1 Anatomy and Histology of the Macula

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1.1 Introduction

As an optical organ, the eye has some unique features. Key structures in the light path must be largely transparent, such as the cornea, aqueous fluid, the lens and the vitreous humour. The retina itself must also be largely transparent as the light-sensitive region of the photoreceptors is in the deeper retinal layers. The eye must also maintain a positive pressure to maintain its shape. Survival and proper function of the neuronal cells within the retina, particularly in the macula, require a stable intraocular environment. Homeostasis of the intraocular environments depends on many specific mechanisms and many signal pathways. These mechanisms and pathways are dynamic and interacting and often require a delicate balance. It means that these mechanisms and pathways can only maintain their integrity if they are capable of adapting to change in the face of physiological challenges such as illumination conditions or other local or systemic conditions. In diseased situations, which may be caused by genetic and/or environmental changes, the macula cannot adapt to these pathological challenges and pathological changes can occur. The rationale for treatment is to attempt to restore normal conditions as much as possible. However, most diseases, including macular diseases, often involve multiple mechanisms and pathways, whilst the treatments usually can only address the major pathogenic factors. So naturally, macular and vitreous surgery are combined with a variety of intervention option such as application of anti-VEGF drugs, intra-vitreal steroids, laser retinal photocoagulation and release of vitreo-retinal traction. All these procedures cause unavoidable alterations of the intraocular environment. How to achieve the therapeutic benefits and restore structure and function using the available interventions is always a challenge for macular surgeons.

1.2 Definition of the Macula

The macula lutea is the region containing a high concentration of yellow pigment. The description of its size in the literature can be confusing and varies by up to a factor of 10, ranging from 0.5 mm to more than 5 mm in diameter [1–3]. The ophthalmoscopy and gross anatomic correlations are not clearly defined. It is more generally accepted that the macula is approximately 5.8 mm in diameter and located approximately two disc diameters temporal to the optic nerve head [1]. The macular region can be subdivided into the foveola, fovea, parafoveal and perifoveal

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areas, although the boundaries of these specialized regions are also not well defined [1]. Figure 1.1 describes the relationship between fundus appearance and a sagittal macular section. Both the fundus image and the optical coherence tomography (OCT) image were sampled from a young healthy subject. Subdivided areas on fundus image are matched with the OCT image. The foveola is the central 350 μm in the middle of the foveal avascular zone (FAZ) and includes the base of the foveal pit where there is a peak density of cone photoreceptors for high acuity vision. It is formed only by cone outer and inner segments, a tightly packed multiple deep layer of cone cell bodies and surrounding Muller glial cell processes. It is surrounded by terminal capillaries, on the slope of the pit. The next ring is the fovea, which extends 750 μm around the foveola. Ganglion cells distribution ranges from an absence of ganglion cells near the foveola to up to eight cells deep on the edge of the fovea. Cone density in the fovea is lower than in the foveola. The outer plexiform layer appears in the fovea. It contains a thick layer of long cone axons called the fibres of Henle and the synaptic pedicles of the foveolar cones. The third ring is the parafovea (500 μm wide), and the outermost ring is the perifovea (1500 μm wide), which extends almost to the optic disc. These are no distinct morphological boundaries between these zones. Rods are

