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Atlas of Animal Anatomy and Histology

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Preface

The purpose of this book is to provide an introduction to comparative anatomy and histology for biology undergraduates and for all those who are interested in the internal structure of animals. The information is presented in the form of colour photographs of step-by-step dissection stages integrated with histological sections of actual organs. A specialty of this atlas is that it contains only high-quality, accurate, and attractive photographs, not idealised line drawings. Dissection plays an important part in understanding the anatomy of an animal, and this book has been designed to make full use of the wealth of information made available through dissection. The accompanying text aims to outline the evolutionary and functional aspects of the anatomy revealed in the photographs. Our book encourages and facilitates active and self-directed learning by the students so that instructors can teach more effectively and efficiently. This manual emphasises dissection procedures that preserve as many structures as possible for later review of the entire specimens. Every effort has been made to give clear, lucid descriptions and instructions, and enough background material has been included to create interest in and understanding of the subject matter.

The animals dissected in this book have been chosen as representative examples of six invertebrate phyla and four classes of vertebrates. This book offers step-by-step illustrations and instructions for dissecting a roundworm, earthworm, snail, mussel, crayfish, cockroach, crucian, frog, chicken, and rat. The types included are commonly studied in undergraduate zoology courses. They can be used also as a guide to dissection of other animals in the same group. Dissections range from beginning to advanced and discuss the digestive, circulatory, respiratory, excretory, reproductive, and nervous systems. Skeletal material of vertebrate animals is also included to show the supporting framework of the body and its development during evolution.

Another valuable aspect of this atlas is that it features large-size, full-colour histological micrographs, with labels and legends that draw attention to details of microanatomy of the most important organs. The histological descriptions follow the anatomical pictures and explanation of an actual organ, and they are highlighted with a coloured background. In this way, students can correlate microscopic structures with the gross composition. Clear histological explanations give details of how tissues are structured and how they work. Students will learn to recognise different types of tissues easily. The detailed photographs enable the reader to gather microanatomical knowledge even in the lack of prepared light microscopic sections or microscopic facilities.

The digital annex of the book includes slide-shows and interactive tests that can be used to check the knowledge. A special item of the software is a stereoscopic (3D) application enabling to visualize three-dimensional (anaglyph) pictures on a monitor or by a projector. Anaglyph pictures should be viewed through red-cyan glasses. The slide-shows are also available on-line at http://bszm.elte.hu/anatomy/, optimized for mobile browsers.

Budapest, Hungary

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Points for Successful Dissection

It is always important to perform a dissection in an appropriate lab under the guidance of an experienced instructor. Do not do anything uncertainly; wait for specific instructions in the lab. Dissection is both a skill and an art. A good dissection requires time and patience. Always prepare for a dissection in advance, learn the structures you want to find, and work deliberately. Make small cuts and do not remove a piece of tissue unless you know what it is. Each dissection chapter in this book includes background information about the sample animal, availability and proper, species-specific anaesthesia of the animal.

The dissections should be performed in a wax-bottomed dish using small pins for attachment and display. Most of the structures described in this dissection guide will be best viewed with the aid of a stereomicroscope (dissecting microscope) or a hand lens. Dissecting tools will be used to open the body of the animal and unfold the structures. Learn the techniques of working with these instruments. The tools are very sharp, use them properly and be careful not to injure yourself. The development of good abilities at dissection desponds upon practice and, above all, patience. A comprehensive dissecting kit (Fig. 1) includes the following tools for almost all types of knacks:

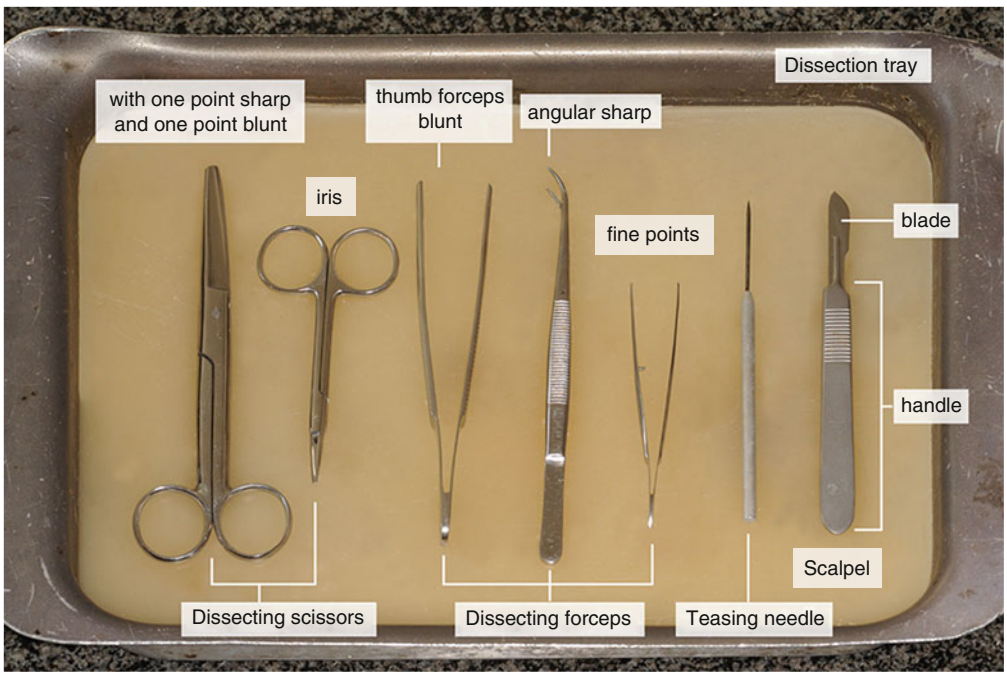

Fig. 1 A comprehensive dissecting kit arranged in a wax-bottomed dissecting dish

Dissecting scissors with one point sharp and one point blunt, 5.5 in.
Dissecting scissors, iris, 4.5 in.
Thumb forceps blunt, 5.5 in.
Forceps angular sharp, 5 in.

Forceps fine points, 4.5 in.
Teasing needle straight with metal chuck
Scalpel handle No. 4
Scalpel blade No. 22

Although these instruments serve the requirements of nearly all kinds of dissecting situations for special tasks and fine, elaborate work, we recommend some further tools (Fig. 2):

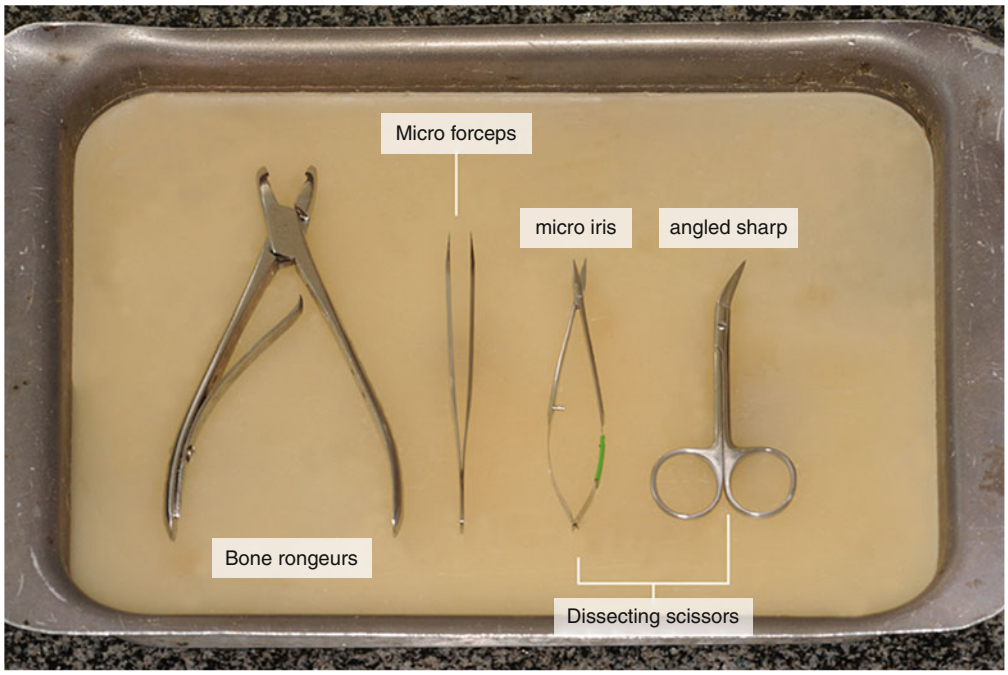

Fig. 2 Special dissection instruments for meticulous tasks

Bone rongeurs (Adson, Blumenthal, or Friedman type), 6 in.
Micro forceps
Dissecting scissors, micro iris (McPherson-Vannas), straight, sharp, 4.5 in.
Dissecting scissors, angled sharp, 4.5 in.

