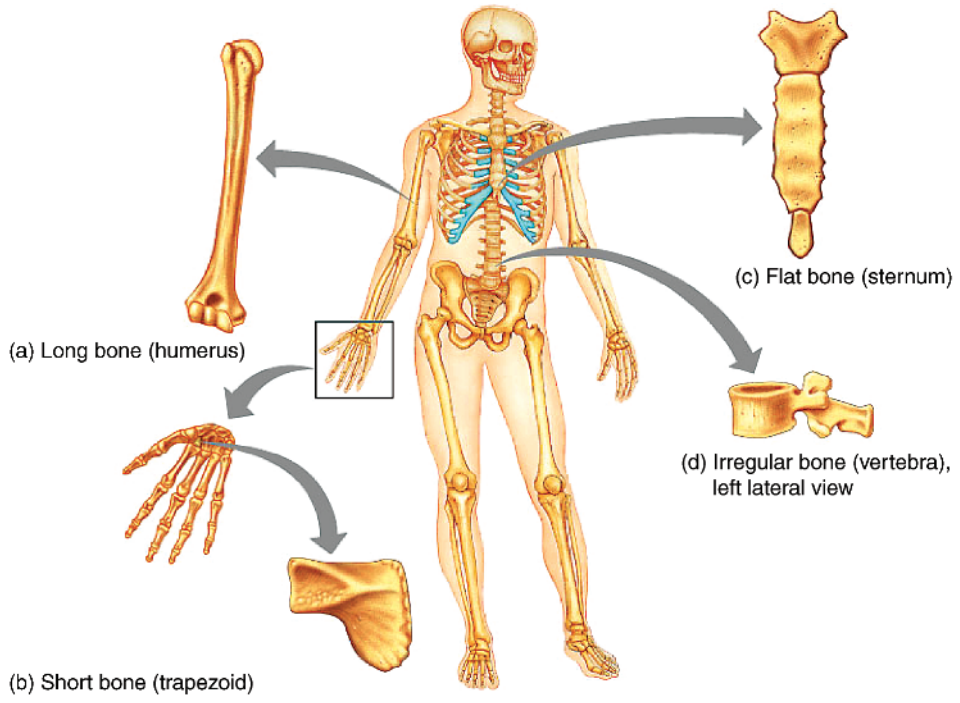

Figure 1.1 The human skeleton and the four bone categories which are shape descriptors. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

cavity) filled with the specialist tissue of the bone marrow or a spongy bone of small cavities. The spongy bone is always found at the end structures of articulating long bones and is a region of continued bone turnover lying above a line of active bone cells called the epiphyseal line. This spongy bone region is called the epiphysis, whilst the bone marrow dominant region between the two epiphyseal lines is termed the diaphysis where highly active bone turnover (remodelling) does not continuously occur (Figure 1.2).

Bone is derived from connective tissue and there are two types of connective tissue in the skeletal system — calcified bone and cartilage. Cartilage tissue forms a covering of articular surfaces, ligaments and tendons, as well as sheaths around bone (periosteum).

Bone tissue is calcium phosphate ($Ca_3(PO_4)$) crystals embedded in a collagen matrix peppered with bone cells. Thus bone is 60% minerals and collagen and 40% water where the collagen enables bones to resist tensile forces (i.e. are elastic) and minerals which enable bones to resist compressive forces, but this does makes them brittle.

Bone (osseous tissue) is, however, living tissue and therefore has an abundant blood and nerve supply: periosteal arteries supply the periosteum (see Figure 1.3 (a)); nutrient arteries enter through nutrient foramen supplies compact bone of the diaphysis and red marrow (see Figure 1.3(b)) and metaphyseal and epiphyseal arteries supply the red marrow and bone tissue of epiphyses (see Figure 1.3(a)).

1.1.2 Spongy bone and compact bone

Bone tissue is of two types — spongy and compact. Spongy bone forms 'struts' and 'braces' with spaces in between. Spaces contain bone marrow allowing production and storage of blood cells (red marrow) and the looser structure allows the bone to withstand compressive forces. Compact bone makes up the outer walls of bones, it appears smooth and homogenous and always covers spongy bone. Denser and stronger than spongy bone, compact bone gives bones their rigidity. Spongy and compact bone are biochemically similar, but are arranged differently. In compact bone the structural unit is the osteon (see Figure 1.4).

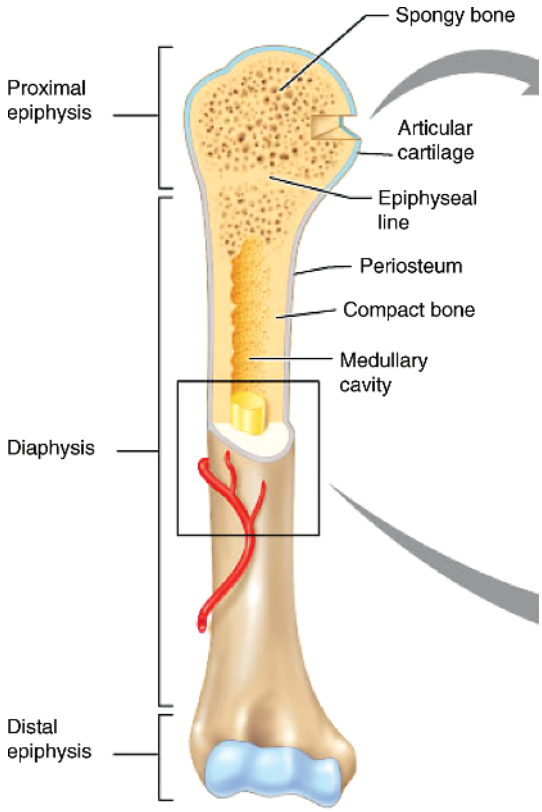

Figure 1.2 Structural components of the long bone. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

1.1.3 Osteocytes — mature bone cells

There are two types of bone cell:

- **Osteoblasts** — bone forming cells.
- **Osteoclasts** — bone destroying cells.

In the formation of new bone osteoblasts cover hyaline cartilage with bone matrix. Enclosed cartilage is digested away leaving the medullary cavity. Growth in width and length continues by the laying down of new bone matrix by osteoblasts. Remodelling to ensure the correct shape is effected by osteoclasts (bone-destroying cells). In mature bones osteoblast activity decreases whilst oesteoclast remodeling activity is maintained. However, bone remodelling requires both oesteocytes. Triggered in response to multiple signals stress on bones means that there is considerable normal 'turnover' — bone is a dynamic and active tissue; for example, the distal femur is fully remodelled every 4 months.

Osteoclasts carve out small tunnels and osteoblasts rebuild osteons: osteoclasts form a leak-proof seal around cell edges and then secrete enzymes and acids beneath themselves. The resultant digestion of the bone matrix releases calcium and phosphorus into interstitial fluid. Osteoblasts take over bone rebuilding,

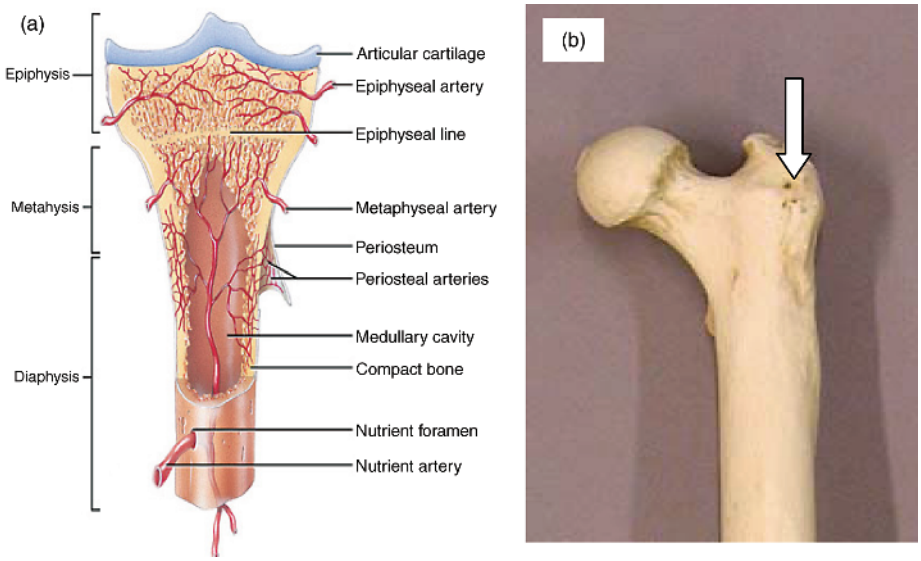

Figure 1.3 Detail of the blood supply of a long bone (a) and example of entry position, the nutrient foramina, is indicated in (b). *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

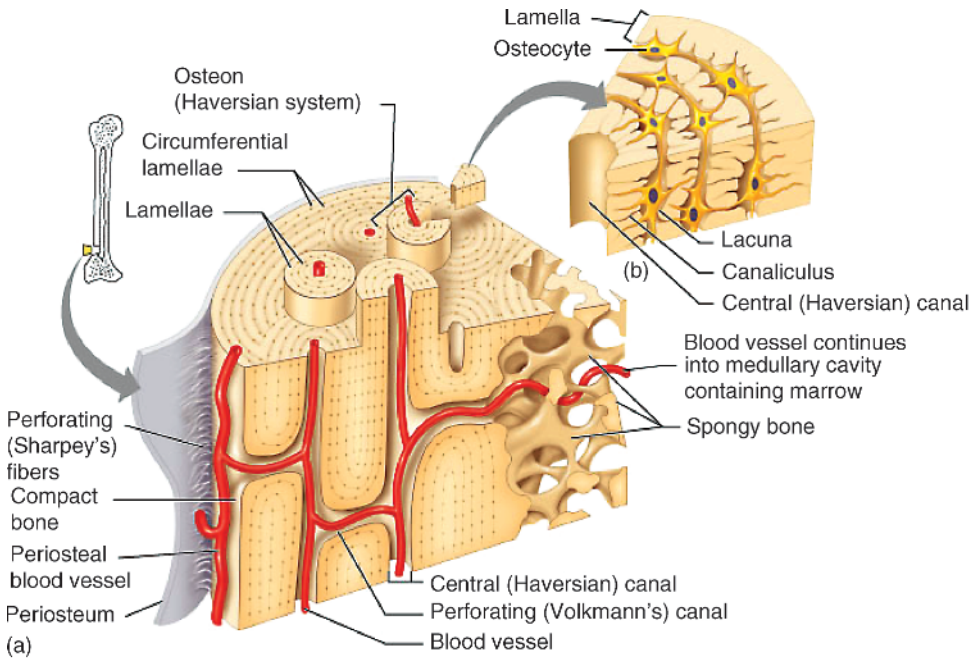

Figure 1.4 Microanatomy of the bone. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

continually redistributing bone matrix along lines of mechanical stress.

1.1.4 How bones grow

Bone growth only occurs in those young enough to still have an active, unfused epiphyseal plate (roughly < aged 16—19). The epiphyseal plates fuse earlier in females than in males — generally, females have stopped growing by around the age of 16, while for males this is around 18 to 19 (see Figure 1.5).

Cartilage cells are produced by mitosis on the epiphyseal side of plates (ends of bones) — this is continuous with articular cartilage at the end of the bone. Cartilage cells are destroyed and replaced by bone on the diaphyseal side of plates (middle of long bone)and a zone of resting cartilage anchors the growth plate to the bone. The epiphyseal plate is at the top of Figure 1.5, and this is where new cartilage cells are being created by mitosis. As they are 'pushed away' from the epiphyseal plate by new cartilage cells being created 'behind' them, osteoblasts lay down a calcium phosphate matrix in and around the cartilage cells, ossifying the area. This gradually takes on the structure of bone. The epiphyseal plate cartilage is continuous with the articular cartilage at the end of the bone, and new cartilage (and bone formation) is occurring in both areas rather than strictly just at the epiphyseal plate. Furthermore, the bone has to be remodelled as it increases in length, or the whole bone would be as wide as the epiphysis — but what you actually need is a narrower diaphysis (shaft) in the middle of the bone. The thick articular cartilage, at either end of the bone, is continuous with the thin (but tough) periosteum around the outside of the rest of the bone. Periosteum has a rich blood supply which is important when you consider bones grow not only in length but in width.

Periosteal cells (from membrane around the bone) differentiate into osteoblasts and form bony ridges and then a tunnel around a periosteal blood vessel. Concentric lamellae fill in the tunnel to form an osteon (see Figure 1.6). Blood vessels around the outside wall of the bone, on the periosteum, are 'walled in' as periosteal cells convert into osteoblasts and build new bone around them. This is why cortical bone is composed of osteons.

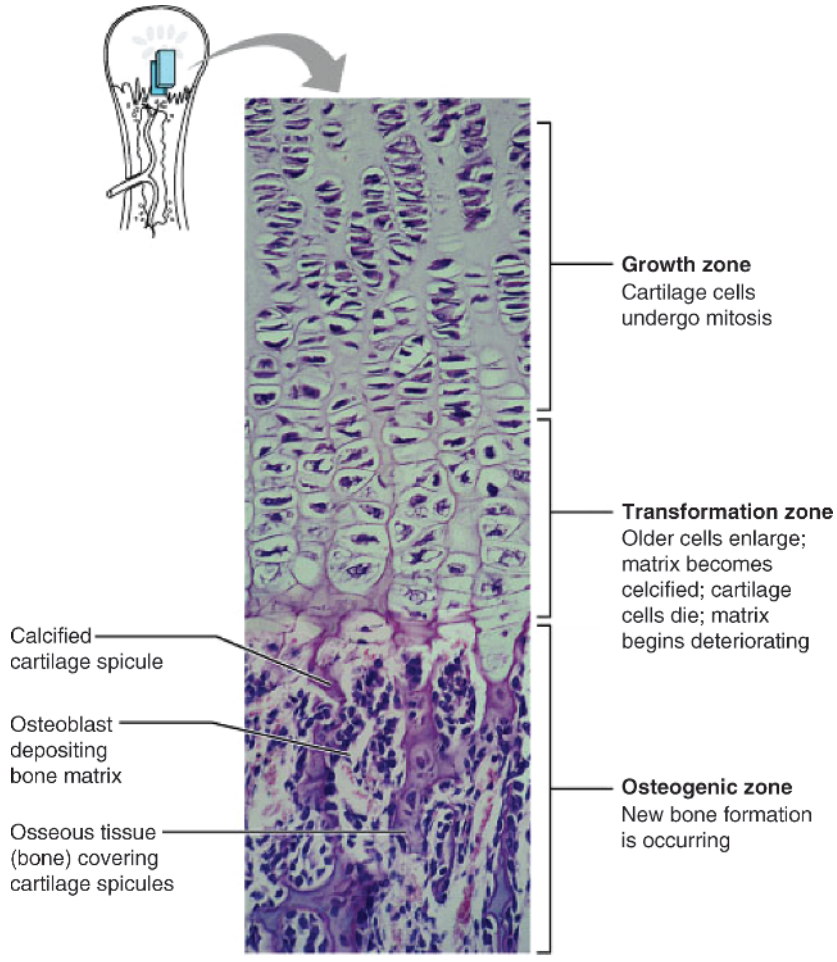

Figure 1.5 Histological appearance of epiphyseal plate. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

1.1.5 Endocrine regulation and nutritional requirement of bone growth

Several hormones are involved in endocrine control of bone growth: growth hormone, thyroid hormone, insulin and calcitonin. Before puberty growth hormone is the most important hormone involved in regulating bone growth. The metabolic hormones, thyroid hormones and insulin are involved in modulating the activity of growth hormone and ensuring proper proportions in the skeleton. Together these maintain the normal activity at the epiphyseal plate until the time of puberty. At puberty the increase in sex hormone production results in an acceleration of bone growth. These hormones promote the differences in the shape of the skeleton associated with males and females such as density and shape such as a flatter and wider pelvis in females. However, in both sexes the rate of ossification starts to outpace the rate of cartilage formation at the epiphyseal plates. Eventually the plates ossify and bone growth stops when the individual reaches sexual and physical maturity.