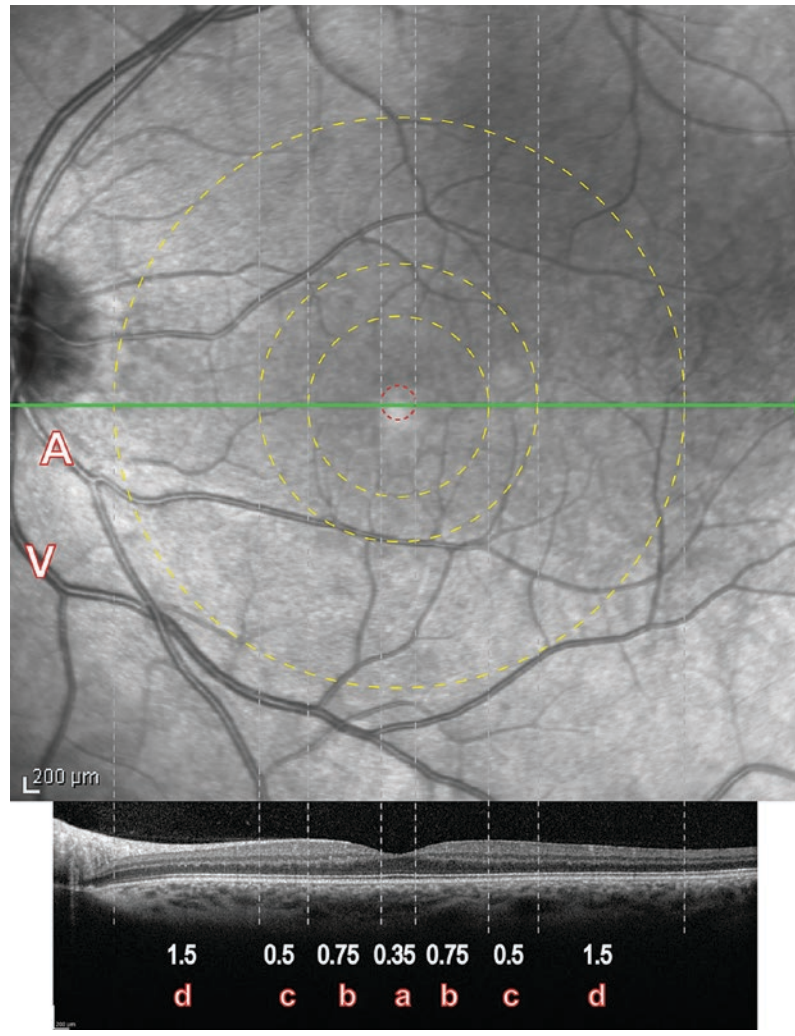

Fig. 1.1 Fundus image and OCT image from a young healthy subject illustrating the relationship between fundus appearance and sagittal macular section. Subdivided areas on fundus image are matched with OCT image. (**a**) The foveola: central ~350 μm includes the base of the foveal pit. (**b**) The fovea: extends 750 μm around the foveola. (**c**) The parafovea: third ring ~500 μm wide and (**d**) The perifovea: the outermost ring ~1500 μm wide, extending almost to the optic disc [4]

absent in foveola, have a low density in the fovea, are more numerous in the parafovea and predominant in the perifovea. In the parafoveal region, the retina has maximum thickness, owing to the high density of neural elements.

1.3 Macular Cellular Structure

1.3.1 Fovea and Foveola

The fovea is located roughly 4.0 mm temporal and ~0.8 mm inferior to the centre of the optic disc as shown in Fig. 1.1a. In the central fovea, there is a small excavation in the internal surface of the retina (Fig. 1.1b).

The foveola is roughly 350 μm across and is formed entirely by cones. Cone cell bodies, outer and inner segments are tightly packed (Fig. 1.2), and surrounded by Muller cell processes. All other layers are displaced peripherally from the pit. The foveola is the region of highest cone density so foveolar cones are very thin and have the longest inner and outer segments in the retina.

The fovea is the next ring around the foveola with width of approximately 750 μm. There is a variation in depth of the excavation in normal eyes. The averaged depth is about 250 μm in the human eye. The foveal slope is formed by walls of the pit (Fig. 1.2). Multiple layers of ganglion cell bodies are found in the fovea. Cone density is lower than in the foveola, and the cones are thicker. Rods are present at low density in the fovea (Fig. 1.2). A thick outer plexiform layer can be seen in the fovea. It consists of aggregated horizontally oriented fibres (long cone axons) called the fibres of Henle. The synaptic pedicles of the foveolar cones are also in the fovea (Fig. 1.2). Capillaries appear in the inner retina and encircle the foveal slope, where they form the border of the FAZ about 400–500 μm wide.

Cone density peaks sharply in the foveola and drops rapidly into the periphery, reaching a 1:1 ratio of rod/cone at approximately 500 μm eccentricity. The ratio of total rods/cones is ~20:1 based on estimates of 92 million rods and 4.6 million cones in the adult human retina [5]. Red and green cones constitute around 90% of the

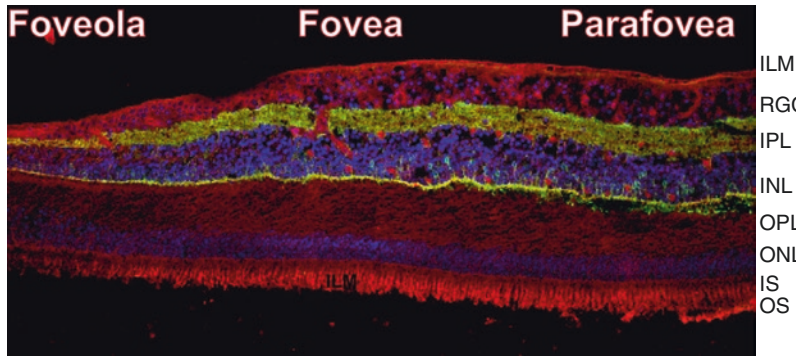

Fig. 1.2 Confocal image (8.05 μm total thickness projected) of a cryosection through the macula region of donor eye triple labelled for rod ON bipolar cells (anti-Goα, green), horizontal cells (anti-parvalbumin) and Lectin-TRITC (red) which is more strongly picked up by the Glycocalyx on the luminal side of vascular endothelial cells. The nuclei are count-stained using Hoechst (blue). In the foveola, multiple layers of cone nuclei are located in the outer nuclear layer (ONL) and the outer segments (OS) and inner segments (IS) are relatively thin. This section could be slightly off the centre of the foveola. In the fovea, the inner retina becomes thicker with multiple layers of retinal ganglion cells (RGC) layer, inner plexiform layer (IPL), inner nuclear layer (INL) and outer plexiform layer (OPL) in addition to the ONL, OS and IS. The foveal slope is clearly evidenced as part of the foveal pit. Cone nuclei in ONL are less than that in the foveola. However, the IS becomes thicker. Abundant fibres of Henle are found in the OPL. The cone pedicles seen in the fovea are the displaced pedicles of the foveolar cones during pit formation. In the parafovea, full thickness of the inner retina is present and the number of cones in the ONL is markedly reduced whilst number of rods is increased