Finally, it is well worth to use dissecting pins (insect pins) to position parts as you proceed with your examination of the specimen, so that you have a clearer view of the structure and organisation of the organism.

Keep in mind that dissecting does not mean "to cut up"; in fact, it means "to expose to view". Careful dissecting techniques will be needed to observe all the structures and their connections to other structures. You will not need to use a scalpel very often. On the contrary to popular belief, a scalpel is not the best tool for dissection. Scissors are better because the point of the scissors can be pointed upwards to prevent damaging organs underneath. Always raise structures to be cut with your forceps before cutting, so that you can see exactly what is underneath and where the incision should be made. Never cut more than is absolutely necessary to expose a part. Sometimes the so-called blunt dissection is the most appropriate when you only tear connective tissue structures with forceps to reveal an underlying compact organ and do not cut anything.

When completed, clean up your dissection. Dispose of your materials according to the directions from your instructor. Pour your excess liquid into the sink and wrap the body parts in a paper towel before throwing them in the carcass container. Never dispose the body parts into ordinary communal waste. Immediately after use, rinse instruments under warm or cool running water to remove all blood, body fluids, and tissue. Dried soils may damage the instrument surface and make cleaning very difficult. Do not use hot water as this will coagulate proteinous substances. Clean up your work area and wash your hands before leaving the lab.

Histological Methods

Histological Sections

Histology is the study of the microscopic anatomy of cells and tissues of animals (or plants). During the routine procedure, the organs are fixed to prevent decay and embedded in paraffin (paraplast) to give support for cutting very thin (2–5 μm thick) sections. The sections are placed onto microscope slides and stained with histological stains, then covered with a coverslip and mounting medium for preservation. Histological slides are examined with light microscope.

Histological Stains

Histological stains are used to increase the typically minor differences in light refraction of biological samples. The procedure is based on the variances in binding of histological stains by tissue and cell components.

HE (haematoxylin – eosin) **stain:** It provides a general overview – haematoxylin stains the nucleic acids, and eosin stains the cytosol and the extracellular matrix.
Azan (azocarmine – aniline blue) **stain:** It provides a general overview – azocarmine stains the cell nucleus and the cytoplasm, aniline blue stains the connective tissue matrix and fibres and some mucous secret.
PAS (Periodic acid-Schiff reaction) **stain:** This reaction is used to detect structures containing a high proportion of carbohydrate macromolecules (glycoproteins, glycolipids, and polysaccharides). The reaction gives a purple-magenta colour typically in mucus gland cells, connective tissue, and basement membrane.

Semithin Sections

Plastic (epoxy resin) embedding is commonly used in the preparation of material for electron microscopy. Semithin sections (0.8–1 μm) are cut using glass knives. The sections are stained with toluidine blue and examined using a light microscope.

Important Technical Terms

Here we explain compass points of anatomy. Many of these are taken from Latin or Greek languages, and each has a very specific meaning. It is really important to understand the basic terms, which are used throughout the anatomical and histological descriptions.

Frontal plane: It is a vertical plane at right angle to median plane. If you draw a line from one ear to another from above the head and then divide the whole body along this line, the plane formed will be frontal plane. It is also known as coronal plane.
Median or mid-sagittal plane: This is the plane which divides the body into equal right and left halves.
Oblique plane: Any plane other than the above described planes will be oblique plane.
Sagittal plane: It is any plane parallel to the median plane. This plane divides the body into unequal right and left halves.
Transverse plane: It is the horizontal plane of the body. It is perpendicular to both frontal and median planes.

Directional terms describe the positions of structures relative to other structures or locations in the body:

Anterior: Towards the head end (e.g. the oesophagus is located anterior to the stomach)
Caudal: Away from the head, towards the tail end of the body
Cranial: Towards the head end of the body
Distal: Away from or farthest from the middle line of an organism or from the point of attachment (e.g. the hand is located at the distal end of the forearm)
Dorsal: Towards the back or upper part of the animal
Inferior: Lower
Lateral: Situated at the side away from the midline of the body (e.g. the little toe is located at the lateral side of the foot)
Longitudinal: Lengthwise; along the length of the body
Medial: Towards the midline of the body (e.g. the middle toe is located at the medial side of the foot)
Median: Along the middle of the long axis
Periferal: Referring to parts away from the centre
Posterior: Facing towards the tail end (e.g. the pelvic girdle is located on the posterior end of the backbone)
Proximal: Towards or nearest to the middle line of the organism or the point of origin of a part (e.g. the proximal end of the femur joins with the pelvic girdle)
Sagittal: along or parallel with the middle plane of the body
Superficial: On or near the surface
Superior: Upper
Transverse: Lying across or between or at right angles to the longitudinal axis
Ventral: Towards the abdominal surface

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Part I

Invertebrates

Examination of a Hydra

1

The cnidarian body consists of a central blind sac, the *coelenteron* (gastrovascular cavity), enclosed by a body wall comprising two epithelia, the outer *epidermis* and the inner *gastrodermis* (Fig. 1.1). A gelatinous connective tissue layer, the *mesolamella* (mesogloea), lies between the two epithelia. The *mouth* opens at one end of the coelenteron and marks the oral end. The mouth is at the tip of a process, the *hypostome* that elevates it above the oral surface. The opposite pole is the aboral end forming the *pedal disc*. The imaginary line connecting the oral and aboral poles is the axis of symmetry around which the radial symmetry of the body is organised. The mouth is usually surrounded by a ring of hollow *tentacles*, which are well endowed with *cnidocyte* batteries (white spots in Fig. 1.1).