For adequate bone growth good nutrition is also required as are adequate levels of minerals and vitamins: calcium and phosphorus, vitamin D for bone formation, vitamin C for collagen formation and vitamins K and B_{12} for protein synthesis.

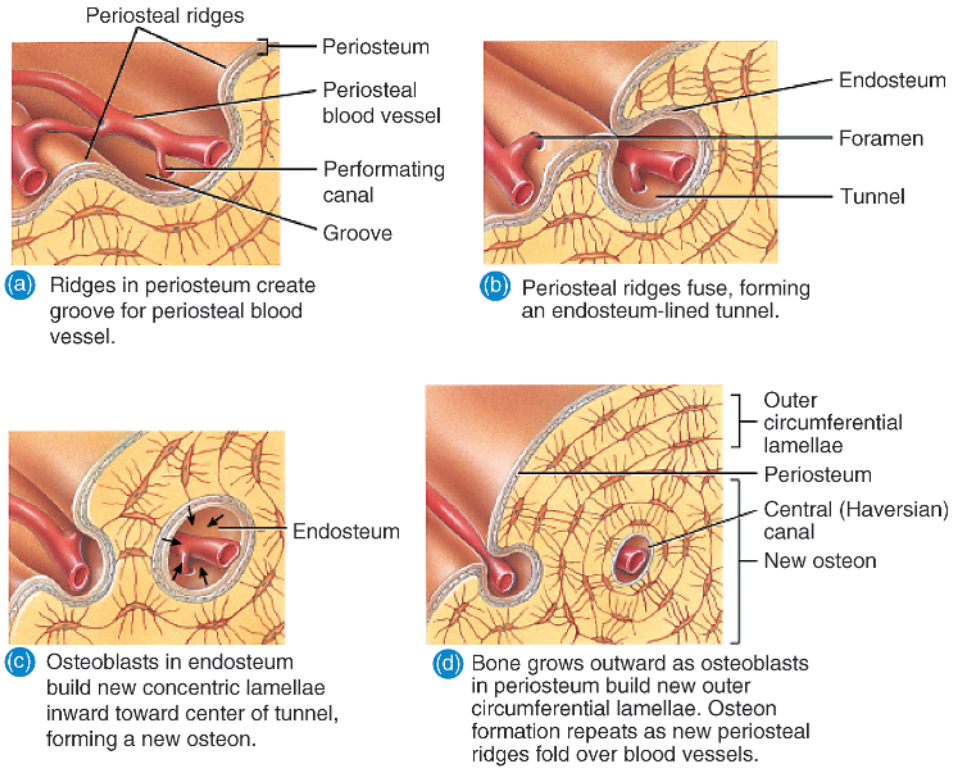

Figure 1.6 Appositional bone growth

1.1.6 The role of bone as a mineral store

A critical mineral which bones are involved in regulating is calcium as its ion concentrations in plasma must be very carefully controlled. Calcium homeostasis is affected by a negative feedback system involving the action of two primary hormones; calcitonin, produced from parafollicular cells of the thyroid gland in the neck and parathyroid hormone (PTH, also called parathormone) produced by the parathyroid glands (which lie on top of the thyroid gland). Responding to a fall in plasma calcium ions, released PTH, among other effects, induces the release of calcium by bone, whilst a rise in plasma calcium results in calcitonin which has the opposite effects, one of which is to promote increased deposition of calcium in bone.

1.2 The digestive system

This section aims to give an overview of the anatomy of the digestive system, identifying the major organs of the alimentary canal and the accessory digestive organs. In particular, the structure and function of the following organs and accessory organs of the alimentary canal are briefly described (see Figure 1.7):

- the oral cavity, pharynx and oesophagus;
- the stomach;
- the small intestine;
- the liver and gallbladder;
- the pancreas;
- the large intestine.

In so doing, it is possible to outline the major processes occurring during digestive system activity and give an overview of digestion and absorption.

1.2.1 Nutrition and absorption

The overall function of the digestive tract is to process not only the macronutrients (carbohydrates, proteins and fats) but also vitamins and minerals. Vitamins are complex organic substances essential for health,

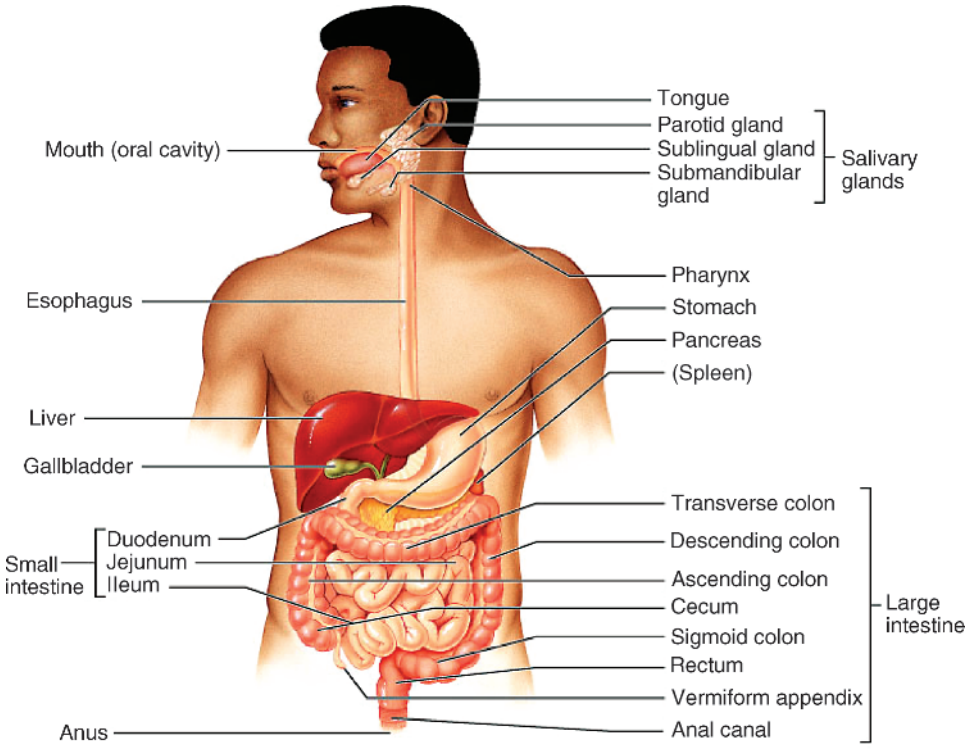

Figure 1.7 Overall anatomy of the digestive system. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

required in very small amounts (mg or µg per day) but most cannot be made by the body. They function as cofactors in enzyme activity, antioxidants to deal with free radicals generated during metabolism, and even as prohormone (i.e. vitamin D).

Minerals are inorganic compounds required by the body, like vitamins, for a variety of functions but often as cofactors or the reactive centres of functional proteins. Some minerals are needed in larger amounts than others, for example calcium, phosphorus, magnesium, sodium, potassium and chloride. Others are required in smaller quantities and are sometimes called trace minerals, for example iron, zinc, iodine, fluoride, selenium and copper. However, despite being required in smaller amounts, trace minerals are no less important than other minerals.

In order to extract macro- and micronutrients from food stuffs the digestive system must bring about ingestion, digestion (mechanical and chemical), enable movement through the digestive tract, facilitate absorption of nutrients and finally defaecation of the nondigestible elements and some waste products.

1.2.2 Ingestion

The oral cavity is a far more complex mechanism than just a set of teeth. You unconsciously analyse food when you put it in your mouth to check it isn't too large a chunk to sensibly chew, that it doesn't contain very hard bits, and that it isn't in some way mouldy or otherwise unpleasant. Only then do you start chewing properly and contemplating swallowing it. Thus the oral cavity analyses the food, mechanically processes (chews to smaller pieces), lubricates (saliva) and starts the process of chemical digestion via the enzymes secreted as part of saliva (see Figure 1.8).

After chewing we swallow but there are two phases:

- buccal phase (voluntary);
- pharyngeal phase (involuntary).

1.2.2.1 Pharynx and oesophagus

During the pharyngeal phase, the airways have to be shut off by the **epiglottis** to prevent food from going

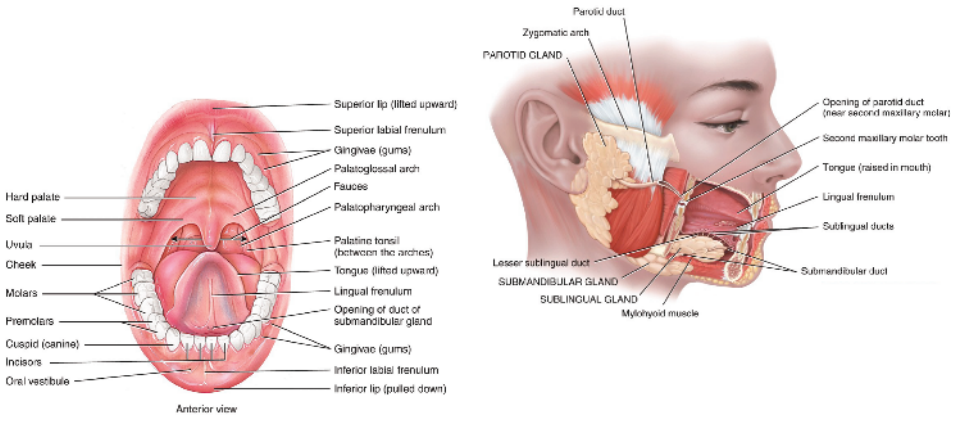

Figure 1.8 Structures and exocrine glands of the oral cavity. From Tortora and Derrickson, *Principles of Anatomy and Physiology*, Twelfth Edition, 2009, reproduced by permission of John Wiley & Sons Inc.

down the air passages/windpipe (see Figure 1.9). Babies don't have quite the same set up, and this allows them to breathe while drinking milk. Peristalsis carries food in one direction only — down, so you can eat and drink standing on your head if you want to; animals such as horses effectively do this by eating with their heads lower than the level of their stomach.

1.2.3 The stomach

Lying in the upper part of the abdominal cavity, this sac or balloon like stomach occupies a volume of 50 mL empty, but expands to 4 L when full. The different orientations of muscle layers in the stomach allow it to contract in different directions to maximize the effectiveness of mechanically breaking down food. The folds (rugae) increase the surface area for maximum absorption (see Figure 1.10). It is also important to note that there is a cardiac sphincter between the oesophagus and stomach, and a pyloric sphincter between the stomach and duodenum — sometimes the pyloric sphincter is malformed (this predominantly affects baby boys) and will not open, which causes projectile vomiting and failure to thrive until it is surgically corrected. At the other end the stomach sits below the diaphragm, but sometimes part of the stomach is squeezed up through the diaphragm, resulting in heartburn and reflux as acid enters the oesophagus.

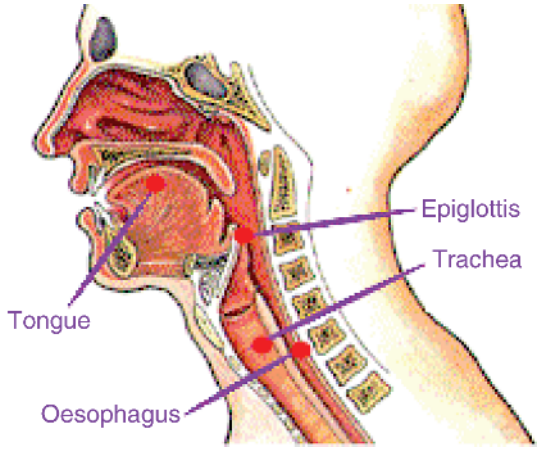

Figure 1.9 Position of the epiglottis in respect to closure of the trachea

1.2.3.1 Stomach mucosal lining

The gastric mucosa contain three predominant differentiated cell types: parietal cells which secrete hydrochloric acid and intrinsic factors facilitating the absorption of vitamin B12; chief cells which secrete pepsinogen (inactive form of pepsin) — which is activated by HCl and begins the digestion of protein; and mucous cells. The stomach secretes a thick mucus to protect itself from its own hydrochloric acid (see Figure 1.11).

1.2.3.2 The gastric digestive process

Swallowed food collects in the upper storage area. Starch (complex carbohydrate) continues to be digested until the mass has been mixed with gastric juice. Small portions of mashed food are pushed into the digesting area of the stomach where acid in gastric juice unwinds (denatures) the proteins and the enzyme pepsin breaks up the chains

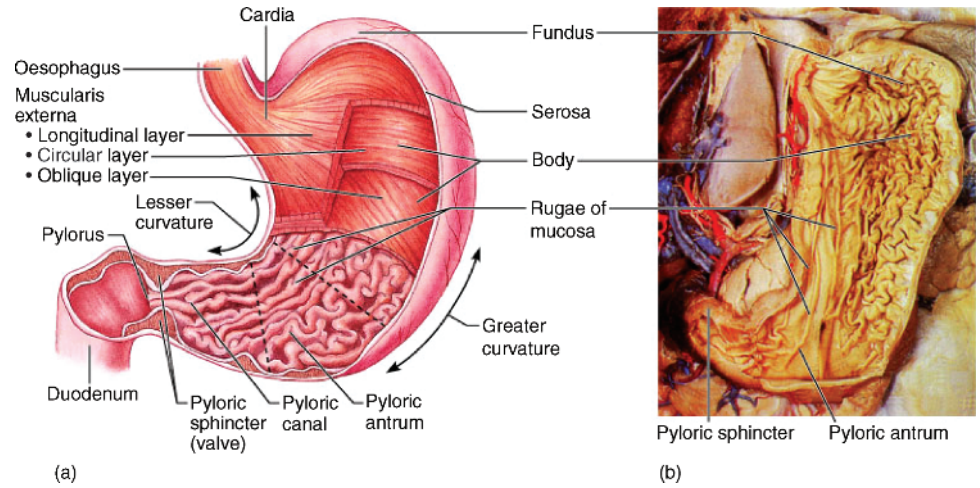

Figure 1.10 (a) Anatomy and (b) cross-sectional appearance of the stomach. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

of amino acids. This all forms a thick liquid mass called chyme which moves on and enters the small intestine. Fat forms a separate layer on the top.

1.2.4 The small intestine

The small intestine consists of three distinct anatomical regions: the duodenum, pyloric sphincter to jejunum; jejunum, duodenum to ileum; and ileum, jejunum to large intestine. The small intestine is where most nutrients are absorbed, and it is all about surface area maximization (see Figure 1.12).

The mucosal folds of the small intestine are covered in villi (Figure 1.12(a) and (b)), and each villus in turn is lined with columnar cells that have a brush border (Figure 1.12(c)), all to give a large surface area for absorption. Note too that each villus has a rich blood supply to help with this too (see Figure 1.12(c)).

1.2.5 Liver and gall bladder

Positioned below the diaphragm and protected by the lower half of the rib cage, the liver is divided into a right and left lobe by the round ligament. The gall bladder nestles into it from underneath and in real life this is a dark green colour and really stands out. Among other functions the liver produces bile. Bile contains bile acids, which assist with the absorption of fats and fat-soluble vitamins in the small intestine. Many waste products, including bilirubin, are eliminated from the body by secretion into bile and elimination in faeces. Adult humans produce 400 to 800 mL of bile per day.

