Kidney:

The kidney of the teleost is a mixed organ comprising hematopoietic, phagocytic, endocrine, and excretory elements. The kidneys vary greatly between different species of fish, both grossly and histologically. Often (partially or totally) fused (Clupeidae, Salmonidae, Anguillidae, Cyprinidae, etc.). The kidney of fish is usually located in a retroperitoneal position up against the ventral aspect of the vertebral column.

It is a light or dark brown or black organ normally extending the length of the body cavity. The entire kidney of adult fishes is a mesonephros. It is usually divided into anterior or head kidney, which is largely composed of hematopoietic elements, which also contains chromaffin and adrenocortical endocrine elements; few renal tubules are observed. The posterior kidney (Fig. 1) contains more renal tubules with a lesser amount of interstitial hematopoietic and lymphoid tissues and thus functions as an osmoregulatory organ.

The ureters, which conduct urine from the collecting ducts to the urinary papilla, may fuse at any level and may be dilated, after fusion, to form a bladder. The urinary ducts open to the outside posterior to the anus.

Excretory Kidney

The primary function of the kidney in fish is the osmotic regulation of water and salts rather than the excretion of nitrogenous wastes as in mammals. In fish, the majority of nitrogenous wastes are excreted by the gills. In freshwater, the kidney must conserve salt and eliminate excess water. This is accomplished by a high glomerular filtration rate, reabsorption of salts in the proximal tubules, and dilution of urine in the distal convoluted tubule.

Nephron

The primary task of a freshwater fish kidney is to produce copious dilute urine to counteract the passive influx of water across the gills and integument. By contrast, saltwater fish need to conserve fluid and this is achieved through modifications in the histology of nephrons. So, the component structure of the fish nephron varies considerably between marine, euryhaline, and freshwater forms mirroring the significant differences between their respective function. Even though this is true, the basic cellular architecture is similar.

Each nephron consists of several segments with specific structure and function. A typical freshwater nephron consists of cytologically distinct regions: renal corpuscles, neck segment, proximal, intermediate, and distal tubules. The distal tubules connect to small collecting tubules which join larger collecting ducts that empty into ureters. Fluid loss is limited in saltwater fish by reducing the size and number of glomeruli, and in some species (such as toadfish, goosefish, and syngnathids) by eliminating glomeruli altogether.

The fish renal corpuscles (Fig. 1:B,C) consist of a glomerulus and a glomerular (Bowman's) capsule. The glomerulus is a globular network of densely packed anastomosing capillaries that invaginates Bowman's capsule. The relatively wide diameter afferent arteriole enters Bowman's capsule at the vascular pole of the renal corpuscle and then forms the network of glomerular capillaries. The efferent arteriole drains the glomerulus and leaves the capsule at the vascular pole which is usually situated opposite the entrance to the renal tubule, the urinary pole. Bowman's capsule consists of a single layer of flattened cells resting on a basement membrane; it forms the distended, blind end of the renal tubule.

Bowman’scapsule has two layers: visceral and parietal layers. The internal or visceral layer of the glomerular capsule surrounds the glomerular capillaries with modified epithelial cells called podocyte. At the vascular pole of the renal corpuscle, the epithelium of the visceral layer reflected to form the simple squamous parietal layer of the glomerular capsule. The space between the visceral layer and parietal layer of the renal corpuscle is called the capsular (urine) space. There are numerous nuclei in the glomerulus that bare capillary endothelial cells, mesangial cells, and podocyte. The development of diameter and number of glomeruli clusters is strongly agedependent. In the glomerulus, an ultrafiltrate of plasma is formed from the blood. This filtrate then passes into the renal tubule where it is altered to form urine.

The neck region (Fig. 1C) is continuous with the parietal and visceral epithelia of Bowman’s capsule and shows a narrow lumen surrounded by ciliated cuboidal/columnar epithelial cells. The cytoplasm of these cells stains slightly basophilic. This segment is usually short, and opens into a wider proximal tubule. The proximal convoluted tubule (Fig. 2: A,B) is the longest and most developed segment of the nephrons. This tubule is lined by eosinophilic granular simple columnar cells with a well-developed brush border. In these cells, the nuclei are mainly spherical and situated in lower part of the cells. The brush border enhances reabsorption of fluid and solutes from the lumen through or between the cuboidal epithelial cells and into capillaries.