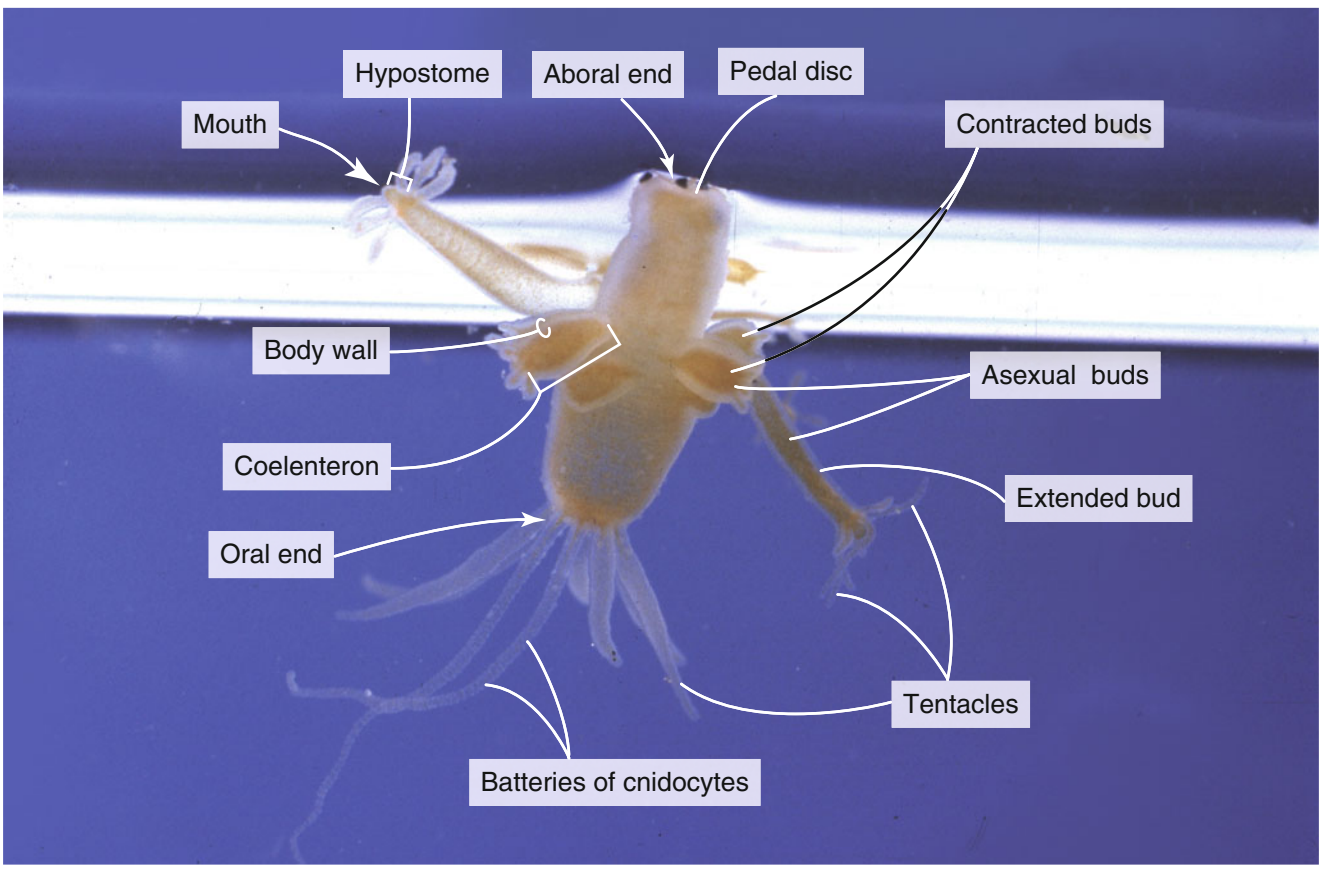

Fig. 1.1 A living hydra (*Hydra vulgaris*) attached to the water surface by its pedal disc. There are at least 11 buds on the parent animal, the size of which is 3 mm in this half way extended state

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Cnidarians are chiefly marine but the well-known *Hydra* is an exception. The *Hydra* is found in pools, quiet streams and spring ponds, usually on the underside of the leaves of aquatic vegetation. All cnidarians are carnivores feeding on live prey which they usually capture using tentacles armed with cnidocytes. Digestion occurs in the coelenteron which is typically equipped with ciliated canals for distribution of partly digested food. Cnidarians are ammonotelic, and diffusion across the body and tentacle surface eliminates the ammonia from the body. Gas exchange is across the general body surface. The nervous system is a plexus of basiepithelial neurons serving sensory and motor systems. Most cnidarians are gonochoric. Asexual reproduction is via asexual *buds* that form on the parent animal. They are small hydras that will separate from the parent and adopt an independent existence. *Hydra* does not form colonies. *Hydra vulgaris* is a freshwater species in which the medusoid generation is absent and the polyps are solitary. Polyps are small, about 1–5 mm in length, when contracted and up to 15 mm elongated. Slides can be used to supplement, or if necessary replace, the study of living specimens.

The body wall of hydra is composed of three layers: the outer epidermis, the inner gastrodermis and the middle mesolamella (ML) (Fig. 1.2, left). The two epithelial layers are formed by *epitheliomuscular* (myoepithelial) *cells* (EMCs) together with some additional cell types. All of them rest on a basement membrane attached to both sides of the *mesolamella* (mesogloea), which give a support for them. The visible thickness of epithelial layers in the section depends on the contraction state of the animal at the time of fixation. Epidermis synthesises a thin, protective cuticle, which detaches from epidermis during the histological procedure (Fig. 1.2, left). The gastrodermis surrounds a *gastrovascular cavity* (GVC). On a higher magnification, several cell types become identifiable in both layers (Fig. 1.2, right).

The *epidermis* contains dark particles: these are the nematocysts in the characteristic stinging cells of cnidarians, the *cnidoblasts* (CB, nematoblasts) and cnidocytes (nematocytes) (Fig. 1.2, right). The *cnidocyst* (nematocyst) is an explosive organelle, which, upon proper stimulation, inverts and ejects a slender, often barbed and toxic filament in the direction of prey or predator. Cnidoblasts originate from *interstitial cells* (ICs) which are in basal position and have large, round, euchromatic nuclei. They are mitotically active stem cells and give rise to cnidoblasts and neurons. *Neurons* have three main types: ganglion cells are connected into a network running on the basal membrane to form a diffuse nervous system. It contains neuroendocrine cells as well. Sensory cells reach the surface for taking up stimuli. Nerve cell types are not distinguishable in our section. Epitheliomuscular cells have an independent self-renewal population. Their basal portions contain myofibrillary bundles running parallel with longitudinal axis of the body. Their central portions contain the nucleus.

The *gastrodermis* is made of epitheliomuscular and gland cells. The latter have two types. *Mucous gland cells* (MGCs) contain empty-looking vacuoles in their apical domain and secret mucous into the gastrovascular cavity. *Enzymatic gland cells* (EGCs) synthesise enzymes and their secretory granules become visible if stained. The flagellated epitheliomuscular cells have digestive (nutritive) function (DC): they phagocytose food particles partly digested extracellularly and finish their digestion intracellularly (Fig. 1.2, right, arrowhead). The undigested remnants are exocytosed into the gastrovascular cavity.

Lots of empty spaces with various sizes can be seen in the epidermal and gastrodermal layers. These are intracellular vacuoles of epitheliomuscular cells, which serve as buffer spaces for the enormous size changes during contraction and elongation cycle.