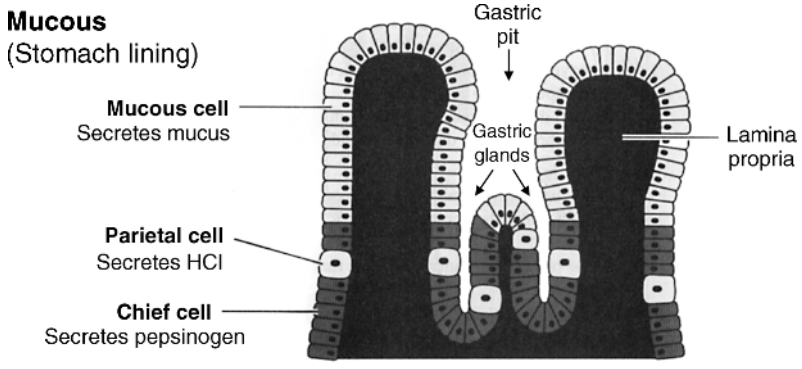

Figure 1.11 Microanatomy of the stomach lining

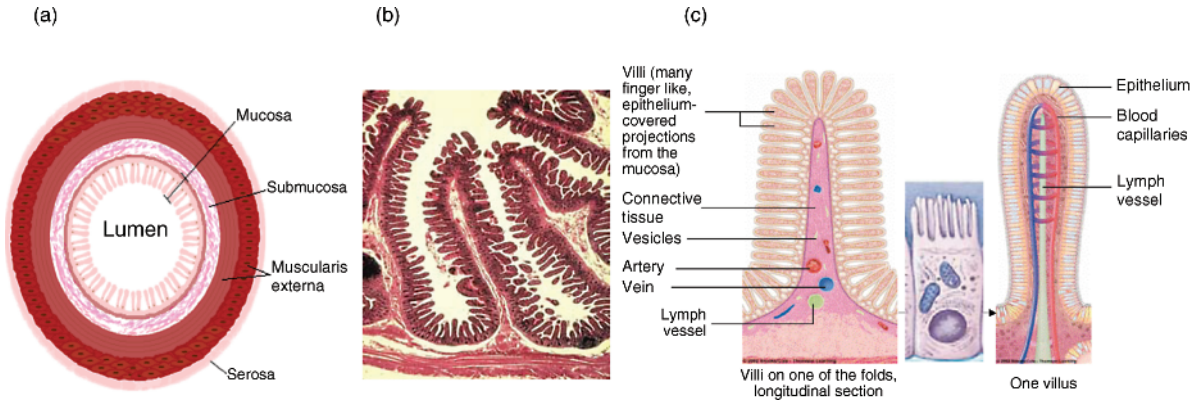

Figure 1.12 Small intestine: cross-sectional and microanatomy

Further modification of bile occurs in that organ. The gall bladder stores and concentrates bile during the fasting state. Typically, bile is concentrated fivefold in the gall bladder by absorption of water and electrolytes — virtually all of the organic molecules are retained. The liver drains bile out towards the gall bladder in the bile duct, and further down this is joined by secretions from the pancreas to form a common bile duct, which secretes a mixture of bile and pancreatic juices into the duodenum as food passes through (see Figure 1.13). The bile duct can become obstructed by small gallstones (and other things, like a tumour in the head of the pancreas), which causes jaundice and is described in several of the following chapters.

1.2.6 The pancreas

The pancreas is both an exocrine and endocrine gland. Its endocrine function is fulfilled by the pancreatic islets cells which secrete insulin and glucagon, whilst its digestive system exocrine function is to produce and secrete digestive enzymes: trypsin and chymotrypsin which break proteins into peptides (short chains of amino acids); pancreatic lipase which digests triglycerides into a monoglyceride and two free fatty acids; amylase which hydrolyses starch to maltose (a glucose—glucose disaccharide) and others such as nucleases (ribonuclease, deoxyribonuclease) and those that digest fibrous tissues (e.g. gelatinase and elastase). The pancreas is a highly sensitive organ and can become inflamed (pancreatitis) — this is caused by pancreatic enzymes from damaged pancreatic cells leaking into pancreatic tissue and digesting it.

1.2.7 Small intestine and associated organs and digestion

It must be remembered that the small intestine is a major site in the digestive process, the pancreas liver

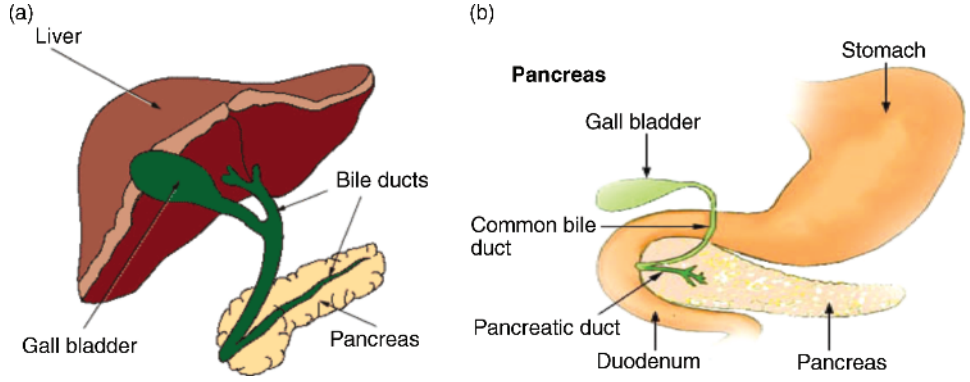

Figure 1.13 (a) Diagrammatic representation of the relative positional anatomy of the liver, gall bladder and pancreas, and (b) in relationship to the stomach and small intestine

and gall bladder all work in concert with the absorption function of the mucosal folds and villi cells found here. Thus, chyme squirts into the duodenum from the stomach and peristaltic movement pushes the chyme along and mixes with secretions for chemical digestion. In particular pancreatic juice and bile help to digest carbohydrate, lipids and proteins. All the while the macro- and microanatomy of the small intestine optimizes absorption and facilitates the transport of nutrient across the mucosal barrier and into the blood stream. Most digested food is absorbed in the small intestine so there is a rich and complex net of blood and lymphatic channels around and leading to and from the small intestine as it winds backwards and forwards.

1.2.8 The large intestine

The residual chyme moves from the small intestine via the Illeocecal valve (which prevents the contraction from these larger vessels forcing waste back into the small intestine) into the first pouch or haustra of the large intestine — the caecum. Herbivores have a large caecum and appendix that contain symbiotic bacteria that synthesize the enzyme cellulase, allowing them to digest plants cell walls, these pass through us as fibre. The human appendix is roughly the size of the little finger, but in some people it is relatively long and thin (with a small diameter that is more likely to block, possibly resulting in appendicitis).

The movement of this residual digestive chyme through the large intestine is slow and rather laborious in the mechanical mechanism that operates: pouches (or haustra) fill to capacity, when stretched they contract and force the contents into the next haustra (and section of the colon). During this slow passage water is absorbed or reabsorbed, and vitamins and minerals are absorbed along with it. As water is absorbed the residual chyme is dehydrated and compacted to form faeces. Mass peristalsis forces the contents into the rectum for the storage of faecal material prior to defecation (see Figure 1.14).

The average passage time of undigested food residues through the human gut is about 50 h in men and 57 h in women, but ranges from well under 20 to over 100 h. It also changes from one day to the next. However, about 80—90% of the entire transit time of food in the body is spent in the colon, so it needs to be large and have a good capacity. Thus, movement through the digestive tract varies dramatically section per section: Oesophageal peristalsis is fast with a transit time of about 3 s; time in the stomach is about 1—3 h; small intestine digestion and absorption is 2—6 h, whilst 12—48 h is spent in the large intestine prior to defecation.

1.3 The cardiovascular system

The function of the cardiovascular system is as a transport system of the body carrying:

- respiratory gases;
- nutrients;
- hormones and other material to and from the body tissues.

The fluid component of this system — blood — is a complex of specialized cells and solution of salts (electrolytes) and soluble proteins. At the centre of the cardiovascular system is the heart to which structurally distinct vessels — arteries — carry blood away, and equally structurally distinct vessels — veins — carry blood back to the heart.

However, the cardiovascular system has two divisions: pulmonary and systemic (see Figure 1.15). In the pulmonary division, blood flows from the right ventricle of the heart to alveolar capillaries of the lungs and back to the left atrium of the heart. In the systemic division the left ventricle pumps blood to the rest of the body and all other body capillaries, and the blood returns to the heart's right atrium. Hence there is an asymmetry in muscle mass between the two ventricles. In addition the two divisions have two different profiles with respect to the transport of respiratory gases; pulmonary arteries are low in O_2 high in CO_2 whilst the arteries of the systemic division are high in O_2 low in CO_2 (and the pulmonary—systemic veins vice versa). Capillaries, minute blood vessels found throughout tissues, connect the small arteries to the small veins. Exchange of respiratory gases and nutrients with the tissues occurs across the walls of the capillaries.

1.3.1 The heart

The heart is a complex structure of four chambers, powerful muscles, specialized valves that contract and

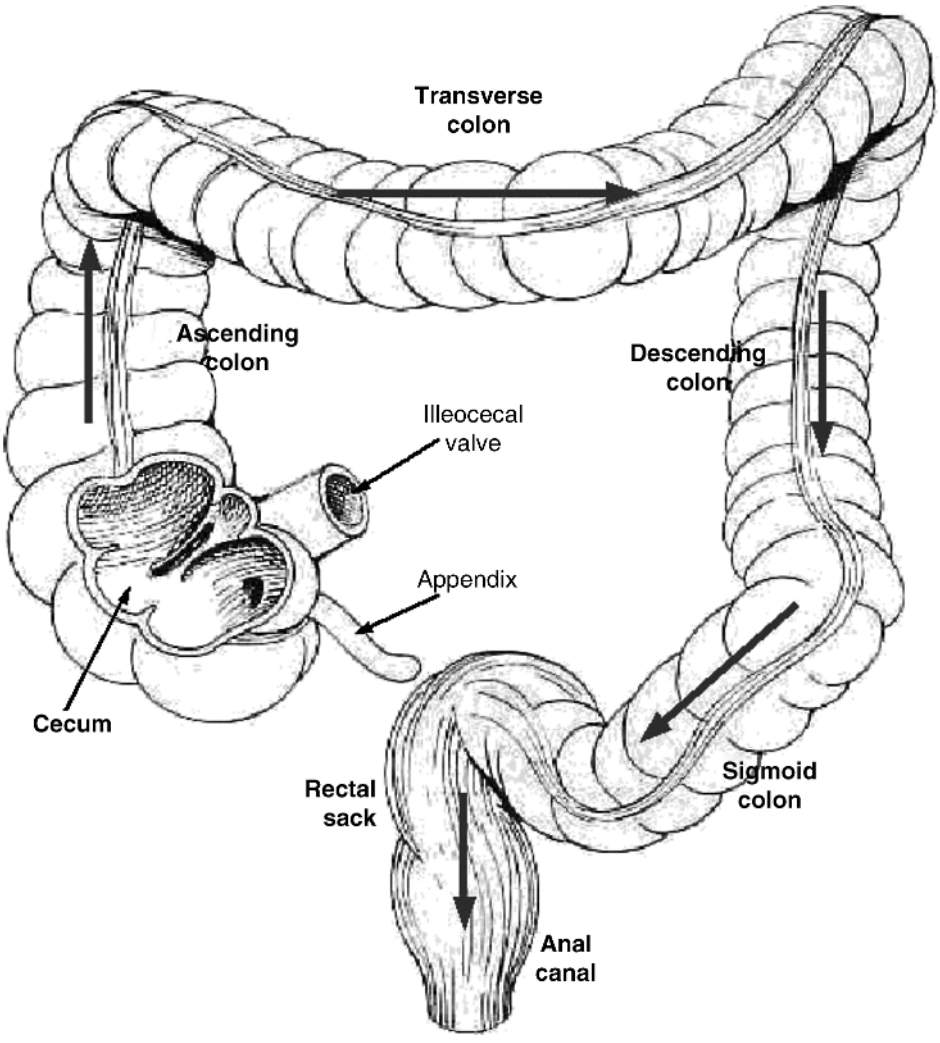

Figure 1.14 Diagrammatic representation of the structure of the large intestine

open/close in a coordinated manner, regulated by its own specialist sensory and responsive neurological system (see Figure 1.16). The entire organ is surrounded by a protective barrier called the pericardium. It is in fact a protective sac surrounding the heart consisting of an outer tissue layer called the parietal pericardium, a proteinacious (pericardial) fluid and a heart wall contacting tissue, the visceral pericardium also referred to as the epicardium.

The heart wall consists of two tissue layers the inner endocardium which is contiguous with blood vessel endothelium and the myocardium of specialist cardiac muscle. The heart has two structural classes of chambers: receiving chambers or atria (singular, atrium) and pumping chambers or ventricles. The right ventricle pumps for the pulmonary circulation, the left ventricle pumps for the systemic circulation. The 'Great Vessels' of the heart are the aorta and pulmonary trunk. Heart valves ensure the one-way flow of blood through the heart and there are two types: semilunar valves (pulmonary semilunar and aortic semilunar) lead from the ventricles and prevent back flow from pulmonary and systemic vasculature. The atrio-ventricular (AV) valves are the tricuspid — right atrium into the right ventricle; and bicuspid (mitral) — left atrium to the left ventricle. If a section is cut through the heart at the atrial ventricular boundary through the four valves a structural skeleton of (four) fibrous rings can be seen. These tough fibrous rings provide rigidity to prevent the dilation of valves and provide a point of

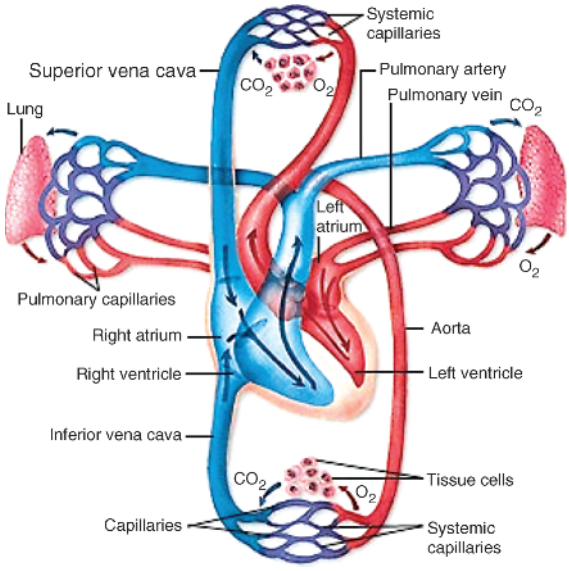

Figure 1.15 The systemic and pulmonary systems

attachment for valves. This fibrous skeleton also electrically isolates the atria from the ventricles. The AV bundle ('bundle of His') is the only electrical connection between the atria and the ventricles (see Figure 1.17).

The origin of heartbeat is located in a sinoatrial (SA) node of the heart, where a group of specialized cells continuously generates an electrical impulse. The SA node generates such impulses about 100—120 times per min at rest. However, in a healthy individual the resting heart rate (HR) would never be that high. This is due to continuous control of the autonomic nervous system (ANS) over the output of SA node activity, which net regulatory effect gives real HR. In a healthy subject at rest it is ranging between 50 and 70 beats per min.

The electrical impulse of the sino-atrial (SA), stimulated by blood flow, first induces the muscle tissue of the atrial chamber to contract. The electrical impulse travels to the atrio-ventricular node and synchronizes with this tissue's inherent but weaker electrical pulsivity. This combined and synchronized electrical pulse travels down the conductive fibres (bundle of His, bundle branches)of the noncontractive muscular cardiac septum (i.e. this tissue does not contract in response to this electrical signal) to the Purkinje fibres which originate at the base of the ventricle muscle walls and travel up towards the atrioventricular boundary. The result is that the signal is delayed, atria muscles are relaxing, but the impulses then induce waves of contraction of the ventricles from the bottom up. This efficiently empties the heart ventricles — like squeezing a toothpaste tube from the bottom and not the middle, whilst the atrium refill. The order of impulse spreading all over the heart muscle through specialized pathways creates synchronized heart muscle contraction between both atriums (first) and then the ventricles which contracts in a wave starting from the bottom of the heart to the top of the ventricles.

1.3.2 The vasculature

The blood vessels are the **arteries**, **arterioles**, **capillaries**, **venules** and **veins** and all blood vessels are lined with specialist cells of the endothelium (see Figure 1.18). The arteries which carry blood away from the heart are subject to the highest blood pressure and located deep within tissues. Subject to much lower pressures, veins return blood to the heart.

1.3.2.1 Structure of arteries and arterioles

Arteries consist of three tissue layers: **tunica interna**, **tunica media** and **tunica externa**. However, there are two types of artery: elastic arteries, which contain elastic fibres in the tunica media and interna, which are the largest. Muscular arteries have little elasticity and abundant smooth muscle in the tunica media.

Arterioles are less than 1 mm in diameter and consist of endothelium and smooth muscle. It is the ability of arteries to contract by virtue of the dense smooth muscle layers that allows these vessels to regulate blood pressure in a general and locality specific manner. Indeed the **metarterioles** regulate the flow of blood into capillaries (see Figure 1.19).