cone population with blue cones the remaining 10%. Most humans have a ratio averaging two red cones/one green cone, but individuals can range from one red cone/eight green cones to nine red cones/one green cone and still have normal colour vision [6].

The functional integrity of our high visual acuity region (central 2 mm of retina) is dependent on approximately 90,000 cones [1, 6], which is roughly 2% of the total cone population and only 0.1% of the total photoreceptor population. The number of cones in the foveola is only 7000–10,000 [6]. It is very important to maintain the structural and functional integrity of the foveola and fovea throughout life.

1.3.2 Parafoveal Region

The parafoveal region has a width of about 0.5 mm (Figs. 1.1 and 1.2). It is characterized by the largest accumulation of nerve cells in the entire retina, especially those of the ganglion cell and inner nuclear layers and a thick outer plexiform layer, known as the fibres of Henle in this region. Rods are more numerous in the parafovea when compared within the fovea and foveola and cones are thicker and less numerous. There are four to five rows of nuclei seen in the outer nuclear layer, and in the outer part of this layer, they are mostly rod nuclei. The layer of fibres of Henle is still thick, and both rod spherules and cone pedicles appear here. The inner nuclear layer has more than ten rows of nuclei. The ganglion cell layer appears to have smaller and relatively uniform cell bodies forming multiple rows.

1.3.3 Perifoveal region

The perifoveal region measures 1.5 mm in width. Therefore, the entire macular area is 5.85 mm in diameter. In the perifovea, rods are the dominant photoreceptor and the retinal ganglion cells reduce their numbers towards the optic disc. The thickness of the ganglion cell layer is further reduced. The thickness of the outer nuclear layer is unchanged from that of the parafoveal region, but the numbers of cones are reduced. Five to six rows of nuclei are seen in the outer nuclear layer. The outer plexiform layer is reduced to half the thickness of that in the perifoveal region. The inner nuclear layer is also reduced to the same thickness as in the peripheral retina, but the thickness of the inner plexiform layer is slightly increased.

1.4 Blood Supply of the Macula

The retina is supplied by both the retinal and choroidal circulations. An ophthalmic artery leads into the long and short posterior ciliary arteries feeding the choroidal/uveal circulation, and a central retinal artery and sometimes cilioretinal arteries feeds the retinal circulation. These two circulations possess significantly different properties and constraints. The visual image is focused on outer segments of the photoreceptors. The photoreceptor region is avascular to ensure optimal visual acuity with minimum optical interference from vascular structures. As a consequence, the photoreceptors' main source of nutrients, the choroidal circulation, lies totally outside the retina and supplies the photoreceptor layer with nutrients such as oxygen by diffusion [7–9]. The oxygen supply from the choroid is barely enough to prevent some regions of the outer retina from becoming hypoxic, which suggests that the high rate of blood flow through the choroid may be essential to maintain a sufficiently high oxygen level in the choriocapillaris to drive the oxygen diffusion process. The choroidal circulation possesses both sympathetic and parasympathetic innervation [10], presumably allowing systemic control of choroidal blood flow. However, there has been considerable disagreement as to whether the choroidal circulation is capable of functional regulation [11–15]. The retinal circulation is differently constrained in its design. Although it is responsible for feeding a high metabolic rate tissue, it must be anatomically sparse to minimize optical interference with the light path to the photoreceptors. A further unusual feature of the retinal circulation is that it has no autonomic innervation [16], so total reliance must be placed

on local vascular control mechanisms. These requirements result in a limited flow circulation, with a high arterio-venous oxygen tension difference. In most retinal regions, this circulation has at least two capillary networks, one feeding into the nerve fibre/ganglion cell layer and other feeding the middle retinal layers including the inner nuclear layer and plexiform layers. There is no controversy about the powerful regulatory ability of the retina circulation from both human and animal data [17]. Interestingly, we have demonstrated that the two major capillary layers have different regulatory capabilities showing that in the rat retina the oxygen level in the region supported by the superficial capillary layer is well regulated, whilst that of the deeper capillary layer is not [18]. This apparent vulnerability of the deep capillary bed area is an important observation as it provides a possible explanation for the high incidence of pathological involvement of the deep capillaries in retinal vascular disease [19, 20]. The feeder vessels to the eye may be also involved in the regulation of ocular blood flow and it is known that their vasoactive properties can vary significantly along their length [21–23]. This adds yet another dimension to the heterogeneity of vascular control mechanisms in the ocular vasculature.