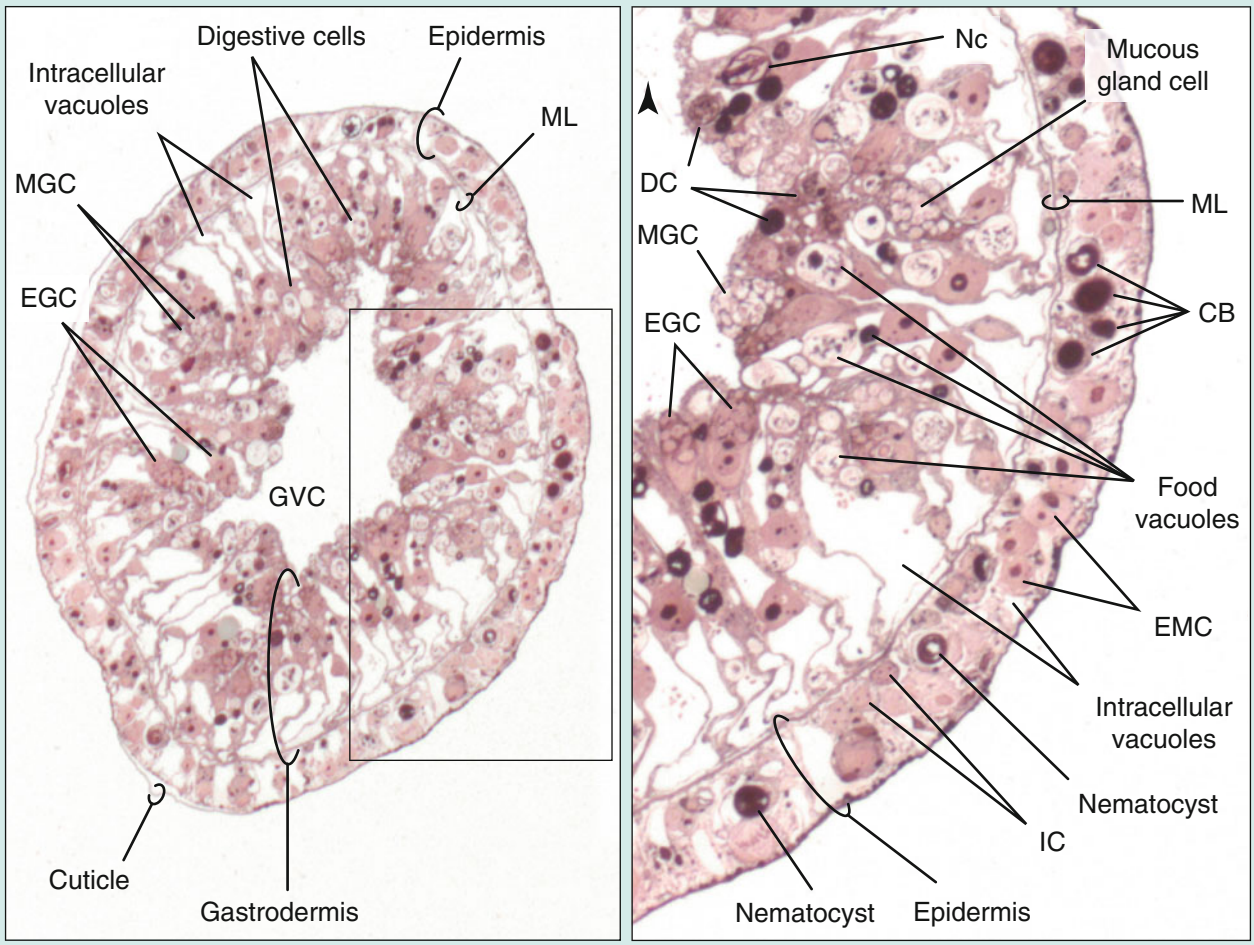

Fig. 1.2 Whole-body cross section of a hydra (*Pelmatohydra oligactis*, silver staining). The *right panel* reveals, at a higher magnification, the cell types of the body wall from the area enclosed in the *left panel*. *Arrowhead* flaggella of epitheliomuscular cells, *CB* cnidoblasts, *DC* digestive (nutritive) cells, *EGC* enzymatic gland cells, *EMC* epitheliomuscular cells, *GVC* gastrovascular cavity, *IC* interstitial cells, *MGC* mucous gland cells, *ML* mesolamella, *Nc* nematocyst in the gastrodermis, that was extruded from the epidermis during the prey catch, but did not open, so the filament is well visible inside (Section is made by Sarolta Pálfia; courtesy of Zsolt Pálfia)

Examination of a Planarian

2

The simplest animals that are bilaterally symmetrical and triploblastic (having three germ layers) are the flatworms (Platyhelminthes). Flatworms have no body cavity (acoelomate) and lack an anus. One of their groups is the freshwater triclads (*Tricladida*), or planarians. They are large free-living flatworms which are commonly found on the underside of stones or submerged leaves or sticks in freshwater springs, ponds, and streams. Planarians are mobile and use cilia on their ventral surface to glide over surfaces (Fig. 2.1).

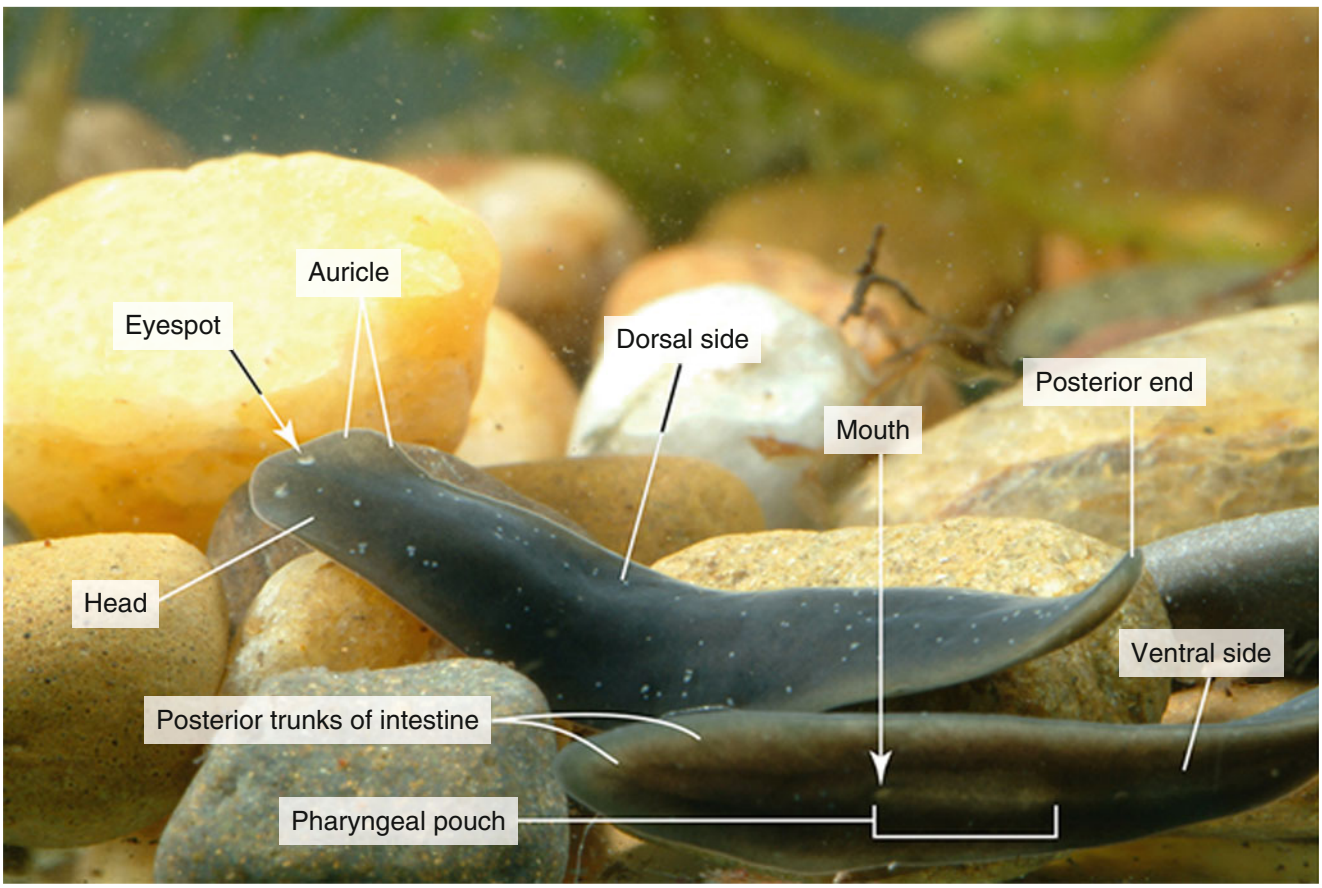

Fig. 2.1 Two living black planarians (*Dugesia lugubris*)

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Planarians can have different pigmentation such as light brown, dark brown, black or white. The characteristic planarian triangular *head* has two *auricles* and two light-sensing *eyespots*. Planarians are predators and scavengers and eat live or dead animals using their muscular retractable *pharynx* which can extend out of the *mouth* opening on the ventral side up to half of their body length. Planarians have very simple organ systems: The digestive system consists of a mouth, a pharynx and a three-branched *intestine* which makes planarians referred to as triclads. The digestion occurs in the intestine after the food has been sucked through the pharynx. The mouth is the only opening in the gut, so undigested food must also exit the body through the mouth. This highly branching gut system is called *gastrovascular system* as it unites the functions of the digestive and circulatory systems. Planarians do not have a skeletal, circulatory or respiratory system. Oxygen and carbon dioxide are transported into and out of individual cells by simple diffusion. The nervous system is made of a small brain beneath the eyes (the *cerebral ganglia*) which is connected to two long parallel *ventral nerve cords* running along the body to the tail. The two cords are connected by transversal nerves. The *auricles* contain chemoreceptors that are used to find food. The eyespots are connected to the cerebral ganglia and are used to detect and avoid sunlight (negative phototaxis) but do not detect images.