Proximal convoluted tubule resorbs 85% of the water and sodium chloride. In addition, glucose, amino acids, proteins, vitamin C, and inorganic elements are also resorbed. The intermediate segment has a narrow lumen surrounded by cuboidal cells that often have cilia, which help move the filtrate along the nephron. The distal tubules are characterized by low columnar cells with oval, basally located nuclei and no brush border, stain less intense than proximal tubules. Within the distal tubules, more water is resorbed and urine concentrated or diluted. In marine fishes, the glomeruli are smaller and the intermediate segment is absent. The requirement here is to slow down the movement of fluid so that there is time for the maximum amount of passive diffusion of water back into the blood. The distal segment is also often absent.

Collecting tubules and ducts (Fig. 2C) are located throughout the kidney. Their columnar epithelium is lightly eosinophilic with basal nuclei and no brush border. Large collecting ducts incorporate layers of smoothmuscle and connective tissue. Collecting tubules are involved in collection of concentrate for excretion and more water resorption. The ureters (Fig. 2D) open directly to the outside by a urinary pore or end into the bladder as in Cyprinidae. The ureter is lined by simple columnar epithelium, followed by smooth muscle and connective tissue. The bladder can be only a simple dilation of the ureters or a true saccular organ (Barbus, Mystus, etc.) emptying outside by a urogenital pore.

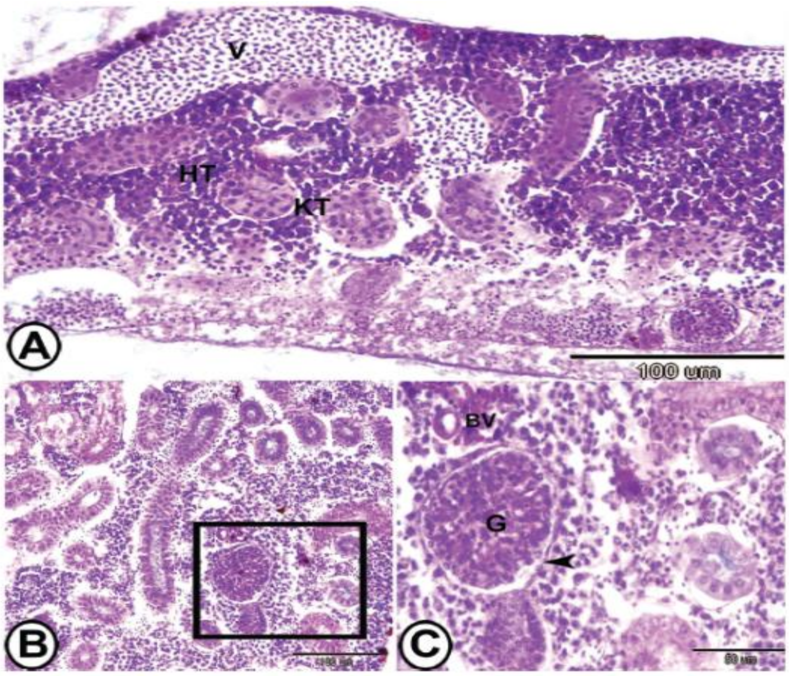

Figure 1: **(A)** General view of a mesonephric kidney in red tail shark. The kidney parenchyma is filled with tubules (KT) and hematopoietic tissue (HT). Renal arteries from the dorsal aorta supply the kidney and blood is carried away by two posterior cardinal veins (V) (PAS-HX). **(B)** Photomicrograph in kidney of molly fish shows at the square a large renal corpuscle containing a well-developed glomerulus (PAS-HX). **(C)** Magnified view in the boxed area in Figure 1B showing the cavity of the renal corpuscle that is lined by single layer of flat cells (arrowhead). Glomeruli consist of a network of capillaries and the numerous nuclei inside are mainly those of podocytes and capillary endothelial cells. The corpuscle is surrounded by connective tissue, tubules of various diameters, and blood vessels (BV) (PAS-HX).