Capillaries are the sites of exchange, they are very thin and permeable, allowing exchange between blood and tissue cells in systemic capillaries and the exchange between blood and air in pulmonary capillaries.

1.3.2.2 Structure of veins and venules

Veins are thinner than arteries, of a much larger diameter and located both deep and superficially

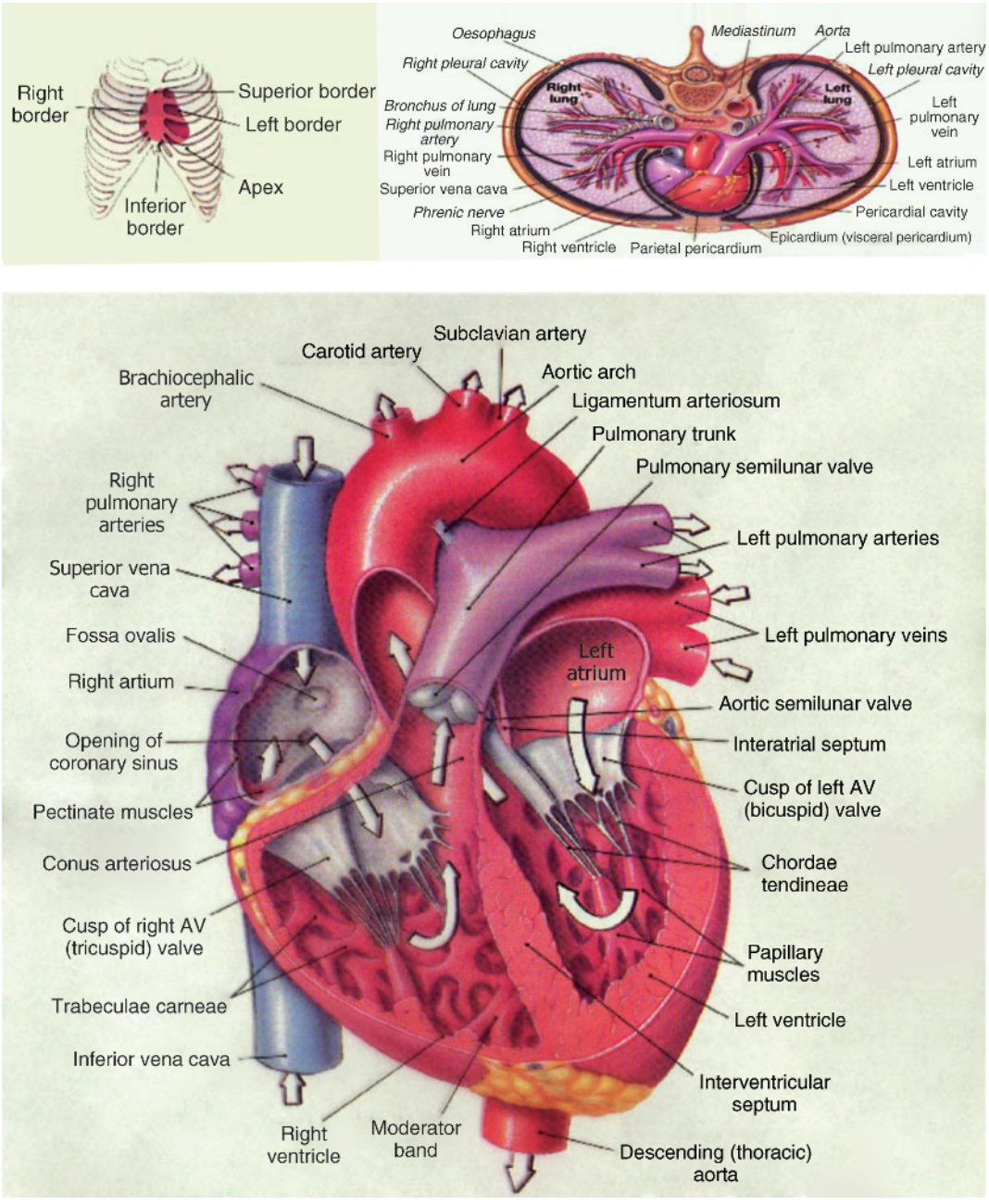

Figure 1.16 The heart, position associated organs and major vessels

within tissue. A key difference is that veins have valves. Since the blood in veins is under much lower pressure after a forward flow pressure beat from the left ventricle, the blood could flow backwards again. The valves prevent this backwards flow and veins within muscles are squeezed by external contraction of muscle tissue mass as a result of movement (and general muscle tone) to help return blood.

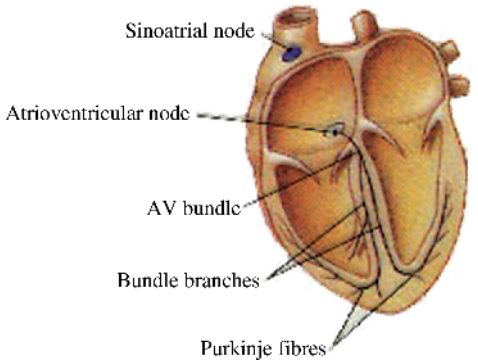

Figure 1.17 Neurological conduction system of the heart

1.3.3 Blood distribution

Blood does not spend its time equally between veins and arteries. Indeed, as demonstrated in Table 1.1, most of the time blood is in the systemic venous system.

The reason is that exchange is not just one way — from the oxygen rich systemic arteries to tissues but huge exchange occurs in the hepatic portal system where food and metabolites are absorbed (see Figure 1.20). Similarly, coming away from bone (marrow) in the exiting veins are new blood cells.

1.3.3.1 The heart's blood supply

The highly active muscle and neurological tissue of the heart has its own surrounding network of capillaries fed by the coronary circulation, some of the major vessel of which are the right coronary artery, the left coronary artery, the circumflex, the anterior interventricular (also LAD) and the coronary sinus.

1.3.3.2 Blood flow

Defined as the volume of blood flowing through a vessel, an organ, or the entire circulation in a given period blood flow is measured in mL per minute. Equivalent to cardiac output (CO), considering the entire vascular system this is relatively constant when at rest. However, it varies widely through individual organs, according to immediate needs.

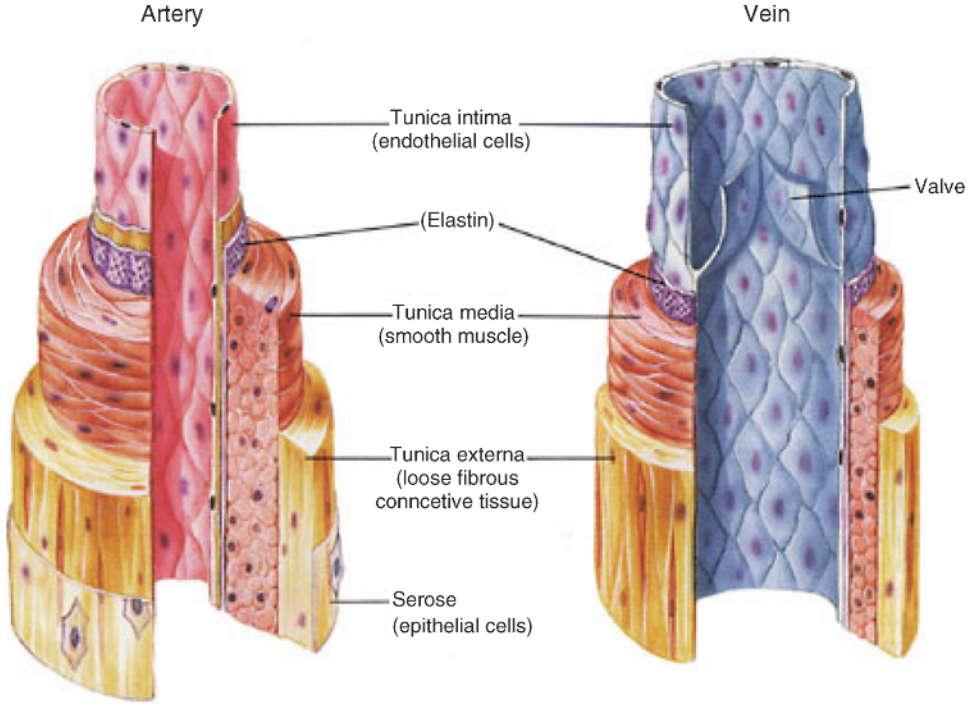

Figure 1.18 Structural comparisons of arteries and veins. *Human Physiology*, 4th Edition, Fox, 1993 © William C. Brown

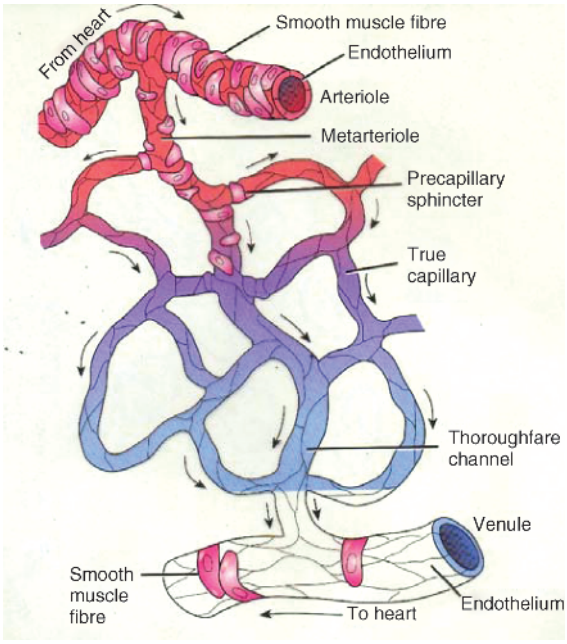

Figure 1.19 Structural representations of arteriole capillary venule 'mesh'

Table 1.1 Percentage distribution of blood in the cardio-vasculature

Systemic venous system	**64%**
Systemic arterial system	13%
Heart	7%
Systemic capillaries	7%
Pulmonary venous system	4%
Pulmonary arterial system	3%
Pulmonary capillaries	2%

Resistance — opposition to flow — is the measure of the amount of friction blood encounters as it passes through vessels. Resistance is more significant in the systemic circulation and is referred to as peripheral resistance (PR).

The three important sources of resistance are blood viscosity — thickness or 'stickiness' of the blood, total blood vessel length — the longer the vessel, the greater the resistance encountered — and blood vessel diameter. Changes in vessel diameter are frequent and significantly alter peripheral resistance. Resistance varies inversely with the fourth power of vessel radius

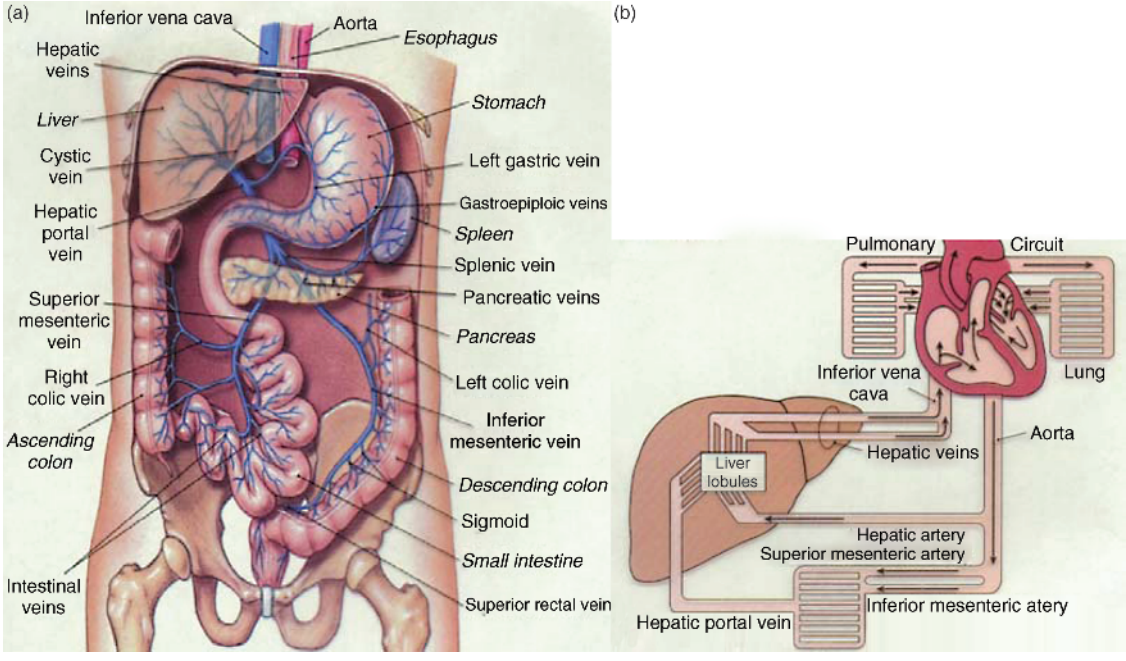

Figure 1.20 (a) Diagrammatic anatomical and (b) functional representations of the hepatic portal circulations demonstrating the dominance of the venous vessels

(one-half the diameter), for example, if the radius is doubled, the resistance is 1/16 as much.

Blood flow (F) is directly proportional to the difference in blood pressure (ΔP) between two points in the circulation. If ΔP increases, blood flow speeds up; if ΔP decreases, blood flow declines. Blood flow is inversely proportional to resistance (R), If resistance (R) increases, blood flow decreases. Resistance is more important than difference in blood pressure in influencing local tissue blood pressure.

The pumping action of the heart generates blood flow through the vessels along a pressure gradient — always moving from higher- to lower-pressure areas — and pressure results when flow is opposed by resistance. Blood pressure is defined as the force per unit area exerted on the wall of a blood vessel by its contained blood and is expressed in millimetres of mercury (mm Hg).

Thus, as the blood vessels get generally wider we find that systemic blood pressure Is highest in the aorta, declines throughout the length of the pathway and is 0 mm Hg in the right atrium. The steepest change in blood pressure occurs in the arterioles.

The fact that there is really no pressure left by the time the blood is returning to the heart means that the body relies on the 'sucking' effect of the diaphragm lowering to cause inhalation (i.e. creating negative pressure in the thoracic cavity) within the thoracic cavity to help draw venous blood back up towards the heart.

1.4 The urinary system

The urinary system comprises the kidneys, ureter(s), bladder and urethra (Figure 1.21). The Functions of the urinary system are:

- to excrete organic waste;
- to regulate blood volume;
- to regulate blood pressure;
- to regulate ion concentrations (sodium, potassium, chloride, calcium, etc.);
- to maintain blood pH at physiological range (7.35—7.45).

The kidneys lie retroperitoneal (behind the peritoneal cavity), so they are separated from the abdominal organs that lie in front of them, in the peritoneal cavity. Weighing approximately 150 g, the distinctively shaped kidney (approximately 12 cm (long) × 6 cm (wide) × 3 cm (thickness)) lies approximately at vertebral level T12—L3 with the upper parts protected by the 11th and 12th ribs. The organs themselves have three layers of protective tissue: renal capsule, adipose capsule and renal fascia. The capsule is a tough connective tissue membrane around the kidney which is quite hard to peel off it. The kidney is also covered in a very thick layer of fat which gives it considerable protection against trauma.

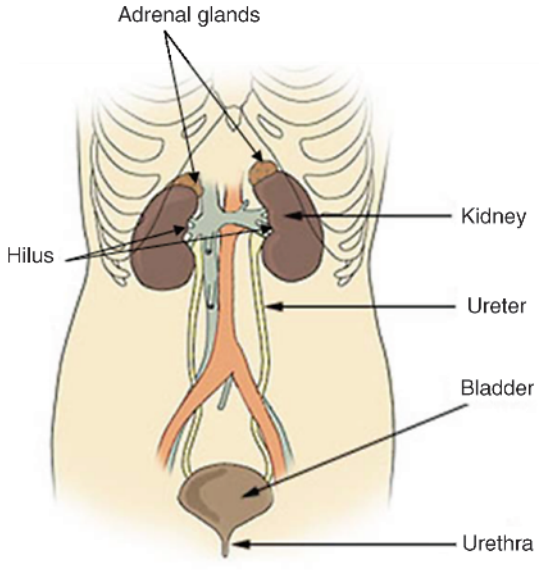

Figure 1.21 Gross anatomy of the urinary system

The female urethra is considerably shorter than the male urethra (meaning that females suffer from far more urinary tract infections than males — bacteria have only a short distance to travel to get into the bladder in women, and the rectum is very close to the urethra in females too). The right kidney is lower than the left kidney, which means it gets more kidney infections (a shorter urethra for bacteria to travel along from the bladder) and suffers more from trauma, as it has less protection from the ribcage (see Figure 1.22).