The *body wall* of a planarian is formed by epidermis and three muscular layers. Epidermis on the dorsal and ventral sides shows some differences. Most frequent cell type is ciliated in the ventral epidermis (VE), whereas the dorsal epidermis (DE) seems to be non-ciliated (Fig. 2.2, upper left, lower left, lower right).

The *epidermis* (E) on the surface is abundant in endo- and subepithelial (parenchymal) unicellular gland cells. *Endoepithelial glands* containing mucous granules (MG) seem to be swollen, and their vacuoles become empty during the microtechnical procedure, so these cells can be easily identified (Fig. 2.2, lower left). They secrete viscous mucus to create a thick coating on the surface. *Parenchymal gland cells* (PG) have a long neck region passing through epidermis to reach the surface. They produce *rhabdites* (RB), which are secretory granules with rod or spherical shape (Fig. 2.2, lower left and right). They bud from a Golgi-derived vacuole. Many types of rhabdites have been documented, but their functions are not yet clarified: they may serve as protective and repellent substances or as territorial markers. They are made of proteinaceous material featured by acidophil staining. There is a characteristic gland strip on the lateral "margin" of the animal called *marginal* (*adhesive*) *glands* (AG) (Fig. 2.2, lower right). Here groups of subepithelial (parenchymal) glands secret adhesive and releasing material onto the surface to adhere and release from a substrate several times within a second.

Musculature is composed of three layers. Outer layer is formed by circular muscle fibres (CML), inner layer contains longitudinal muscle fibres (LML) and there is an intermediate layer of radial (diagonal) muscle fibres (RM) between them. Several dorsoventral muscle bundles (DVM) can be seen between the dorsal and ventral side – they maintain the flattened shape of the animal. Body cavity is occupied by parenchymal tissue (P) embedding mid-gut branches and nervous and genital system. *Pharynx* in resting state is founded in the *pharyngeal pouch* (PP), which is formed by invagination of the outer surface – so it is lined with thin epithelium identical with the epidermis (Fig. 2.2, upper left). It is ciliated on the pharyngeal surface, but non-ciliated and flattened on the surface of the pharyngeal pouch. Pharyngeal musculature is well developed and ordered in outer and inner rings separated by parenchyma. Both rings contain longitudinal, circular and radial muscle layers. *Mid-gut* gives three main and several smaller branches in the parenchyma (Fig. 2.2, upper left, asterisks). Its wall is composed of a tall epithelial layer with gland cells (GC) secreting enzymes and digestive (nutritive muscular) cells (DC) for phagocytosing partially digested food. Digestion begins extracellularly and it is completed intracellularly. Indigestive remnants are exocytosed into mid-gut lumen. Section profiles of the *ventral nerve cord* (VNC) appear in the ventral side of the animal as lighter tissue islands in parenchyma (Fig. 2.2, upper left).

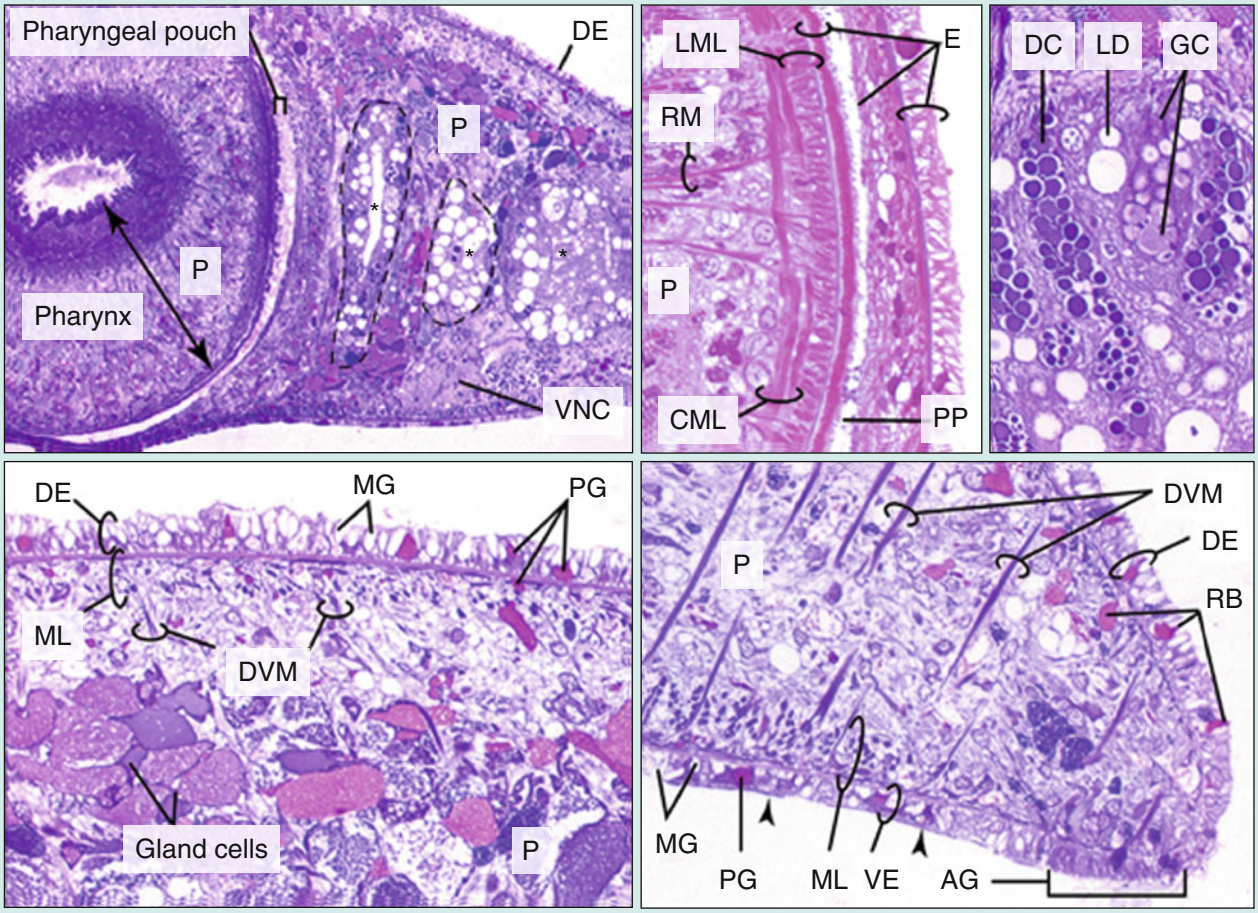

Fig. 2.2 Whole-body histological cross section of a planarian (semi-thin section, cresyl violet staining). *Asterisks* mid-gut branches, *arrowheads* cilia, *AG* adhesive (marginal) glands, *CML* circular muscle layer, *DC* digestive (nutritive muscular) cell, *DE* dorsal epidermis, *DVM* dorsoventral muscles, *E* epidermis, *GC* gland cell, *LD* lipid droplet, *LML* longitudinal muscle layer, *MG* mucous granules, *ML* muscle layers, *P* parenchyma, *PG* protrusions of subepithelial gland cells, *PP* pharyngeal pouch, *RB* rhabdites, *RM* radial bundles of muscles in the pharynx, *VE* ventral epidermis, *VNC* ventral nerve cord

The *eye of planarians* is a cup-shaped organ immersed in the parenchyma (Fig. 2.3). The cup is made by pigment cells forming an epithelial layer. The *pigment cell cup* (PC) has an opening which is oriented laterally. Light may enter the cup only through this hole because pigment cells absorb the light coming from any other directions. Orientation of photoreceptive projections is the opposite of arrival of the light – this eye is an inverse type. On its morphology this eye is suitable for sensing the direction and intensity of light for the purpose of choosing the shady places (planarians show negative phototaxis). Nerve projections of sensory cells enter the *cerebral ganglion* (CG).