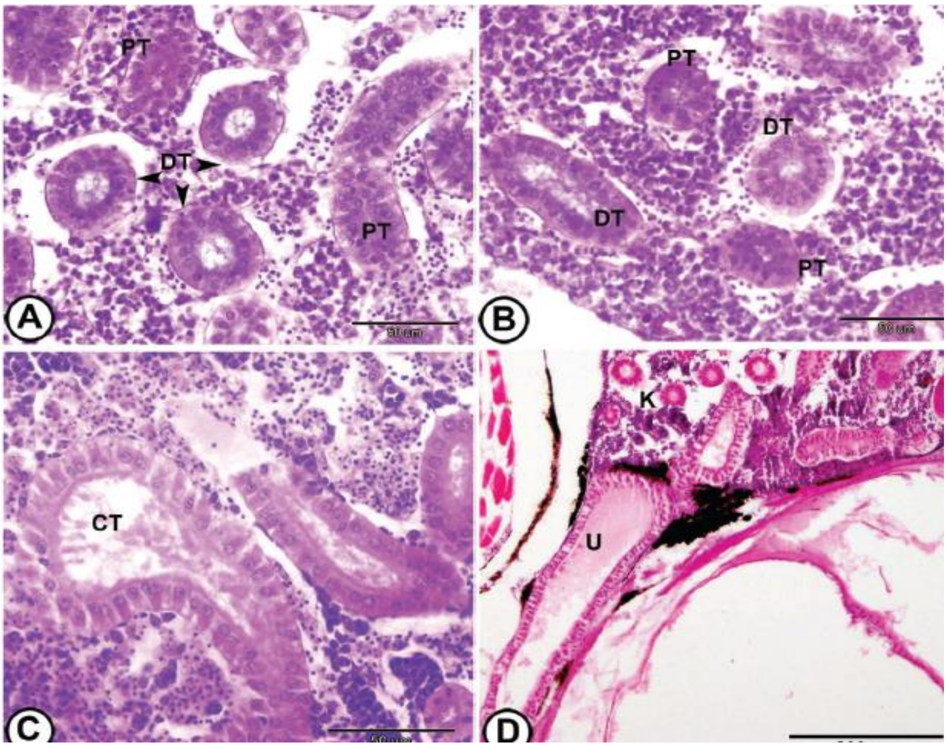

Figure 2: (A, B) Nephron tubules of various diameters in guppy take up a great part of the micrograph. Transverse and longitudinal sections of proximal tubules (PT) can be distinguished from the other tubules by their PAS + brush border. In addition, distal tubules (DT) in transverse and longitudinal section are also noticed (PAS-HX). (C) Transverse section through collecting tubules (CT) in guppy. They are histologically distinct from other segments as they are constructed of tall columnar epithelial cells enclosing wide lumens and surrounded by a thick sheath of connective tissue. Nests of hematopoietic tissue are obvious (HE). (D) The photograph showing one ureter (U) and its tall columnar epithelium extended from the kidney of molly fish (HE).

Swim and Gas bladder

Many bony fishes possess a gas bladder, a single elongated sac dorsally located to the digestive tract. Gas bladders are filled with air that enters via the pneumatic duct or with gas (O2, CO2, N2) secreted into the bladder from the blood. As gas bladders are mainly used to control the buoyancy of the fish, they are often called swim bladders (less appropriate term). Occasionally they may be heavily vascularized to participate in supplementary respiration and called respiratory gas - or air - bladders. The internal vascular walls of respiratory gas bladders are subdivided into many partitions that increase the surface area available for external respiration exchange. The gas bladders are not necessary for life as they are absent in many fishes (*Blennidae*, *Pleuronectidae*, *Thunnidae*, *Scombridae*, some *Scorpenidae*, Chondrichthyes...).

This organ may be one, two or three chambered. Its presence or absence can reflect the behavior of fishes. Swim bladders come in two kinds : physostomous and physoclistous. Physostomous swim bladders are connected to the foregut (esophagus) by a duct called the pneumatic duct. This type of bladder is characteristic of sturgeons and primitive teleosts (*Anguillidae*, *Cyprinidae*...).

In physoclist fishes the pneumatic duct is lost during embryonic development. This type of swim bladder is found only in advanced teleosts. (*Percidae*, *Gadidae*, *Balistidae*, *Tetraodontidae*...). Typically, the filling and the emptying of the gas bladder are respectively made by a secretory section (the gas gland – Figs 3, 4) and a resorbing section (the oval), but the actual anatomy of these sections varies from species to species. In the European eel (*Anguilla anguilla* Figs 5, 6), the pneumatic duct develops into the resorbing section of the bladder, which can be separated from the secretory section by a sphincter. In cod or perch, the oval, can be separated from the rest of the organ by muscular activity and is designed to allow the resorption of gases.