1.4.1 The kidneys

The kidney internal structure consists of a cortex which produces urine and a series of collecting ducts that take the urine from the kidney via a connective tube (ureter) to the major reservoir for eventual excretion (urination from the bladder). In its cross-sectional anatomy the kidney has a ureteric interface cavernous

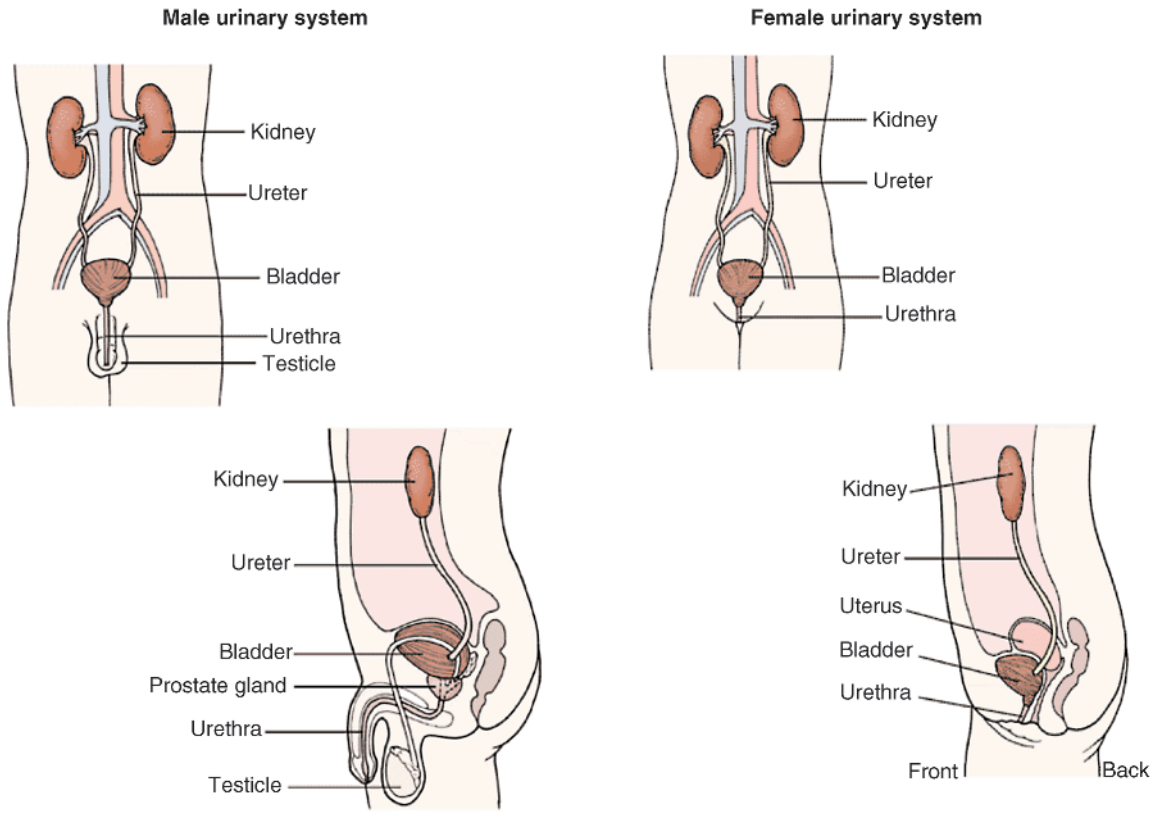

Figure 1.22 Comparative anatomy of the female and male urinary system

region called the hilus (where kidney stones often occur) to which a larger and larger urine draining region (termed calyces) empties. The minor calyces are composed of aggregated collecting ducts — these in turn aggregate into major calyces, which finally become the hilus and ureter. The renal artery supplies the kidney — the kidney is highly metabolically active and needs a good supply of oxygen and glucose. Relative to its small size, it actually uses about a quarter of the arterial blood supply in the body. This also allows it to be highly efficient in terms of filtration of large volumes of plasma and production of urine. The renal vein drains deoxygenated, filtered blood from the kidney (see Figure 1.23).

1.4.1.1 The nephron

The physiological unit of the kidney is the nephron which anatomically straddles the renal cortex with a descending loop into the renal medulla. The blood vessels in the cortex of a kidney reduce from larger vessels, to lots of small round 'tufts' of capillaries each one of these is one glomerulus, the knot of capillaries within a Bowman's capsule (see Figure 1.24).

Blood vessels wrap around the whole nephron, and after the efferent arteriole leaves the Bowman's capsule it continues and is wrapped around the proximal convoluted tubule, loop of Henle, and distal convoluted tubule. This means that water, ions, amino acids, drugs and so on can easily move between the nephron and the bloodstream along the length of the nephron.

Pressure within the glomerulus is kept very high by the diameter of the outgoing arteriole being narrower than the ingoing arteriole. In the Bowman's capsule, fluid is forced out of the glomerulus and into the capsule from the bloodstream. Blood within the glomerulus is under very high pressure, and the capillaries here are very leaky, so a lot of the fluid component of blood is forced straight out into the capsule, and a

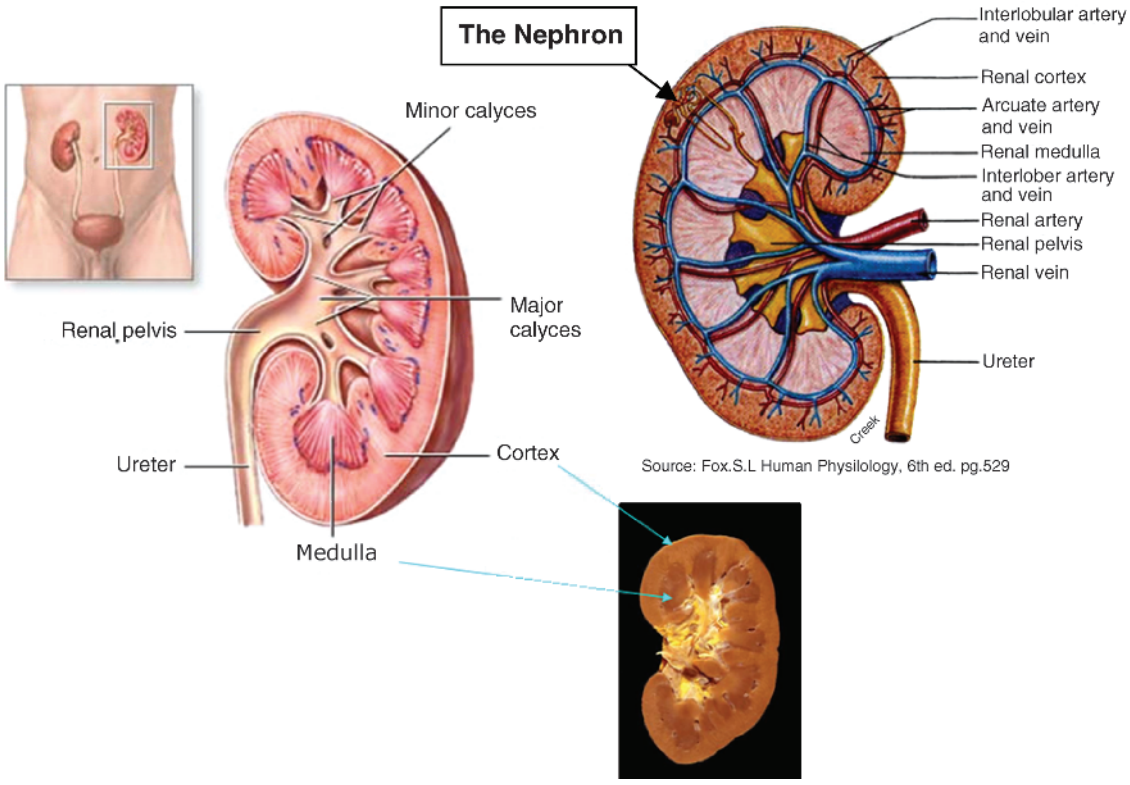

Figure 1.23 Blood supply and metabolic active regions of the kidney. *Human Physiology*, 4th Edition, Fox, 1993 © William C. Brown

large volume of fluid literally pours into the proximal tubule. Proteins greater than 10 kD are generally too large to be forced out of blood (urine should be essentially protein-free in the healthy individual — that is at very very low levels compared to the blood), and the cells of blood are obviously much too large to get between the gaps in the capillaries too (urine should not contain red or white blood cells in the healthy).

1.4.1.2 Glomerular filtration rate (GFR)

This is the volume of blood filtered per unit time by all glomeruli combined, approximately 125 mL per minute (or 7.5 L/h). However 7.5 L of filtrate per hour is entering the nephrons of your kidneys, but how much urine are you actually producing? It should be around 60 mL/h, which tells you that over 99% of the water in the filtrate alone is being reabsorbed. This is fortunate as your bladder capacity is only about 500 mL, and you would otherwise need to empty it 15 times per hour.

GFR varies directly with glomerular blood pressure which, in turn, is determined by systemic blood pressure. This can vary dramatically due the environment or activity; however, renal autoregulation regulates the diameter of incoming arterioles to keep blood flow within normal limits and maintain GFR. If you lose a lot of your blood volume, epinephrine/adrenalin is produced by the sympathetic nervous system, and causes blood pressure to rise (by increasing heart rate and stroke volume as well as via arteriole constriction). However, the kidneys are also partially masters of their own incoming blood pressure via production of renin, which increases blood pressure via the renin–angiotensin system. The cells that produce renins, the juxtaglomerular cells, are located between the glomerulus and the distal convoluted tubule of the same nephron.

1.4.1.3 Reabsorbtion

Nutrients (glucose and amino acids) which pass into the filtrate at the glomerulus are normally all reabsorbed

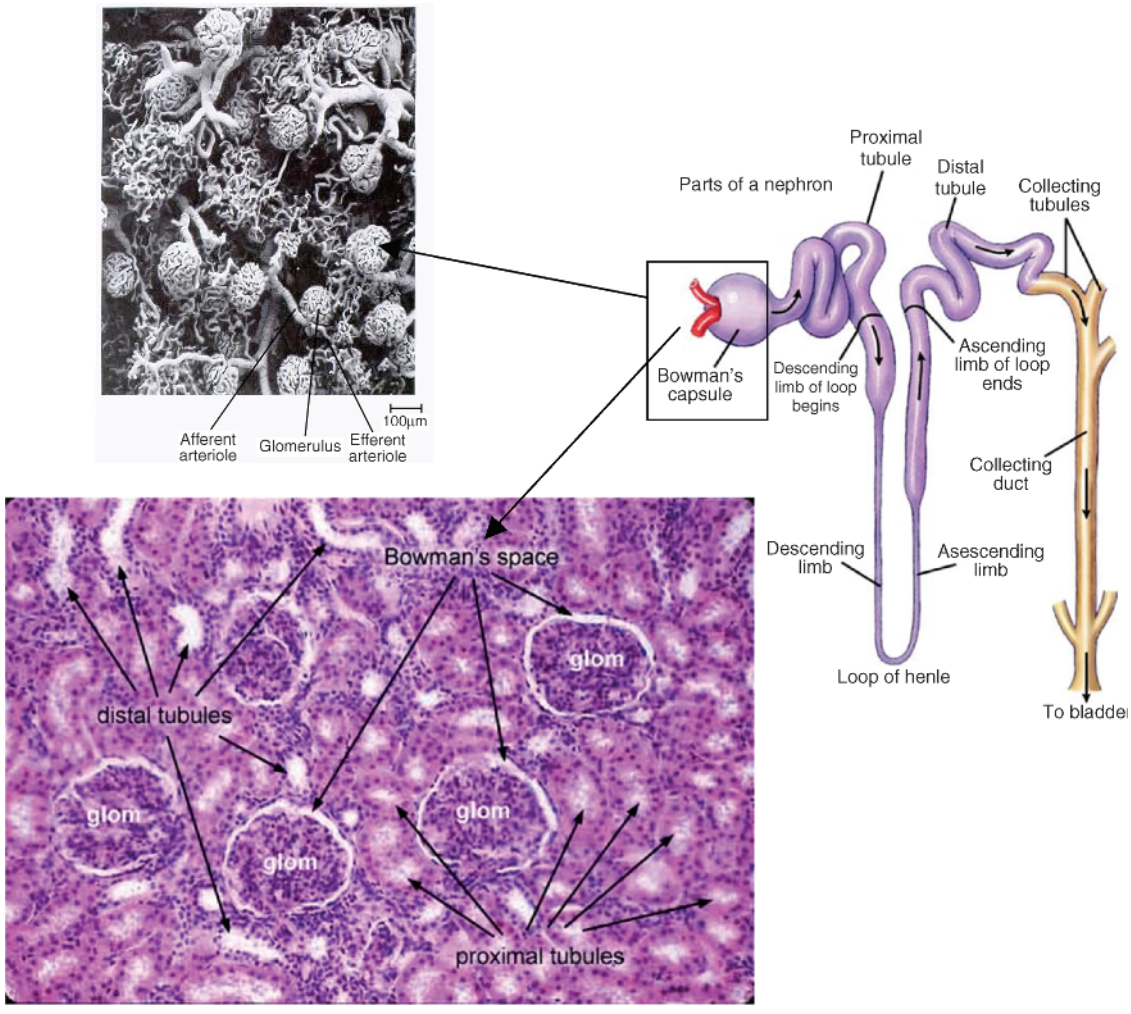

Figure 1.24 The nephron and its microanatomy and histology

again. This reabsorption occurs selectively at specific regions of the proximal and distal tubules and the ascending and descending regions of the loop of henle (see Figure 1.25) We generally need to expend energy (i.e. use ATP) to reabsorb all of the small molecules that left the bloodstream in the leaky glomerulus and entered the nephron.

Sodium (Na) is actively reabsorbed due to the action of aldosterone (produced by the adrenal gland) by activating specific Na transporters in the cells of the proximal tubules. This increased local blood level of Na causes osmotic uptake of water from the loop of henle. ADH, antidiuretic hormone, is produced in the pituitary gland in response to dehydration. It causes more water to be reabsorbed from the nephron and put back into the bloodstream, that is it makes it easier for osmotic reabsorption.