There are also a number of competing or complementary mechanisms that are responsible for locally regulating the vessel tone. These local factors include bloodborne factors, tissue released factors and factors released from the autonomic system. They combine to ensure that the blood flow to the tissue is matched to the metabolic requirements. This integration of total blood flow is known to be achieved by the continuous and dynamic interplay between many regulatory factors, including factors emanating from the blood, the endothelial and smooth muscle cells of the vessel walls, the surrounding metabolizing tissue and the input pressure.

The vascular endothelium is a vital component of vascular regulation. It consists of a monolayer of thin squamous cells, which line the inside surface of blood vessels. One intracellular structure implicated in sensing external changes and mediating the output of the huge array of autocoids known to change smooth muscle cell response is the cytoskeleton. The cytoskeleton gives the cell its shape as well as mediating the transmission of intracellular signalling. The response of the endothelium to shear stresses associated with local blood flow is another important mechanism for regulation of blood flow. The vascular endothelium in the retina is considered as the major component of blood–retinal barrier, which is a highly specialized structural, transport and biochemical barrier. It regulates the entry of compounds and cells between blood and retinal tissue, plays a fundamental role in retinal homeostasis and also forms a route of communication between circulating blood and underlying retinal tissues. Much of the structural barrier is due to the presence of tight junctions between the vascular endothelial cells. These junctions can be regulated, affected by disease states and can also be manipulated therapeutically.

1.4.1 Macula Blood Supply from the Retinal Circulation

Like most regions of the retina, the macula has dual supplies from both the retinal and choroidal circulations. However, there is a unique pattern of retinal vasculature in the macular area. Figure 1.3a shows a low magnification projected confocal image from the macula region of the left eye from a human donor eye [24]. The area imaged covers the foveola, fovea and parafovea regions indicated by three concentric circles superimposed on the vascular network. The microvasculature network distribution appears random; however, some common properties in topographic distributions can be identified in most normal subjects. An arteriole is easily differentiated from a venule by its thicker wall with stronger stain and a circular pattern of smooth muscle cells (Fig. 1.3b) [24]. It is also notable that the capillary free zone along the arteriole is less apparent around the macular region than that in the peripheral retina as previously reported [25]. There is a one-to-one relationship between a relatively large arteriole and a venule, the two being connected by a capillary plexus without

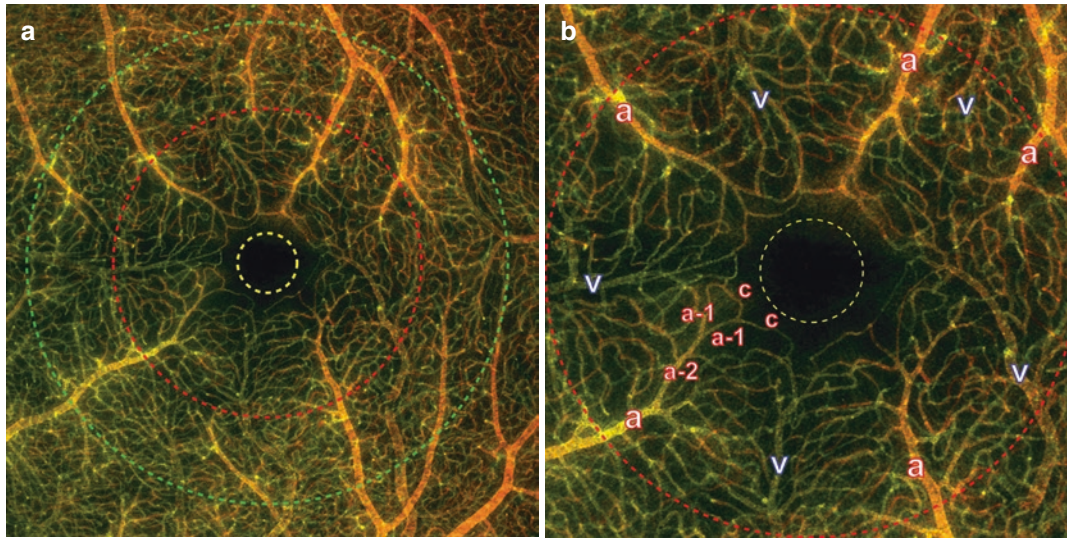

Fig. 1.3 Confocal images of retinal microvasculature at the macular region obtained from a donor eye after perfusion staining labelled for filamentous actin. The foveola, fovea and parafovea regions are indicated by three concentric circles (yellow, red and green, respectively). Capillary density in the foveal region is less than that in the parafoveal region.
A higher magnification image of the foveal region from figure (**a**) showing arterioles (**a**), venules (v) and the subsequent branching of the retinal arteriole into smaller arterioles (a-2 and a-1) and capillaries (**c**). Two capillaries (**c**) join together to form a first-order arteriole (a-1), and two a-1 arterioles join together to form a second-order arteriole (a-2). The capillaries branching off the retinal arterioles are predominantly in the superficial half of the image stack (red pseudocolour) before connecting to the capillaries draining towards the retinal venules lying in the deeper half of the stack (green pseudocolour). Foveolar area is located in the avascular region. Only a few pairs of arterioles and venules enter the foveal region [24]