The swim bladder wall consists of several layers. The outer layer, consisting mainly of fibromuscular tissue, is called the *tunica externa*. The *submucosa* may be impregnated with guanine crystals, which render the swim bladder wall impermeable to gases. In some fishes large amounts of membranous material is present which typically is arranged in a bilayer structure. Below the *submucosa*, smooth muscle cells are present, termed the *muscularis mucosae*. The *tunica interna* comprises a cuboidal secretory epithelium. Anteriorly this epithelium is modified into the gas gland, which is made up of folded columnar epithelium heavily vascularized by long loops of densely packed capillaries. This type of structure is called a *rete mirabile* (Figs 7, 8). This *rete* in association with the gas gland allows gas secretion into the bladder. The production of gas in the bladder is made possible among others by the countercurrent arrangement of the arterial and venous capillaries of the *rete mirabile*.

Although hydrostasis is the primary function of gas-filled organs in the vast majority of present- day bony fishes, these structures sometimes perform a respiratory function. A phylogenetically diverse array of fishes breathe air through their air-bladder. Air breathing through the use of an air-bladder is restricted to those fishes that have retained a connection between the esophagus and the bladder. This is the case in diverse primitive teleosts, for example, the bony tongue fishes *(Osteoglossoidei*), the tarpons *(Megalopidae*), the gars (*Lepidosteidae*), the bowfin (*Amiidae*), the aba (*Gymnarchidae*), the knifefishes (*Notopteridae*) and the trahiras (*Erythrinidae*). Functional lungs are found among relatively primitive fishes. There are few examples, among preteleosts : the bichirs *(Polypteridae*) and the lungfishes (Dipnoi).

Most bottom-dwelling teleosts (*Pleuronectidae, Blennidae, Cottidae*) and deep-sea species(Stomiiformes, Aulopiformes, Myctophiformes) whose protective and food-gathering mechanisms depend on their staying at the bottom of the sea do not have a gas bladder. It is also usually lost or greatly reduced in certain other fishes whose functioning would be impeded by a large bubble of gas, for instance, in freshwater species that live in turbulent streams and in the most rapidly swimming marine fishes such as mackerels (*Scombridae*), tunas and pelagic sharks.

In addition the gas bladder has evolved other functions. It facilitates auditory reception in several teleosts (*Ostariophysi*) by means of tiny Weberian ossicles. In others it is involved in sound production (*Balistidae, Triglidae, Batrachoididae*…).

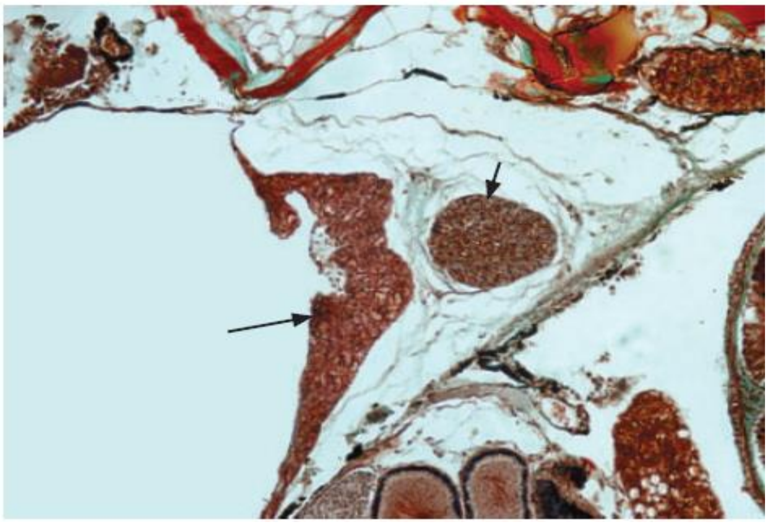

Figure 3: The gas gland (long arrow) and a portion of the *rete mirabile* (short arrow) are illustrated ; together they are sometimes called the (red body)ensuring gas secretion into the gas bladder.