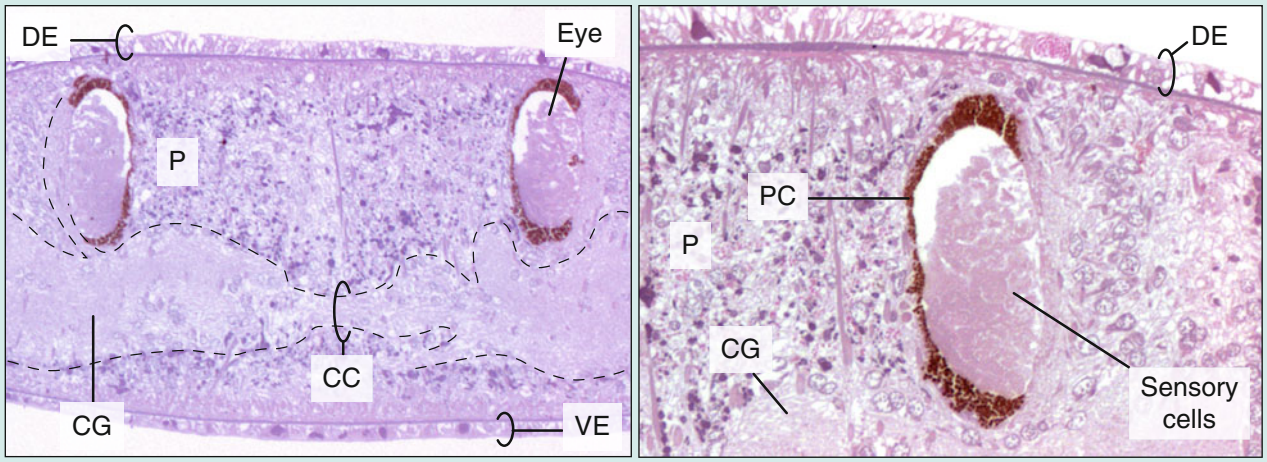

Fig. 2.3 Histological section of the planarian eye (semi-thin section, HE staining). *CC* cerebral commissure, *CG* cerebral ganglion, *DE* dorsal epidermis, *P* parenchyma, *PC* pigment cell cup, *VE* ventral epidermis

Dissection of a Roundworm (*Ascaris suum*)

3

- *Availability:* Specimens preserved in alcohol are available at biological supply companies. Cross section slides are also offered commercially. Ascaris eggs are extremely resistant to chemical treatment. Although it is unlikely, some eggs may survive immersion in preservatives for short periods. To avoid ascariasis (a disease caused by the parasitic roundworm; see life cycle at the end of the chapter), you should keep your hands away from your mouth and nose while performing this dissection and wash your hands afterwards. Put on a laboratory coat and make sure you handle all specimens with rubber gloves.

The roundworms (nematodes) are an extensive group with worldwide distribution. They inhabit terrestrial, marine and freshwater environments and are found in almost all moist habitats. The taxon includes numerous plant and animal parasites, many of which are of medical or agricultural importance, but the majority are free living (non-parasitic). Most roundworms are long, slender and almost featureless externally, tapered at both ends, and round in cross section. *Caenorhabditis elegans* is the most extensively studied roundworm. It is a free-living nematode, 1 mm in length and transparent; it can be cultured in a laboratory. It is an organism where it is possible to identify every cell as it develops and to trace its lineage. The genome of *C. elegans* was the first invertebrate genome to be sequenced. Genes controlling programmed cell death were also discovered in *C. elegans*. For laboratory studies of roundworm anatomy, however, *Ascaris suum*, the pork roundworm (Fig. 3.1), is convenient because of its large size (lengths up to 40 cm) and availability.

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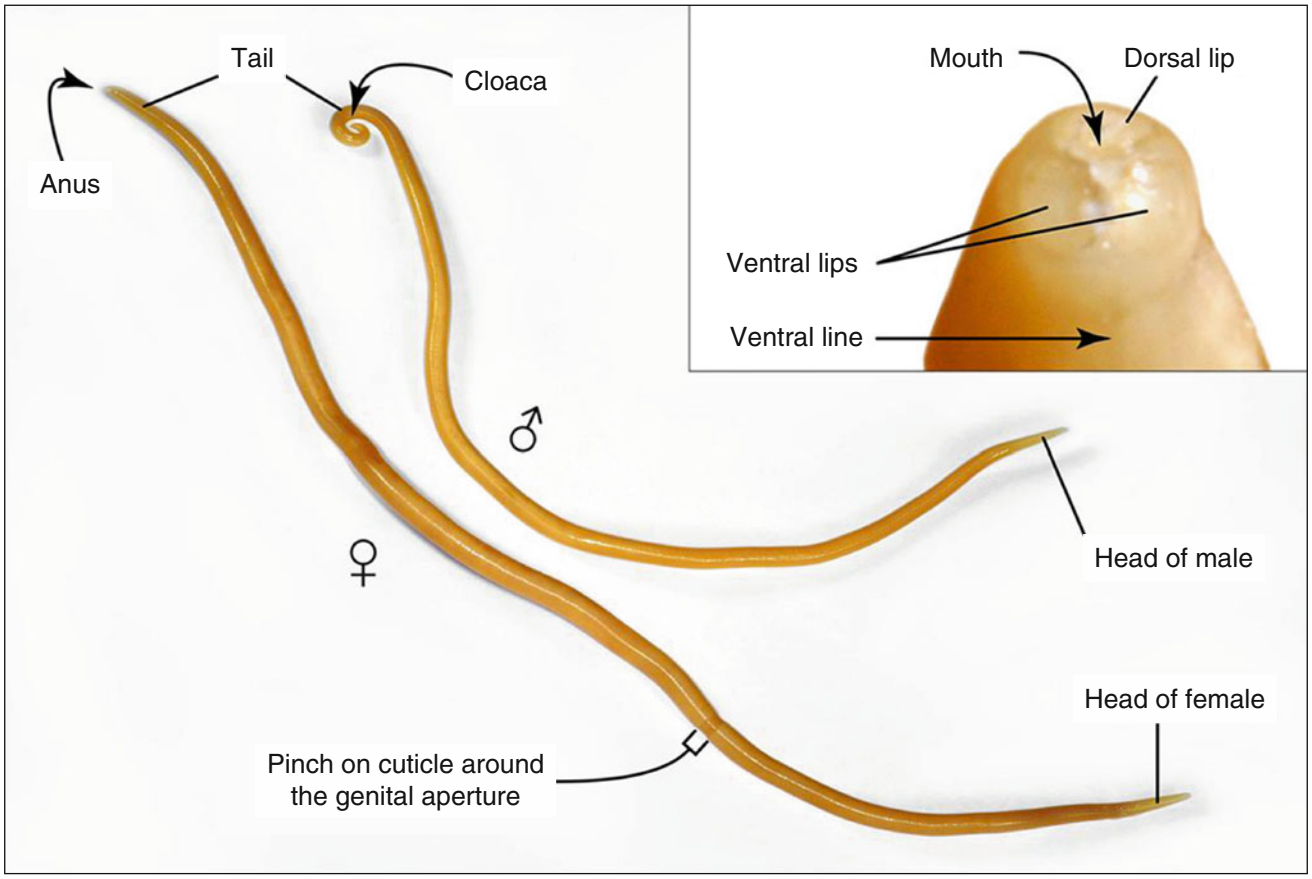

Fig. 3.1 External views of a male and a female roundworm (*Ascaris suum*). *Inset*: the head region enlarged

The body wall of preserved worms is reasonably tough, but the internal organs are extremely brittle and must be handled very carefully. The dissection should be performed in a large wax-bottomed dish using small insect pins to hold the body wall. The dissection is best conducted with a dissecting microscope. Place an adult *Ascaris* in the dissecting pan. Examine the external appearance carefully, using a hand lens to study the lips, genital aperture and anus (Fig. 3.1). In both sexes, the mouth is terminal at the anterior end, but the posterior end has no terminal opening. Viewed head-on with the help of a hand lens, the mouth can be seen to be surrounded by three small lips (Fig. 3.1, inset). One of the lips is dorso-median in position, whereas the other two are ventrolateral. The subterminal anus of both sexes is located slightly anterior to the posterior tip of the worm (Fig. 3.1). It is a transverse ventral slit and is the best landmark for recognising the ventral surface.