shunt pathways that are present in other microcirculatory systems [1]. There are no arteriolar–venular shunts or connections between macular venules in the macular area. No evidence was found of a capillary arcade system as seen in peripheral retinal vessels suggesting that there is no bypass between the macular arterioles and venules or connections between pairs of arterioles or venules [26, 27]. Therefore the haemodynamics of the macular vasculature appears to be mainly determined by the branching structures. Numerous pairs (~9) of arterioles and venules are found in the macular area arranged in a radial pattern surrounding the foveola. Only a few arterioles (~3–4) enter the foveal region where they directly supply the terminal capillary ring (Fig. 1.3b). The avascular region is surrounded by terminal capillaries forming a terminal capillary ring which often has an irregular oval shape with a diameter of ~360 μm vertically and ~ 410 μm horizontally. In addition to these unique macular vascular patterns and distributions, the vascular tree distribution of individual vessel is also interesting. The topological description of vascular trees has been proposed by the Horton–Strahler and generation nomenclatures. The Horton–Strahler approach starts at the capillary level and proceeds centripetally. The order is increased if two segments of equal order join at a bifurcation. The generation (centrifugal) scheme starts from the most central vessel considered and proceeds to the capillary level, increasing the generation by one at every branch point. Figure 1.3b shows arterioles, venules and the subsequent branching of the retinal arteriole into smaller arterioles (a-2 and a-1) and capillaries (c). Two capillaries (c) join together to form a first-order arteriole (a-1), and two a-1 arterioles join together to form a second order arteriole (a-2). The capillaries branching off the retinal arterioles are predominantly in the superficial half of the image stack (red pseudocolour) before connecting to the capillaries draining towards the retinal venules lying in the deeper half of the

stack (green pseudocolour). The retinal arteriole traversed the parafoveal region before entering the foveal region (starting from top to the bottom of this image), and stop short of the foveola. It is also evident that there are many bifurcations from each arteriole or venule indicating that many generations are present in a short segment length. Some arterioles and venules only reach the parafoveal or perifoveal region. Higher order arterioles give off twigs of smaller branches of capillaries and arterioles which further bifurcate to form the capillary networks before converging to the venules. The number of vessel generations in the macular area imaged is ~12 and there are ~4 different orders of the vessel. A significant asymmetry exists between the order and generation counts of vessels in the macular region.

1.4.2 Macular Blood Supply from the Choroidal Circulation

The choroid is composed of various sized blood vessels surrounded by melanocytes, nerves and connective tissue. The macular choroid has an abundant blood supply and almost all temporal short posterior ciliary arteries supply the choroid in the macular region [28]. The macular choroid is much thicker than in other parts of the choroid. The choriocapillaris is thickest along with greatest density in the macular region [29]. Figure 1.4a shows a choroidal section from a human donor eye. The choroid can be divided into three parts from internal to external: (1) Bruch's membrane; (2) the vascular layers and (3) the suprachoroid (Fig. 1.4a). The inner boundary of the choroid is formed by Bruch's membrane, a thin layer derived in part from the retinal pigment epithelium and the choriocapillaris. Large- and medium-sized choroidal arteries and veins with increasing luminal diameters from internal to external can be found in the macular region. The innermost layer is capillaries (the choriocapillaris), the middle layer and the outer layer are medium-sized vessels and large vessels, respectively (Fig. 1.4a). Arterioles and venules join the choriocapillaris either obliquely or at right angles. There are no capillaries in the deeper layers of the choroidal stroma or the suprachoroidal lamellae. The melanocytes are mostly distributed in the outer layers of the choroid.

It is also important to appreciate that the posterior ciliary arteries and choroidal arteries are end arteries. Choroidal blood circulation has strictly segmental distribution without anastomoses between the adjacent segments at any level [28]. The border between the territories supplied by any two end arteries is called a watershed zone, in which actual perfusion flow could be relatively poor and vulnerable to ischemia. The location of the watershed zones is critical. Watershed regions between the posterior ciliary arteries could be crucial in ischemic disorders of the optic nerve head and the location of multiple watershed zones of the short posterior ciliary arteries in the macular choroid may play a role in macular ischemic lesions.

There is significant disagreement regarding the appearance and organization of the choroidal vasculature, particularly of the choriocapillaris. In fact, variation in the pattern of choroidal vasculature is great within different areas of the same eye and in eyes from different individuals. The choriocapillaris appears as a single layer of broad, wide capillaries lying in a plane just external to Bruch's membrane. Figure 1.4b shows a confocal image of choriocapillaris plane from a human donor eye. A high density of choriocapillaris is found in the macular region providing a large surface area for metabolic exchange. The capillaries appear as a continuous meshwork with irregular shape and sized channels separated by small columns or septa. These columns are formed by choroidal stroma tissues covered by endothelial cells.