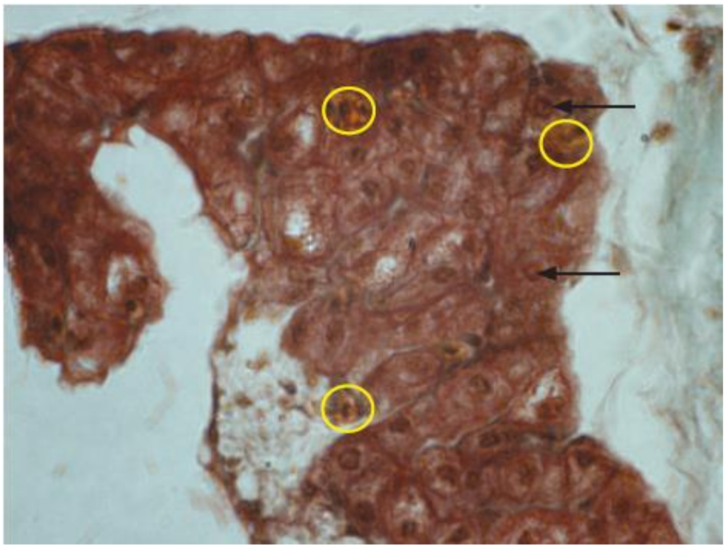

Figure 4: The gas gland is a modification of the inner lining (tunica interna) ; it is composed of a highly specialized and vascularized epithelium whose cells produce lactic acid and CO2. The induced acidification allows gas diffusion from afferent arterial capillaries into the bladder. This high magnification shows gas gland cells (arrows) with capillaries (circles red blood cells stained by orange-G) in between.

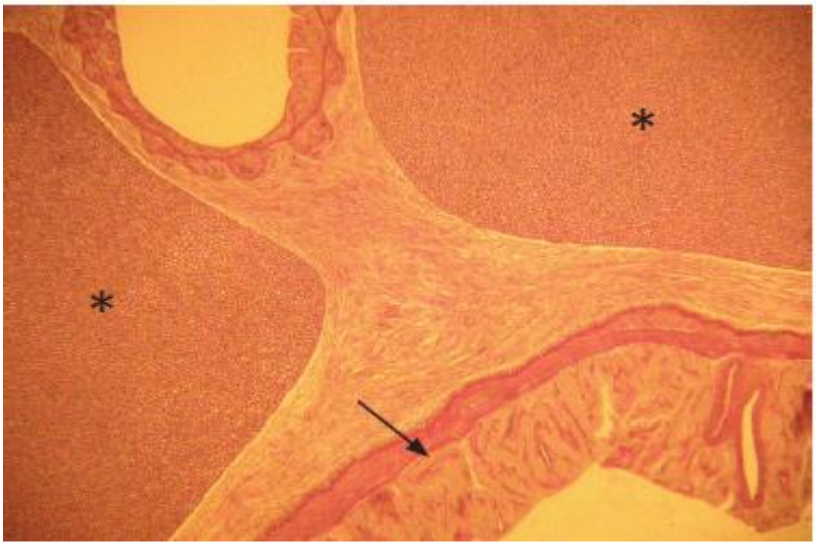

Figure 5: General view of the gas bladder in eel illustrates part of the gas bladder wall (arrow) and its bipolar *rete mirabile* (*), a clump of parallel arterial and venous capillaries found on the outside of the gas bladder.

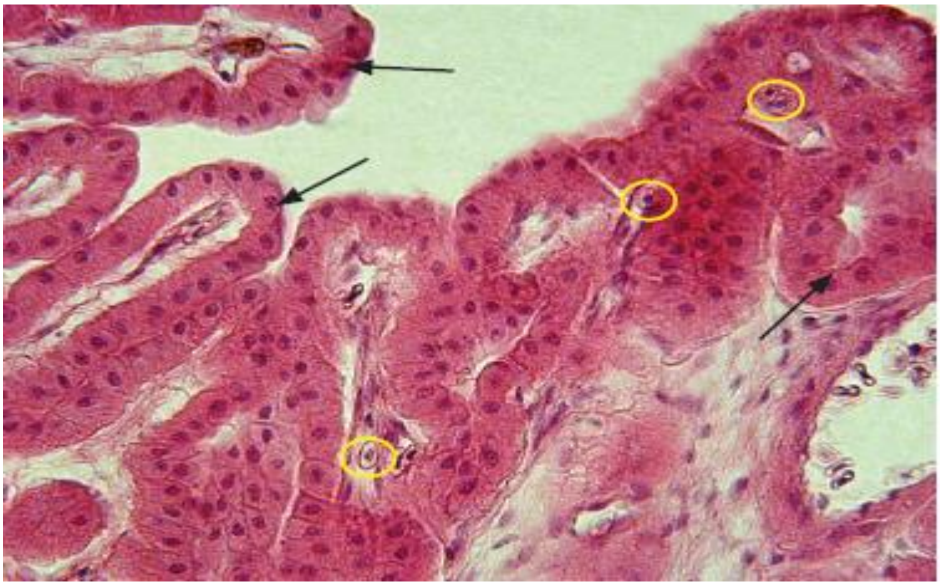

Figure 6: A portion of the gas gland is magnified. The gas gland cells form a cuboidal columnar folded epithelium (arrows). Like the epithelial cells of the tunica interna, gas gland cells produce surfactant which is released at their apical membranes. The epithelium is heavily vascularized by long loops of densely packed capillaries (circles) belonging to the *rete mirabile.*