1.4.1.4 Tubular secretion

Most of the processes of tubular secretion again involve energy expenditure. These processes tend to happen further down the nephron than tubular reabsorption, around the distal convoluted tubule area (see Figure 1.25). It is a process in which substances move into the distal and collecting tubules from the blood:

- disposing of substances not already in the filtrate (e.g., certain drugs such as penicillin);

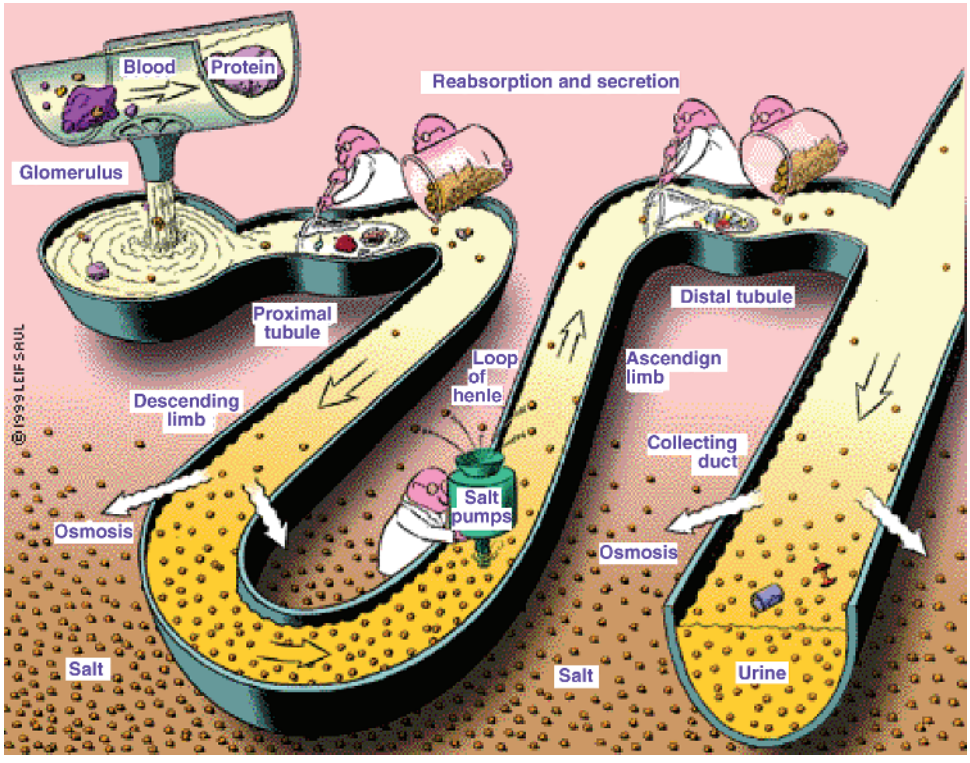

Figure 1.25 Reabsorption and secretion regions of the nephron's post glomerulus draining tubules

- eliminating undesirable substances (e.g., waste products like urea);
- ridding the body of excess potassium ions; and
- controlling blood pH by H^+ secretion.

1.5 Respiratory system

Each lung is divided into lobes. The right lung, which has three lobes, is slightly larger than the left, which has two. The lungs are housed in the chest/thoracic cavity, and covered by a protective membrane — the pleura (see Figure 1.26). The diaphragm, the primary muscle involved in respiration, separates the lungs from the abdominal cavity. To breathe in (inhale), the diaphragm tightens and flattens and the rib cage rises increasing the volume of the thoracic cavity. This creates a decrease in pressure, a partial vacuum, sucking the air into your lungs. When the diaphragm relaxes to its original shape and the ribs lower, the thoracic cavity volume decreases again and forces out the inspired air.

There are two modes of breathing:

Quiet breathing is where inspiration is active: the diaphragm, external intercostals muscles are involved. However, expiration is passive, that is, no muscles are involved and no energy is expended — elastic rebound of the rib cage and diaphragm reduces the thoracic cavity volume expelling the air.

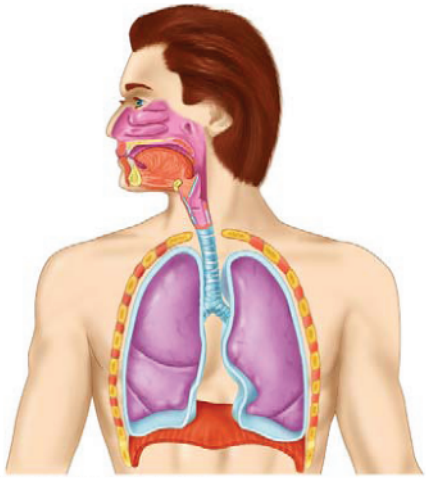

Figure 1.26 Basic anatomy of the lungs. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

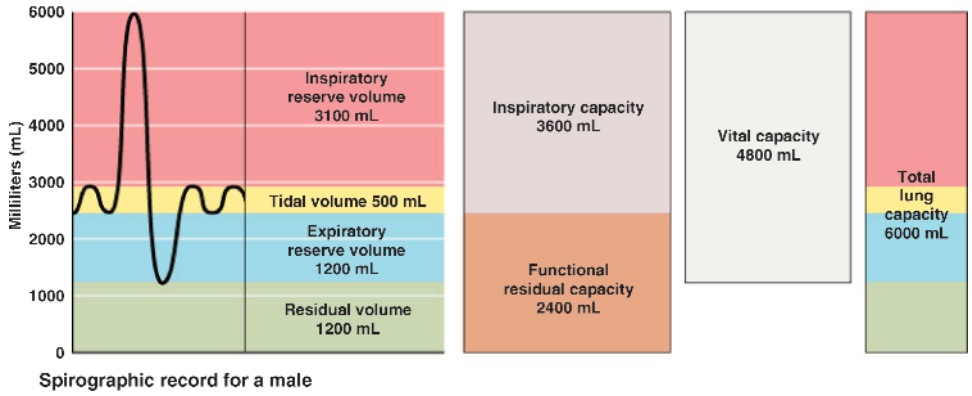

Figure 1.27 Respiratory volumes and capacities. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

In *forced* breathing both inhalation and exhalation are active processes: during inspiration the sternocleidomastoid, scalene and pectoralis minor muscles contract whilst during exhalation the internal intercostals and abdominal muscles contract reducing the thoracic cavity more than with elastic rebound.

1.5.1 Lung function measures

The two different breathing modes give different lung function measures (see Figure 1.27):

- tidal volume (TV) — air that moves into and out of the lungs with each breath (approximately 500 mL);
- inspiratory reserve volume (IRV) — air that can be inspired forcibly beyond the tidal volume (2100—3200 mL);
- expiratory reserve volume (ERV) — air that can be evacuated from the lungs after a tidal expiration (1000—1200 mL); and
- residual volume (RV) — air left in the lungs after strenuous expiration (1200 mL).

This leads to different measures of capacity:

- inspiratory capacity (IC) — total amount of air that can be inspired after a tidal expiration (IRV + TV);
- functional residual capacity (FRC) — amount of air remaining in the lungs after a tidal expiration (RV + ERV);
- vital capacity (VC) — the total amount of exchangeable air (TV + IRV + ERV); and
- total lung capacity (TLC) — sum of all lung volumes (approximately 6000 mL in males).

1.5.2 Respiration

In the exchange of gases — alveoli to blood occurs at the alveoli of the lungs — gas is exchanged between the air in the alveoli and the blood by the process of diffusion. In this process surfactant covers the internal surface of the alveoli air sac (see Figure 1.28). The surfactant is important in decreasing surface tension, increasing pulmonary compliance (reducing the effort needed to expand the lungs) and reducing the tendency for alveoli to collapse.

1.5.3 Oxygen and carbon dioxide exchange

Molecular oxygen is carried in the blood: some is bound to haemoglobin (Hb) within red blood cells and some is dissolved in blood plasma. Each Hb molecule binds four oxygen molecules in a rapid and reversible process. The haemoglobin—oxygen combination is called oxyhaemoglobin (HbO_2) and haemoglobin that has released oxygen is called reduced haemoglobin (HHb).

Carbon dioxide is transported in the blood in three forms: dissolved in plasma, about 7—10%; chemically bound to haemoglobin, about 20% is carried in RBCs as carbaminohaemoglobin; and as bicarbonate ions in plasma, about 70% is transported as bicarbonate (HCO_3^-).

Carbon dioxide must be released from the bicarbonate form before it can diffuse out of the blood into the alveoli. Bicarbonate ions combine with hydrogen ions to form carbonic acid and carbonic acid splits to

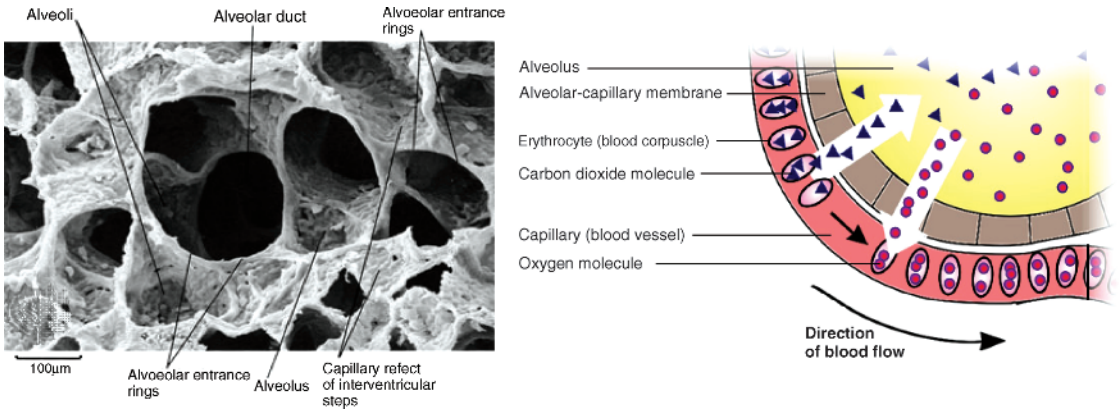

Figure 1.28 The alveoli and gaseous exchange

form water and carbon dioxide. The carbonic acid-—bicarbonate buffer system resists blood pH changes. If hydrogen ion concentrations in blood begin to rise, excess H^+ is removed by combining with HCO_3^- and if hydrogen ion concentrations begin to drop, carbonic acid dissociates, releasing H^+ ions.

1.6 The nervous system

The central nervous system (CNS) consists anatomically of the brain, where high reasoned thought processes occur which influence autonomic nervous responses (of the brain stem), and the spinal cord which affects these neural control signals and the five senses:

- sight;
- sound;
- smell;
- taste; and
- touch.

With such fundamentally important functions the nervous system, at is most critical parts, is protected by the skull and spinal cord (see Figure 1.29).

1.6.1 Central nervous system

The brain and spinal cord make up the central nervous system (CNS). The brain is made of two

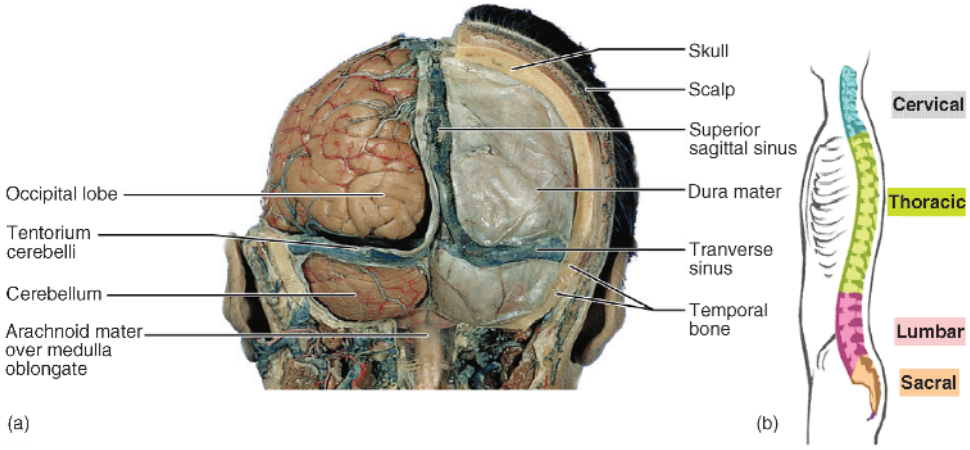

Figure 1.29 (a) Protection for the brain in the head/skull, and (b) and spinal cord by the various vertebrae. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

hemispheres, connected by a bridging connection of nerves called the corpus callosum. These cerebral hemispheres are the newest addition to the human brain in evolutionary terms, so it is called the neocortex. The older part of the brain is the hindbrain. The hindbrain, which is at the back of the brain, includes the cerebellum, which controls balance and the brainstem, which controls the most basic functions of the body, including breathing, blood pressure and heart rate.

Messages are sent from — and received by — the brain by a direct continuation of the spinal cord. The spinal cord has a two-tone colour scheme of grey and white when viewed in cross section with the naked eye (see Figure 1.30(a)). The grey matter looks like a butterfly with outstretched wings, sitting in the middle of the surrounding white matter. The grey matter has nerves which act at a specific site of the body, for example the grey matter at the level of the fourth lumbar vertebra is involved with knee sensation and function, whereas the grey matter at the level of the 10th thoracic vertebra is involved with sensation and muscle control around the umbilicus.

Information is packaged in bundles, or *tracts* within the cord, so that damage to a specific part of the cord creates a predictable functional deficit (Figure 1.30(b) shows the main tracts in the spinal cord — but there are many more).

The corticospinal tracts are nerves which go from the motor cortex of the brain to the muscles which obey the brain and cause a movement. The spinothalamic tracts convey information to the sensory cortex that a specific part of the body has just experienced a sharp pain, a change in temperature or a firm touch. The posterior columns convey information to the brain about where the body currently lies in space, for example standing, raising one arm and so on. This information helps to control balance. The posterior columns also tell the brain if part of the body is experiencing light touch.

The brain is also composed of different centres, which perform specific roles. For example the pituitary gland and hypothalamus are parts of the brain which release hormones (Figure 1.30(c)).

1.6.2 Autonomic nervous system

What cannot be overlooked are the autonomic nervous pathways which reside in the brain stem and control breathing, heart rate, eye responses and even swallowing (see Figure 1.31 and Table 1.2).

1.6.3 Peripheral nervous system

All nerves outside the brain and spinal cord constitute the peripheral nervous system (PNS). The autonomic nervous system is part of the peripheral nervous system and this set of nerves helps to regulate blood pressure, heart rate, crying and sexual function. The autonomic system is subdivided into the sympathetic and parasympathetic nervous systems. In general, the sympathetic system makes us feel excited, angry or frightened — it is part of the 'fight or flight' impulse. On the other hand, the parasympathetic system calms us down, lowering our blood pressure and slowing down our heart rate.

Peripheral nerves/neurons all have a similar structure. They consist of an axon, with a cell body which communicates with other neurons via lots of branches termed *dendrites*.

Signals are transmitted by electrical and chemical (neurotransmitter) means. The electrical signal is created by sodium and potassium ions moving across a membrane, called an *action potential,* which is able to travel considerable distances without losing amplitude, because the nerve cells are lagged with a fatty substance called myelin which acts as an insulating material. The myelin is made by Schwann cells. When one nerve needs to communicate with another nerve, they do so by their dendrites, which have tiny gaps called synapses where the electrical impulse jumps from one cell to the next. Nerve impulses only travel in one direction along a nerve, from the cell body to the terminal endings (Figure 1.32)

There are several different neurotransmitters, including acetyl choline, noradenaline, adrenaline, dopamine, GABA, serotonin and substance P. Different neurotransmitters tend to be found in special areas, for example GABA is associated with brain signals, ACH with muscle and dopamine with sexual function.