The anatomy and function of the choroidal lobuli have been extensively studied; however, the controversy regarding the choroidal angioarchitecture is not yet settled. Fluorescein angiographic studies have shown that each terminal choroidal arteriole supplies an independent lobule of choriocapillaris, with the arteriole joining the segment in its centre and the draining venules lying around the periphery of this lobule. Each lobule of the choriocapillaris is an independent unit with no anastomosis with the adjacent

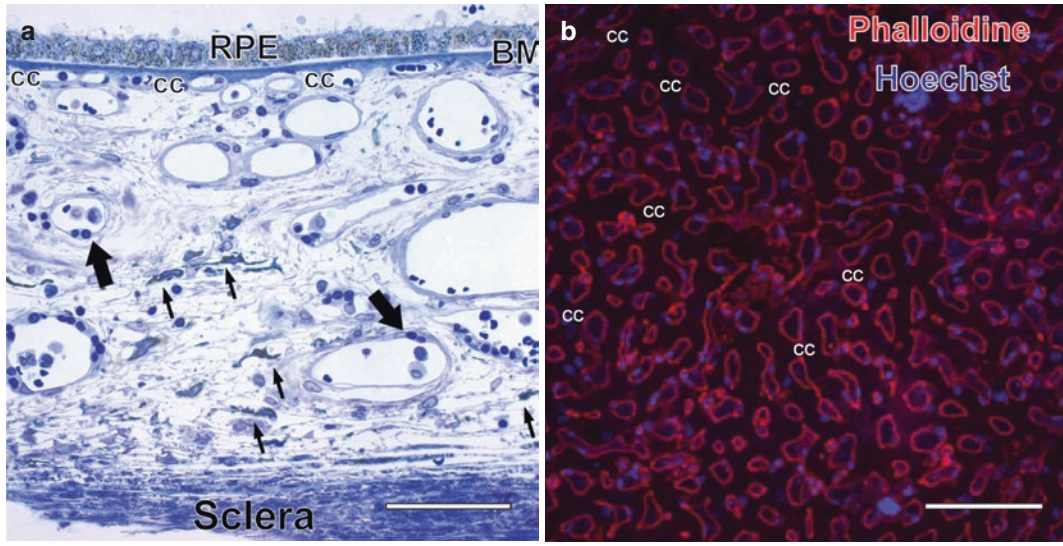

Fig. 1.4 Choroidal vasculature. (**a**) Histological section of the choroid from a human donor eye: The layers of medium and large choroidal vessels thicken the choroid in the macular region. The inner boundary of the choroid is formed by Bruch's membrane (BM), a thin layer which is derived in part from the retinal pigment epithelium (RPE) and the choriocapillaris (cc). Choriocapillaris only occupy a small proportion of the thickness of the choroid in the macular region. Outer choroid consists of multiple layered large- and medium-sized choroidal vessels (large arrows) surrounded by connective tissues and melanocytes (small arrows). Suprachoroidal space is located between the choroid and sclera. Scale bar = 100 μm. (**b**) Confocal image from the choriocapillaris from a human donor eye. The post-mortem eye was intravascularly perfused, fixed and stained with phalloidine (red for endothelium) and Hoechst (blue for nuclei). The choroidal stroma tissue is surrounded by endothelium appeared as numerous small columns. Choriocapillaris (cc) appear to be spaces between these islands. Scale bar = 100 μm [24, 25]

segments in vivo [28]. Reports from vascular casting and scanning electron microscopy studies have shown that collecting venules were found in the centre of 86% of the lobules as anatomic lobules, whilst a central feeding arteriole was observed in 14% as functional lobules [30].

Some histological features of the choriocapillaris are important [31]. The choriocapillaris in the macular region consists of a layer of fenestrated endothelial cells surrounded by a basement membrane similar to other regions of the choroid. The fenestrations are abundant and evenly distributed on the inner wall of the capillaries. The circular fenestrations are ~60–80 nm in diameter with a central thickening of 30 nm of cytoplasm permitting the passage of glucose and lipid-soluble molecules such as vitamin A to the RPE and retina. The nuclei of the endothelial cells are usually located on the external side of the capillaries. The cytoplasm of the choroidal side often contains mitochondria, endoplasmic reticulum, free ribonucleic particles and some pinocytotic vesicles. Pericytes are occasionally found in the external wall of the capillaries. There are some discontinuous tight junctions of the endothelial cells. Collagen from Bruch's membrane may extend down into the intervascular columns or septa which may help to hold the capillaries open.