Look at the surface of the worm with the dissecting microscope or a hand lens and note that it is firm and resists deformation. It is covered with a thick proteinaceous cuticle which plays an important role in containing the high hydrostatic pressure of the body fluid. Look for the characteristic ornamentation of the cuticle, which in this species consists of fine circumferential ridges (Fig. 3.2). These ridges do not refer to inner structures; the animal is unsegmented.

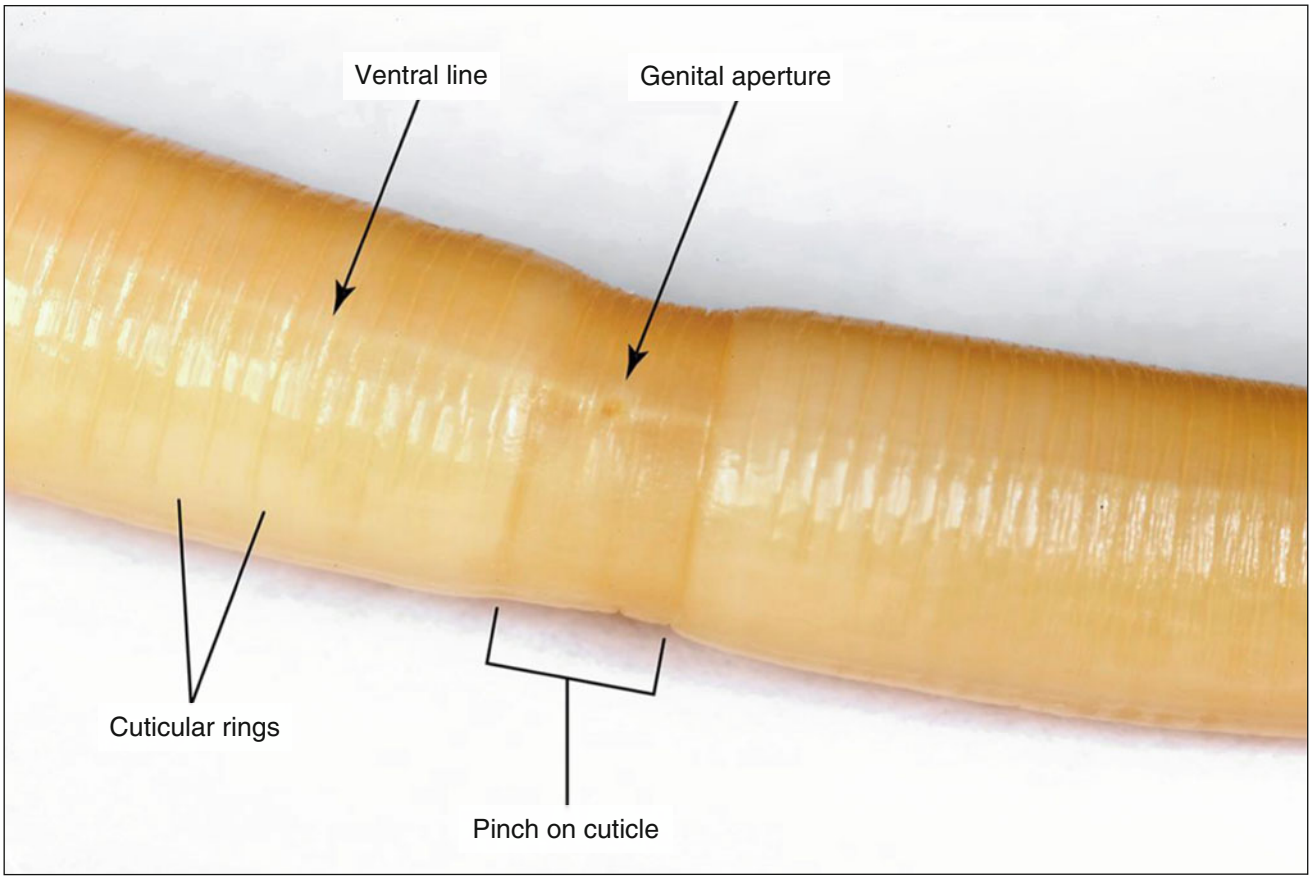

Fig. 3.2 The female genital pore is in the middle of a pinch on the cuticle on the ventral side of the body

Determine the sex of your specimen. *Females*, which run 20–40 cm in length, are more numerous and are larger than males, which average 15–30 cm in length (Fig. 3.1). The female genital aperture, known as the *vulva*, is located on the midventral line about 1/3 of the animal's length from the mouth in the middle of a pinch on the cuticle (Fig. 3.2). The female reproductive system opens to the exterior independently of the gut.

The posterior end of *males* is curved ventrally and looks like a shepherd's crook (Fig. 3.3). The posterior end of females is not noticeably curved.

Fig. 3.3 The posterior end of a male *Ascaris* curved ventrally

The four longitudinal *hypodermal cords* in the body wall are visible from the exterior as thin, pale stripes (Fig. 3.2). These are the dorsal, ventral and two lateral cords. They are faint, but discernible with good light. The two lateral cords are easier to see. Identifying these structures, you can position the worm in the dissecting pan with its ventral side down. Males must be rotated a little to accommodate the curl of the tail.

Fix the worm with two pins on each end. Be careful piercing the body wall as the high-pressure body fluid might gush out. Using a small pair of scissors, cut up the dorsal midline. Do your best to keep the incision on this line. Extend the cut forwards to the lips and backwards to the level of anus. Pin the cut edges of the body wall to the wax using insect pins slanting the pins outwards to allow room for dissection. Handle the internal organs, especially the gut, carefully because they are very delicate and break easily. Opening the middle region of the worm is a bit more difficult because it is packed with the reproductive system (Fig. 3.4). Finally, cover the specimen completely with water.