When a motor nerve stimulates a skeletal or cardiac muscle to contract, the motor cortex of the brain relays the signal along neurons in the corticospinal tract, exit along the anterior horn and the action potential stimulates the release of acetylcholine (ACh) at the motor end plate. The ACh alters calcium channels in the muscle fibres and this causes structural changes within the muscle fibres. The cells in skeletal and cardiac

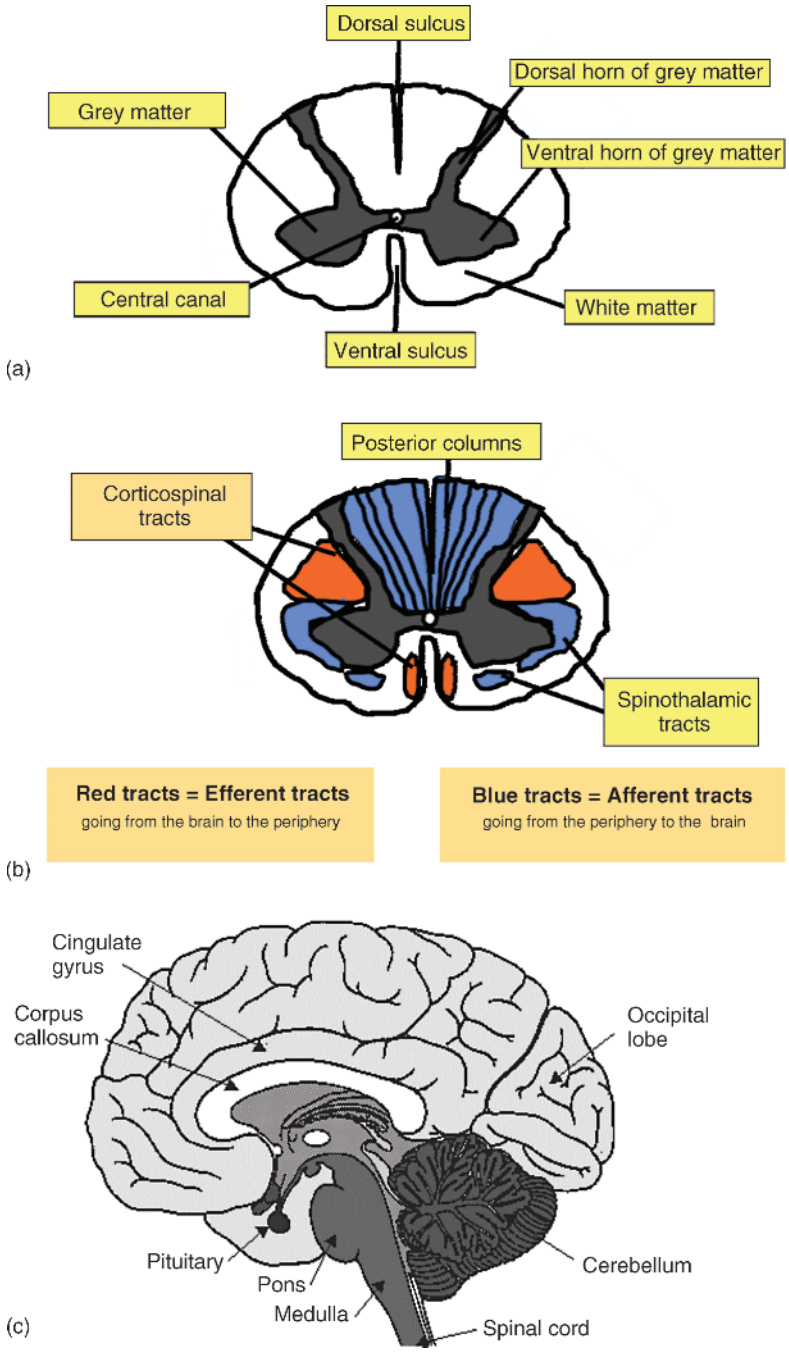

Figure 1.30 Diagrammatic representations of anatomical regions of the brain and spinal cord

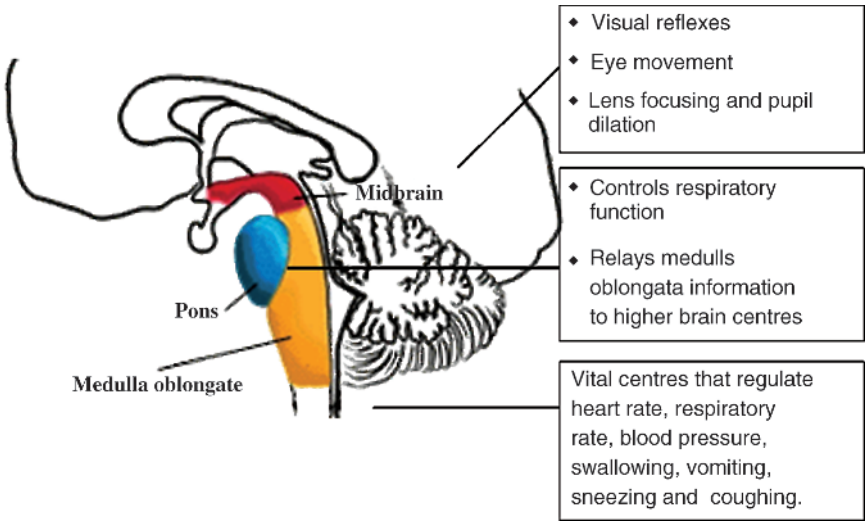

Figure 1.31 Location of autonomic nerve centre of the midbrain and brain stem

Table 1.2 Actions of the parasympathetic and sympathetic systems

	Sympathetic (fight and flight)	Parasympathetic (rest and digest)
Pupils	Constrict	Dilate
Heart rate	Increase	Decrease
Blood supply to stomach	Decrease	Increase
Blood supply to brain	Increase	Decrease
Sexual function	Erection	Orgasm

muscle cells contain sarcomeres with protein filaments called actin and myosin. When a muscle contracts, the myosin proteins, which are found on the thick filaments, ratchet along the thin filaments which contain actin proteins, resulting in increased overlap of the thick and thin filaments. This results in smaller H zones and shorter sarcomeres, as demonstrated in Figure 1.33.

When a muscle contracts it moves its attachments. The muscle is attached to bone at each end by tendons, which are noncontractile. So, for example, the psoas muscle is attached to bone at one end at the top of the femur (specifically on the lesser trochanter) and on the

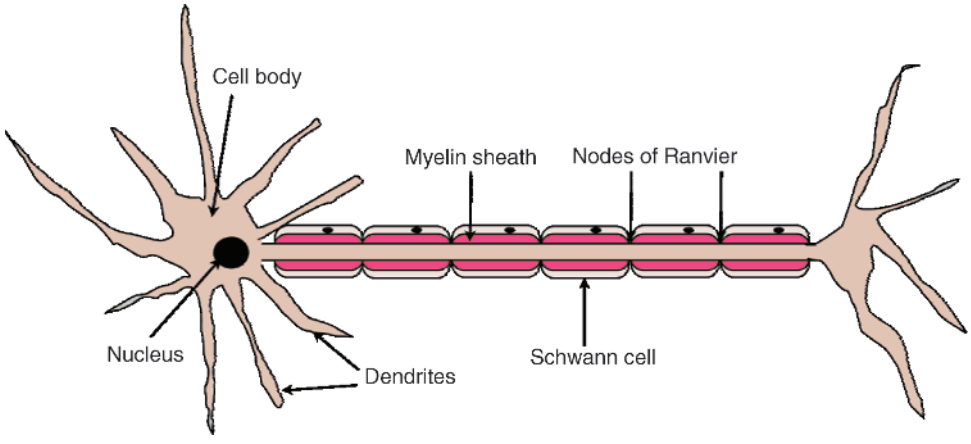

Figure 1.32 Diagrammatic representation of a typical peripheral nerve structure

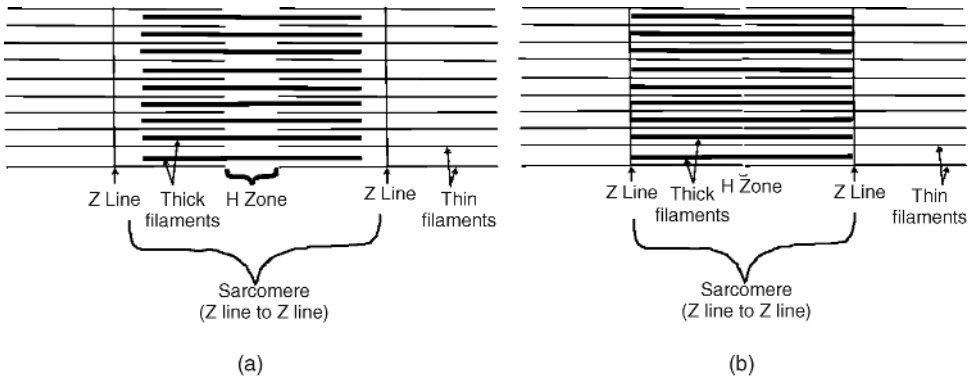

Figure 1.33 (a) Diagrammatic representation of the physiological anatomy of muscle filaments and (b) the changes in positioning upon contraction

other end to the lumbar spine (specifically, the transverse processes of L1 to L5). The main joint between the femur and the spine is the hip joint. As the psoas muscle runs in front of the hip joint, the psoas muscle flexes the hip joint. This results in either the femur being flexed while the torso is still, the torso flexing while the femur is still, or both the femur and torso flexing together. In order to control which movement results from psoas contraction, other muscles contract either with or against the psoas. So, if you want to perform a sit-up from a lying down position, you will want your legs to remain on the floor, while you flex your hips and raise your torso from the ground. Psoas will contract to flex the hip joint, supported by iliacus which runs next to it, the anterior abdominal wall will contract (these muscles attach to the pelvis, so won't influence leg movement) and the hamstrings, which run behind the hips joint, from the pelvis to the tibia will contract to extend the hip joint — thus keeping the femurs from moving. As you begin to appreciate here, a seemingly simple movement involves the coordination of several different muscles working together and against each other to achieve the desired effect — the muscles receive the messages by motor nerves which travel along the front and sides of the spinal cord (corticospinal tracts) from the motor cortex in the brain (see Figure 1.34). The movement will result in the back leaving the floor and this change in sensation, as well as change of position in space is conveyed as nerve impulses along sensory and proprioceptive fibres in the posterior columns of the spinal cord to the sensory cortex and other areas of the brain. The change in position in space is supported by information gleaned from the semicircular canals in the middle ear, because the head position has also moved from a horizontal to vertical position.

1.6.4 The five senses

1.6.4.1 Sight

The eye receives light waves and converts this information into electricity by things called photoreceptors cells. The electrical energy is transmitted to the visual cortex in the brain by the optic nerve. Whereas they eye works like a camera, capturing data as an inverted image, the visual cortex interprets the electrical energy into correctly-orientated images. The eye is globe-shaped and divided into two compartments. The front compartment is called the anterior chamber and contains the lens with its attachments. The watery fluid contained in the anterior chamber is called the aqueous humour and the gelatinous fluid in the posterior chamber is called the vitreous humour (Figure 1.35).

The lens' shape is maintained by muscles (ciliary muscles) which make the lens thinner or thicker to alter focus. The pupil size is controlled by the iris, which is the structure giving us our eye colour (blue, green or brown). Once the light has hit the retina at the back of the eye, two specialized types of cells convert the light energy to electrical energy. The rods are colour-sensitive cells and contain photoreceptors. The rods are found in the highest numbers at the fovea. This is a single spot on the retina, which collects the most

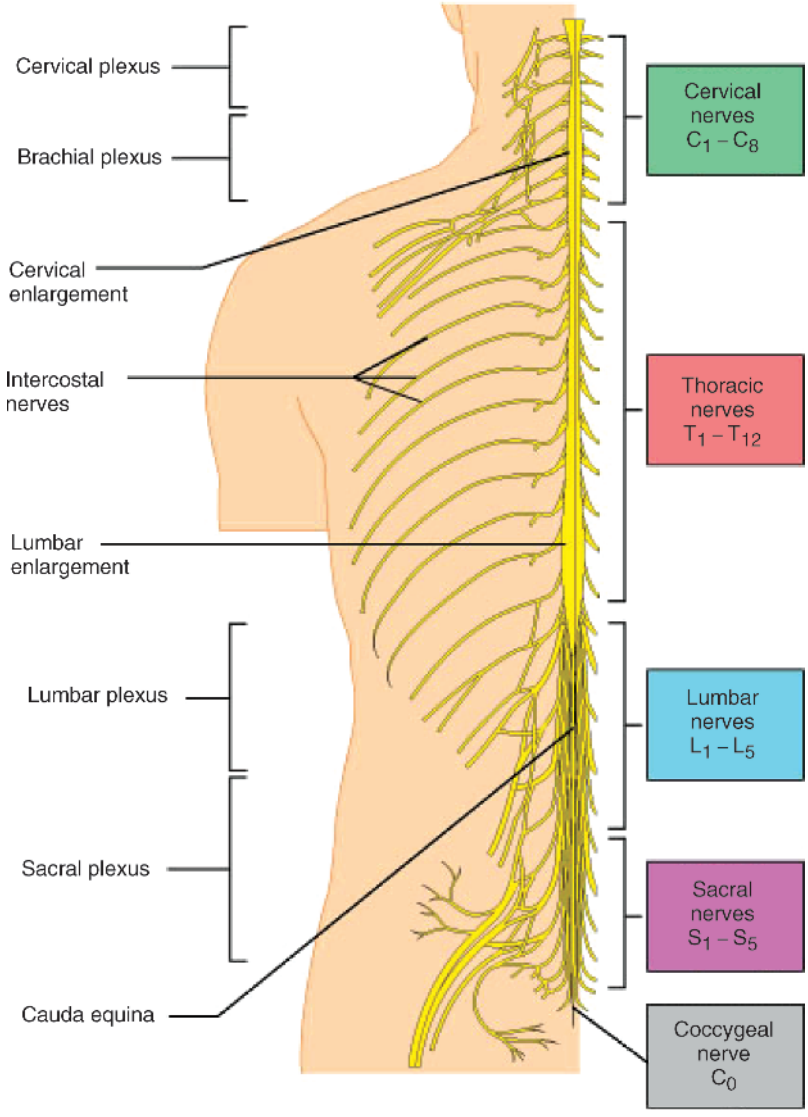

Figure 1.34 The spinal nerves and vertebral exit positions. *Essentials of Human Anatomy & Physiology*, 9th Edition, Marieb, 2008 © Pearson Education Inc.

information. The cones are cells which differentiate between light and dark and are the cells which give us our night vision, where we see in black and white. The optic nerve conveys the information received by the retina onwards to the brain. The optic nerve attaches to the retina by a disc of nerve endings called the optic disc. There are no rods or cones on the optic disc so that any light which lands on the optic disc is not recognized; this is the blind spot.

To find our blind spot, fix your eyes on an object in front of you. Take a small coloured object and move it around your visual field. You will find that the object vanishes at one consistent point with the right eye, and a different point with the left eye. Our brains usually

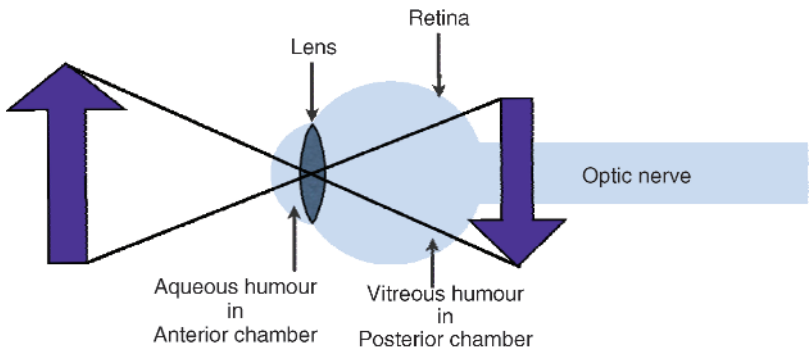

Figure 1.35 Diagrammatic representations of the function components of the eye

ignore the blind spot. The next part of the pathway is very interesting from a clinical viewpoint, as it is sometimes possible to diagnose which part of the brain is damaged when a person loses part of their vision (see Figures 1.36 and 1.37).

The left visual cortex receives information from the outer(lateral) half of the same-sided (=ipsilateral) left eye and the inner (medial) half of the opposite (=contralateral) right eye. The right visual cortex receives information from the ipsilateral visual field's lateral half and the contralateral medial half's visual field. Tracts B and C cross, or decussate at the optic chiasm, which is just above, or superior to, the pituitary gland.