1.5 Vitreal Anatomy and Its Relevance to the Macular Microenvironment

The vitreous has a gel-like structure which occupies four-fifths of the total eye volume. It is well known that it provides support for the ocular tissues and assists in the maintenance of the intraocular pressure and also acts as an optical medium to transmit the light to the retina. The roles of vitreous in providing a passageway for

metabolites utilized by the posterior lens and the retina are important in maintaining the homeostatic environment of the retina. These issues need to be considered following vitrectomy and other interventions that are extensively used in the management of retinal and macular diseases. These interventions unavoidably change the intraocular environment which could be beneficial or harmful in different circumstances.

1.5.1 Vitreal Anatomy and Biochemistry

Human vitreous volume is about 4 ml, containing 99% water. The viscosity of the gel-like vitreous varies regionally, being greater in the cortex than in the central part. Normal vitreous is many times more viscous than water (more than 300 times) [32]. A filtrate of the vitreous contains considerable hyaluronic acid and other colloidal material, but the viscosity is reduced to only ~twice that of water. The osmotic pressure of vitreous filtrate is close to that of the aqueous humour. The pH of normal vitreous is about 7.5.

The vitreous body has two distinct phases: the liquid vitreous humour and the solid residual protein. The residual protein is mainly collagen which is responsible for the gel-like state. There is a relatively high amount of collagen in the vitreous cortex, particularly in the vitreous base around the ora serrata. The liquid phase of vitreous humour contains a mucopolysaccharide called hyaluronic acid which is formed into long chains, arranged in a coil-like structure enclosing a relatively large amount of water.

The chemical composition of the vitreous humour is similar to that of the aqueous humour, except for the collagen and hyaluronic acid. In different parts of the vitreous concentration gradients of some substances are present. These substances may be utilized by the lens and retina. Glucose concentration in the vitreous is lower than plasma, but higher than in the aqueous. It is possible that glucose enters the vitreous mainly from the retina. Glucose level is higher in the anterior than in the posterior vitreous, as are sodium and potassium levels. The blood–vitreous barrier plays a role in regulating the entrance of blood proteins into the vitreous.

Movement of substances through the vitreous is interesting. It has been demonstrated that many substances leaving the vitreous probably exit by more than one mechanism and pathway. Usually substances with large molecules reach a steady state slowly in the vitreous, probably because diffusion is a slow process and because of the special organization of the collagen and hyaluronic acid in the cortex, which may act as a molecular sieve. The concentration of soluble protein is higher in the vitreous cortex, a finding that suggests the origin of these proteins from the adjacent tissues. The content of the acidic glycoproteins amongst these soluble proteins is also very high.

The vitreous can be divided into five components, anterior hyaloid, posterior hyaloid, cortex, central vitreous and vitreous cells [1]. The collagen fibrils and their enclosed elements have been found in the anterior hyaloid and arranged in sheet-like aggregates parallel to the surface of the eye. The laminar appearance is greatest in the pars plana region, particularly in the peripheral portion, where the zonular fibres are observed. Slightly posterior to the vitreous base, the fibrils form very thin layers along the inner retina that gradually move away from the retina towards the central vitreous. Posterior to the equator the vitreous continues to be closely identified with the inner limiting membrane of the retina. Some vitreous fibrils insert into the basement membrane of the Muller and glial cells of the retina. The cortex is approximately 100 μm thick and includes the anterior and posterior hyaloid. It circumscribes the entire vitreous body, being formed by a condensation of collagen fibrils, cells, proteins and mucopolysaccharide in the interfibrillar spaces.

The vitreous has also been described as tract structures with their corresponding circular zonular ligaments [33]. Figure 1.5 illustrates the five major tracts in the normal vitreous. These tracts have their corresponding attached ligaments including: (1) the ora serrata and the preretinal tract, (2) the posterior epiciliary ligament and the posterior ciliary tract, (3) the anterior epiciliary

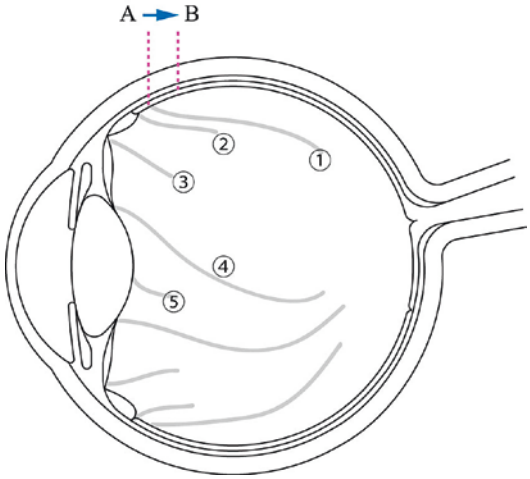

Fig. 1.5 The vitreous tracts in the normal vitreous. Five major tracts are shown in the schematic drawing: ① the preretinal tract, ② posterior ciliary tract, ③ the anterior ciliary tract, ④ the retrolental tract and ⑤ the area hyaloidea. The vitreous tracts are attached to their corresponding zonular ligaments. The vitreous base is located between the preretinal tract and posterior ciliary tract which is relatively invariable. However, the posterior vitreous base could be variable with age. In aged subjects, it may be moved from A towards B