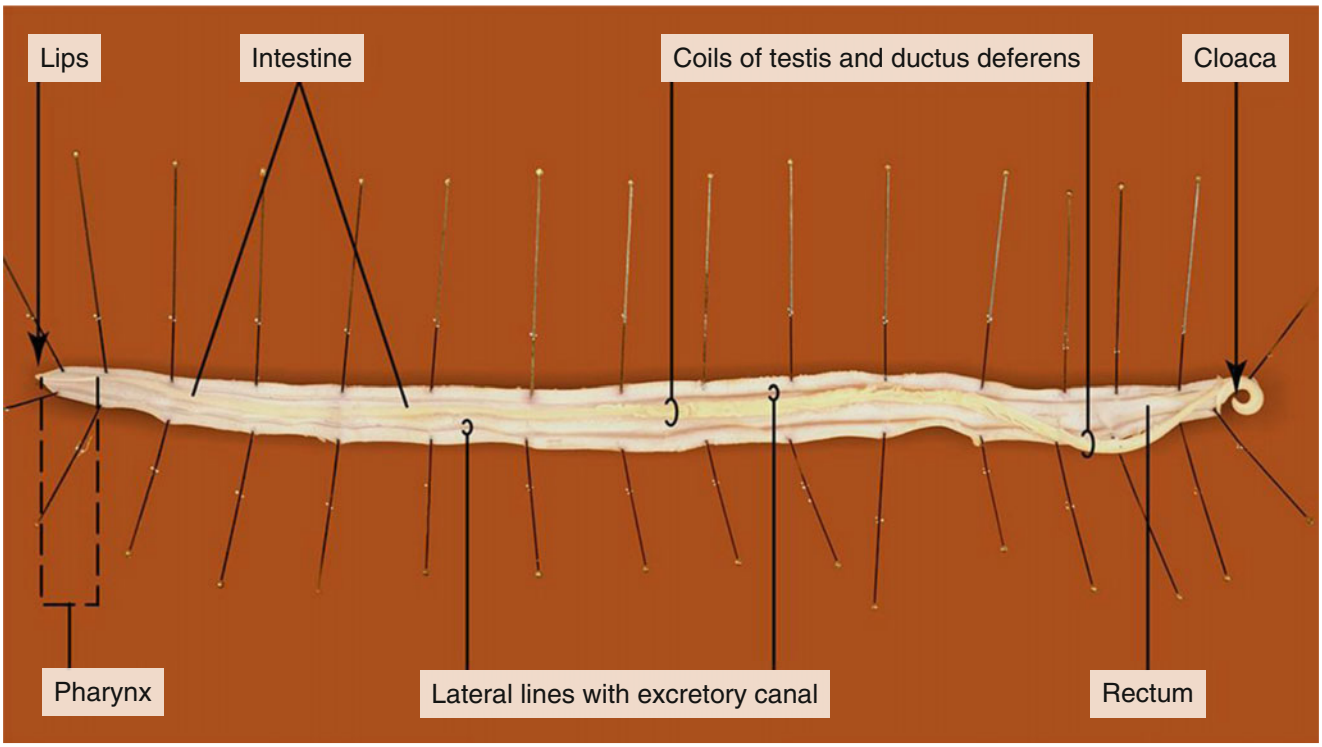

Fig. 3.4 Internal structure of male *Ascaris*

The heavy, transparent *cuticle* is the outermost layer. Immediately under the cuticle is the inconspicuous, thin epidermis. This is called *hypodermis* in *Ascaris* as it is under a very thick cuticle (Fig. 3.6). Inside the hypodermis is a thick, white sheath of *longitudinal muscles* composed of a single layer of cells which protrude into the *pseudocoel* (Figs. 3.5 and 3.6 upper left, bottom right). The pseudocoel, or primary body cavity, is filled with fluid under a high pressure. Virtually all other organs are affected by this pressure and must be able to function under its influence. The pressure maintains the body shape and acts as a *hydrostatic skeleton* against which the body wall muscles act to accomplish locomotion.

The two lateral hypodermal cords are large and well-visible longitudinal ridges and protrude into the pseudocoel (Fig. 3.5). The dorsal and ventral cords are much less evident and the dorsal cord is usually destroyed by the middorsal incision. Push the surrounding muscle cells aside to see the ventral cord. The dorsal and ventral hypodermal cords include longitudinal nerve cords and an excretory canal is present in each lateral cord (Figs. 3.5, 3.6, and 3.8).

The locomotory system comprises the hydrostatic skeleton (the pressurised pseudocoel), the antagonistic dorsal and ventral longitudinal muscle fields of the body wall and the elastic cuticle, which contains the hydrostatic pressure and opposes the longitudinal muscles. When one muscle field contracts, the opposite side of the body elongates to relieve the hydrostatic pressure. Alternate contractions of dorsal and ventral muscle fields result in sinusoidal waves in the dorsoventral plane passing along the length of the body. If living nematodes, like *Caenorhabditis elegans*, are available in the laboratory, place a culture in a Petri dish in an inverted microscope and observe their motion.

The gut is a long, straight tube running from the mouth to anus (Fig. 3.4). It is composed of an anterior, ectodermal foregut, endodermal mid-gut and ectodermal hind-gut. Relocate the terminal *mouth*. The foregut comprises the buccal cavity and *pharynx*, which, consistent with their ectodermal origins, are lined with cuticle (Fig. 3.5). The heavily muscularised wall of the pharynx is used to suck food into the gut in opposition to the high hydrostatic pressure of the pseudocoel. The pharynx is round in cross section. At rest, its lumen is collapsed and is triradiate (Y-shaped) (Fig. 3.5, inset). When filled with food, the lumen expands and becomes circular. The lumen is dilated by contraction of the radial muscles in the pharyngeal wall.

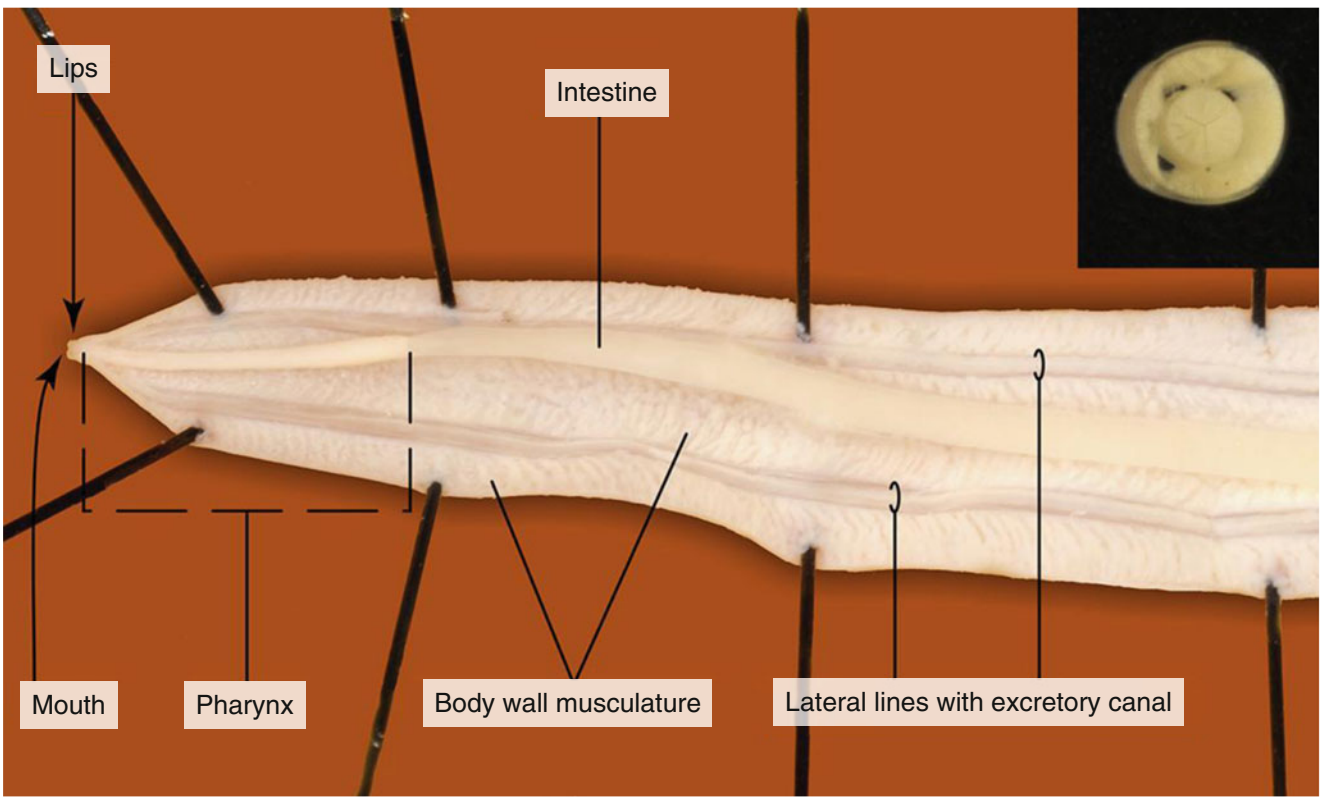

Fig. 3.5 Details of the anterior internal structures of male *Ascaris*. *Inset*: Transverse section of *Ascaris* at the level of the pharynx