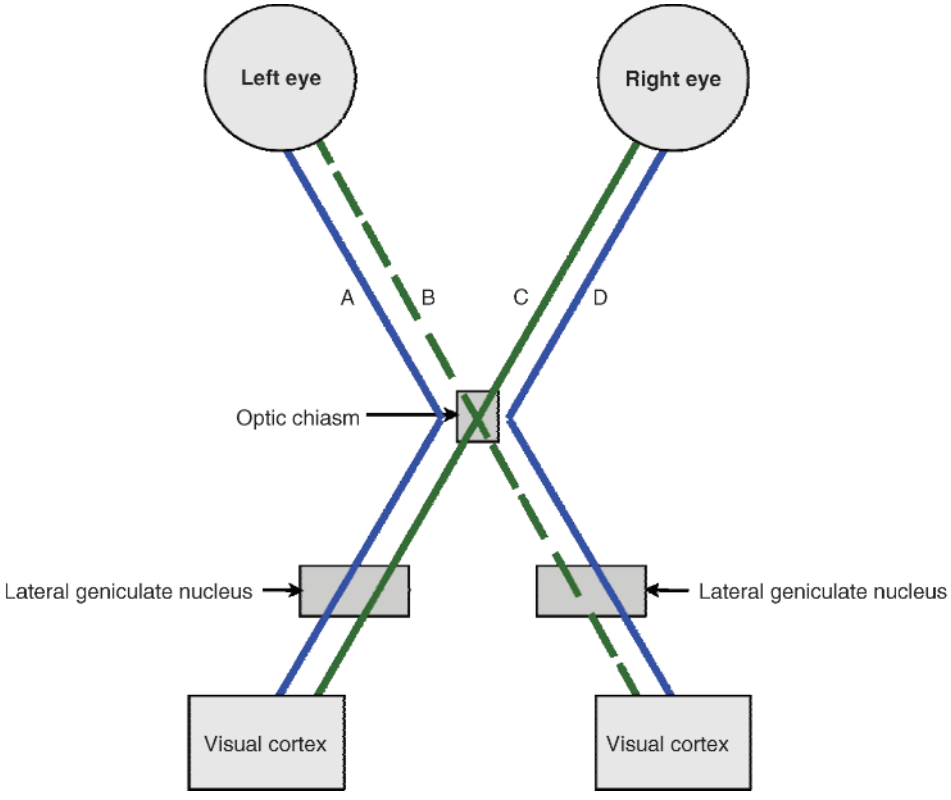

Figure 1.36 Shows how the information from each eye is divided into three tracts per eye, six in total; tracts A and B come from the left eye and tracts C and D come from the right eye

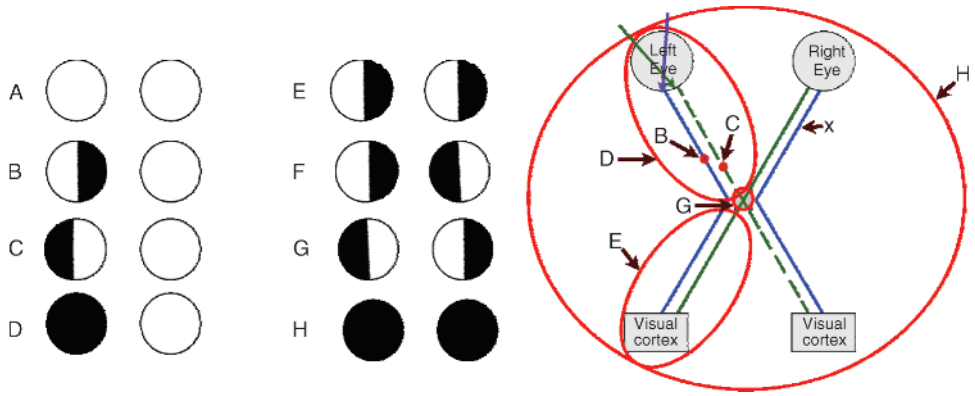

Figure 1.37 Illustration of visual perception as a result of damage to the optic nerve pathways: A = normal vision; B = suspiciously discrete lesion damaging exactly one half of tract B; C = same suspicion as for Mr B, with tract C; D = damaged left optic nerve; E = left-sided brain damage beyond the optic chiasm — termed homonymous hemianopia — may have lost normal vision as a result of a stroke, or a severe head injury; F = two identical discrete lesions at B and X, very unlikely; G = bi-temporal hemianopia, a visual defect which may come on slowly and gradually worsen, commonly a pituitary tumour, pressing upwards and against the optic chiasm; H = damage to both optic nerves, an enormous pituitary tumour compressing all optic tracts, or massive posterior brain damage, affecting both visual cortices (cortical blindness)

1.6.4.2 Sound

Hearing and balance are closely associated, as both rely on structures inside the inner ear. Sound is received by the ear and processed via three compartments into electrical signals, which are then relayed to the brain. The ear is divided simply into the outer ear, middle ear and inner ear (see Figure 1.38). The outer ear is the part that we see, that is, the ear, or pinna, itself. The hole in the ear is the external auditory meatus (='the hole outside that listens', Latin again) and sound waves are transmitted to the ear drum, which is the beginning of the middle ear. The ear drum is called the tympanic membrane. It is called a drum, rather than a membrane, or wall, due to its function. The tissue is stretched like the skin on a drum and, as sound waves strike the drum, it vibrates according to the frequency (pitch) and amplitude (volume) of the sound waves received. The three smallest bones in the body are attached in series to the other side of the ear drum. These are called the malleus (hammer), incus (anvil) and stapes (stirrup). The malleus attaches to the ear drum and the stapes attaches to the oval window, which is a smaller version of the ear drum. The incus links the two bones together. The oval window is the partition between the middle ear and the inner ear. The ossicles of the middle ear act as a dampening system for sound waves which hit the ear drum. When the sound wave amplitude is very large, the ear drum vibration is large too. A negative feedback system comes into play, whereby a muscle attached to the malleus, called tensor tympani, stretches the tympanic membrane, thus reducing the size of the vibrations' amplitude. The second dampening system occurs at the other end of the ossicle chain, by a muscle attached to the stapes, called stapedius. The vibrations from the stapedius are transmitted to the cochlea via the oval window and transferred to electrical energy, which is conveyed to the auditory cortex in the brain via the auditory nerve. Next to the cochlea lie the semicircular canals, which are organized in *x,y,z* planes to help maintain balance.

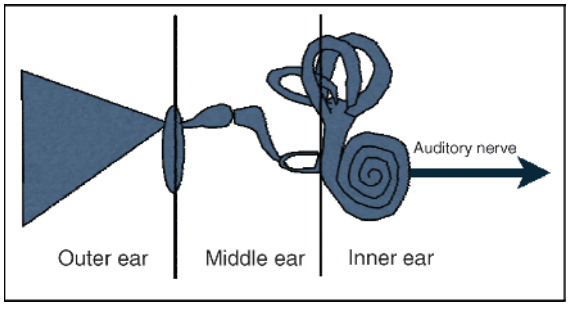

Figure 1.38 Diagrammatic representation of the functional components of the ear

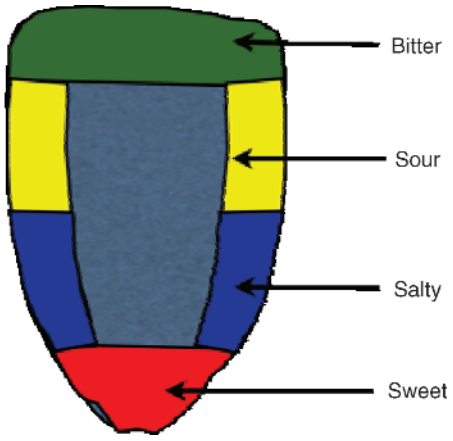

Figure 1.39 Diagrammatic representations of sensory regions of the tongue

1.6.4.3 Taste

This sense is mostly about taste buds on the tongue. There are a few taste buds in the walls of the mouth and the upper oesophagus as well. Different parts of the tongue are better at detecting different types of taste. There are four main tastes (see Figure 1.39).

The chemicals which make up different tastes are converted into electrical activity via the taste buds and then transmitted to the brain via the vagus nerve (10th cranial nerve) and the glossopharyngeal nerve (ninth cranial nerve).

1.6.4.4 Smell

This is another sense that relies on chemical stimuli which are converted to electrical energy. A small surface area around the size of a postage stamp in each nose is responsible for smell. The receptors are called olfactory receptor cells and the olfactory nerves travel up the nose to the cribiform plate at the front of the brain. The olfactory nerves (first cranial nerve) regenerate continually throughout life and for this reason they are the focus of lots of research into nerve regeneration following spinal cord injuries and degenerative nerve diseases.

1.6.4.5 Touch

The fifth sense is touch. Whereas the other special senses have nerves which communicate directly with the brain, via cranial nerves, touch — or sensation — uses mainly nerves which transmit information to the brain via the spinal cord. These nerves are called spinal nerves and they belong to the peripheral nervous system.

Touch can be classified into light touch, vibration, pain and temperature perception. These different types of touch are managed by different types of nerve, which travel along different parts of the spinal cord to the brain.

1.7 The endocrine system

It is appropriate that the endocrine system should be considered in juxtaposition with the nervous systems as there are many similarities and contrasts in their functionality as control systems of the body: both act as communication networks; both use chemical substances as mediators between cells and both cause actions at a distance. In cellular origins they are closely related and in the adrenal medulla and hypothalamus specialized 'neurons' secrete 'hormones' into the circulation. However, whilst neurological signal control is a fast response, short-lived and specific effect,

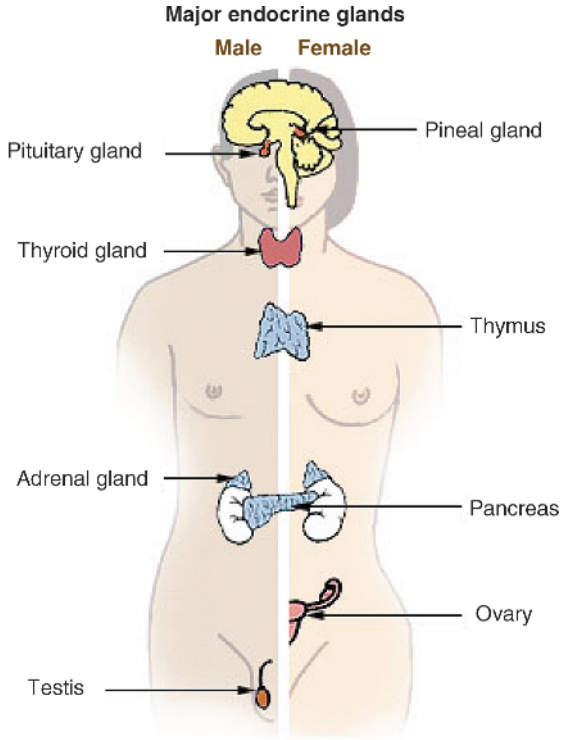

Figure 1.40 The anatomical positioning of the major endocrine glands

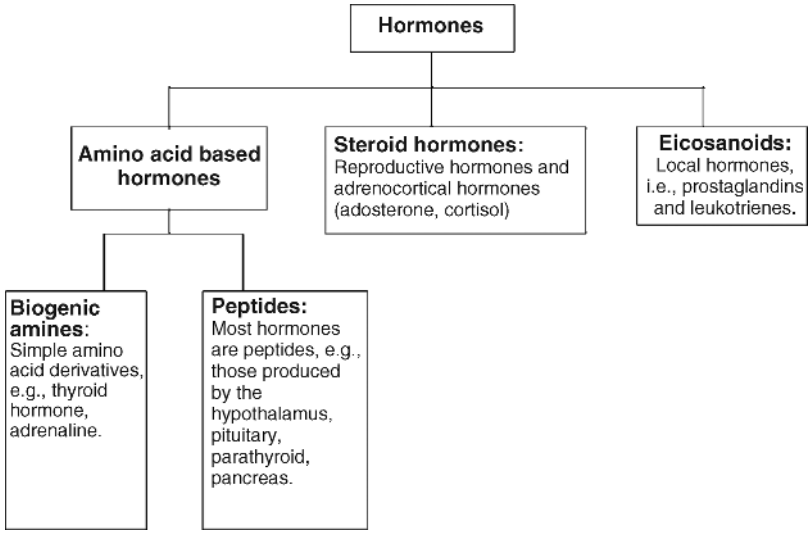

Figure 1.41 Classification of hormones by chemical structure type

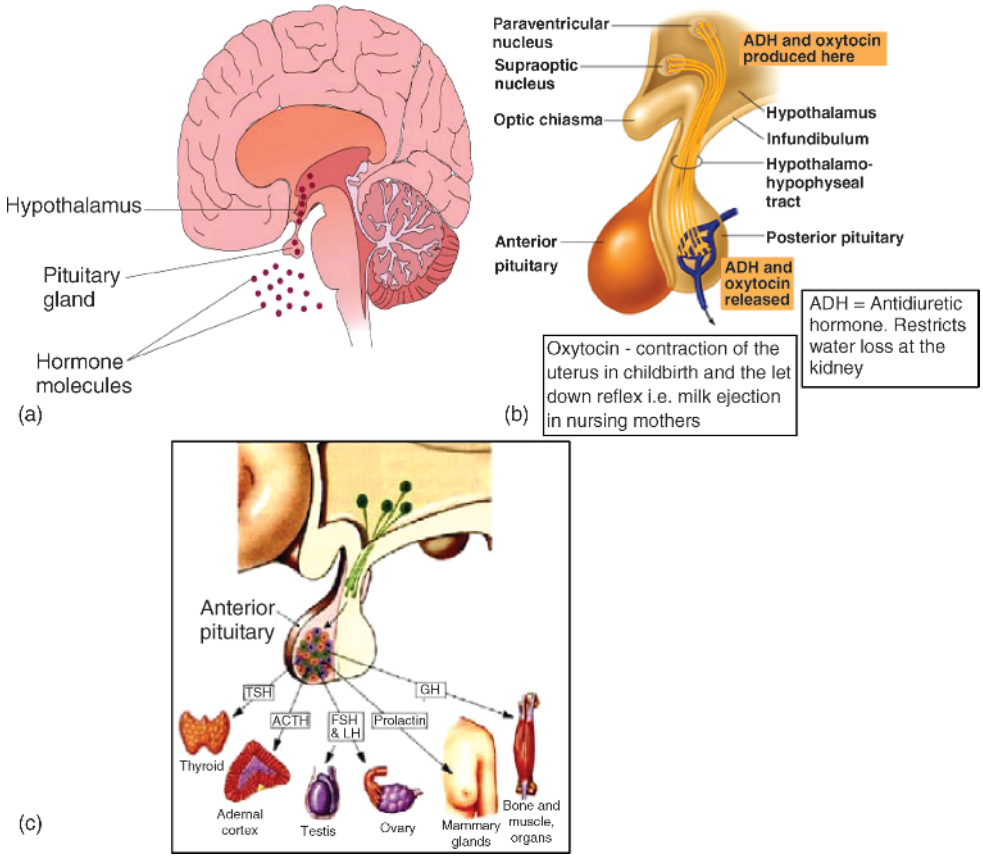

Figure 1.42 (a) Positioning of the hypothalamus and pituitary in the brain and the neuroendocrine and pituitary peptide hormone systems ((b) and (c) respectively) controlled

endocrine control is a slower response to stimuli but responses last for longer and the responses are more generalized.

The major endocrine glands are illustrated in Figure 1.40 and the hormones produced by these glands are chemical messengers carried in the bloodstream to distant target cells where they cause specific changes in function.

1.7.1 Main functions of hormones

The main function of the hormones is (Figure 1.41):

- to promote the development of physical, sexual and mental characteristics (e.g. the sex steroid hormones);
- to promote the adjustments of important bodily functions (e.g. thyroid hormone and adaptation to cold);
- to keep certain physiological parameters constant (i.e. maintain homeostasis, e.g. insulin and blood sugar).

The function of various endocrine organs systems is described in Chapter 2 and others in Chapter 7; however, the hypothalamus and pituitary are the master controllers of the endocrine system.

1.7.2 The hypothalamus and pituitary glands

Positioned at the base of the brain (see Figure 1.42 (a)) the hypothalamus is a direct link between the central nervous system and endocrine signalling. Neuroendocrine cells directly secrete hormone into the circulation in the anterior pituitary (see Figure 1.42(b)) or induce specialist cells of the posterior pituitary to produce more complex peptide hormones. Nevertheless the effects and system controlled by these hormones are broad and widely spread throughout the body. The anterior pituitary gland is often referred to as the 'master' endocrine organ, but it too has a 'master'. The hypothalamus through the secretion of releasing and inhibiting hormones controls all the systemic hormones released (see Figure 1.42(c)).The hypothalamus through sympathetic activation has a direct neural control of the adrenal medulla (which produces adrenaline and nor adrenaline) by controlling the release of adrenocorticotrophic hormone — ACTH — by specialist corticotroph cells of the anterior pituitary. The posterior pituitary is not really an endocrine gland as it simply stores and releases two hormones — oxytocin and ADH — but these are actually made and secreted by the main body of neuroendocrine cells found in the hypothalamus (see Figure 1.42(b)).

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