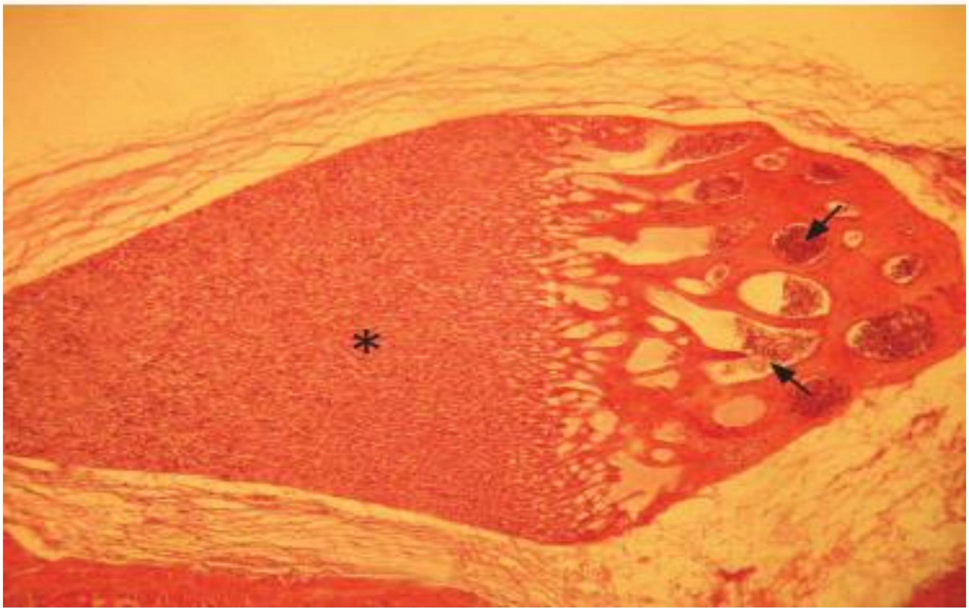

Figure 7: Longitudinal section of the rete mirabile of an eel. The main blood vessel entering the anterior part of the gas bladder breaks up into smaller branches (arrows) which subdivide into a multitude of capillaries (*). The *rete mirabile* is a dense bundle of parallel arterial and venous capillaries arranged side by side and supplying the gas gland with blood.

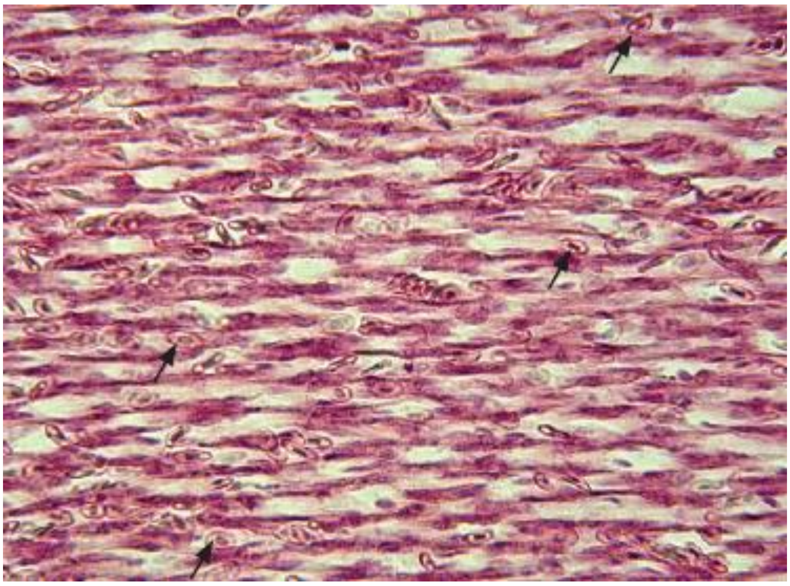

Figure 8:The blood capillaries in the *rete mirabile* are numerous and so closely arranged as to leave no interspaces for any supporting tissue. Arterial and venous capillaries are not distinguishable on this light microscopy image. The pattern of arrangement of the blood capillaries in this mass and the abundance of blood cells (arrows showing erythrocytes) give a fascinating appearance in a longitudinal section.