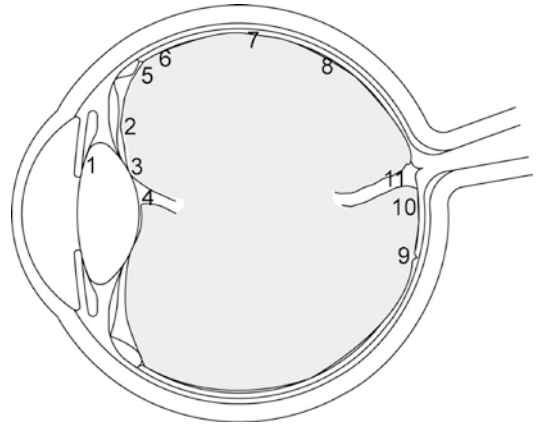

Fig. 1.6 A schematic outline of major vitreous body attachments including (*1*) orbiculo-anterior zonular fibres to the lens; (*2*) orbiculo-posterior zonular fibres to the lens; (*3*) anterior vitreous face to the posterior lens capsule; (*4*) anterior extremity of canal of Cloquet; (*5*) vitreous base to mid pars plana (origin of vitreous face); (*6*) region of vitreous base; (*7*) region of diminishing adherence of vitreous base to the retinal surface; (*8*) vitreous–retinal attachments; (*9*) vitreous–retinal attachment in the fovea centralis; (*10*) attachment of posterior vitreous around the optic disc; (*11*) posterior extremity of canal of Cloquet (area Martegiani)

ligament and anterior ciliary tract, (4) the retrolental ligament and retrolental tract and (5) the area hyaloidea [33]. The vitreous base is the region in which the vitreous is solidly attached. It plays an important role in inducing clinical complications when iatrogenically affected during surgery or trauma. The vitreous base can be divided into two parts: anterior and posterior vitreous base. The anterior vitreous base is located from the ora serrata and preretinal tract to the posterior ciliary tract which is invariable, whilst the posterior vitreous base is variable and may only be identified after posterior vitreous detachment in elderly subjects. Different appearances of the vitreoretinal detachment can be caused by changes in vitreo-retinal adhesions.

In addition to attachment in the vitreous base, the vitreous is also attached to the retina in the peripapillary region through a narrow zone and several other locations shown in Fig. 1.6 [34]. With ageing, this attachment could be weaker. The cortex in the peripapillary attachment has more fibrils which are towards the basement membrane of the retinal Muller cells.

1.5.2 Vitreous and Its Interface with the Retina and Macula

It is well known that the vitreous plays an important role in maintaining the functional and structural stability of the retina and macula. Changes in vitreous properties either anteriorly or posteriorly can potentially cause problems for the retina and macula, which may or may not be evident clinically. However, we need to know how to predict and how to avoid the possible complications in the retina if possible.

The anterior vitreous membrane, particularly the thin vitreolenticular part, could be damaged during cataract surgery or trauma resulting in rhegmatogenous retinal detachment and/or cystoid macular oedema. Damage to the vitreolenticular barrier in the anterior vitreous may have repercussions on the vitreoretinal zone in the posterior vitreous and may cause either a volume shift or a chemical transfer. The volume shifting anteriorly may induce posterior vitreous detachment which exposes vitreoretinal adhesion. Chemical transfer may cause a movement of the substances between

the vitreous and the anterior chamber. It is undoubtedly true that the vitreous base – its posterior retinal part – plays the most important role in inducing clinical complications in the posterior segment when iatrogenically affected during surgery or trauma. This region of the eye is usually not visible without indentation. It is the most peripheral zone of the retina, the ora serrata, the posterior ciliary body and the vitreous base.

There are two types of posterior vitreous detachments: rhegmatogenous and non-rhegmatogenous vitreous detachment. Rhegmatogenous posterior vitreous detachment often occurs in the elderly and liquefied vitreous may pass through the hole into the retrovitreal space. During this process, retinal horseshoe holes may occur at the site of vitreoretinal adhesions. In a non-rhegmatogenous posterior vitreous detachment, volume transfer is a relatively slow process without hole formation, leading to a partial posterior vitreous detachment at least in the initial stage. It may induce cystoid macular oedema rather than a retinal hole. The consequence of the posterior vitreous detachment is that retina could be exposed to direct vitreous traction without stable vitreous cortex shielding. However, the traction affecting the retina and leading to the retinal detachment does not occur by the vitreous tract but by the posterior hyaloid membrane [31]. It is likely no further tearing will occur if complete posterior vitreous detachment is present.

1.6 Summary

This chapter mainly describes the anatomy and histology of the macula relevant to macular function. Macular cellular structure is highly dependent on the different regions, foveola, fovea, parafovea and perifovea. Blood supply from the retinal circulation and choroidal circulations is well matched to the demands of these regions but also determined by the functional requirements of high visual acuity. The human macula is very well structured in order to achieve the best vision. In addition, the vitreous has a very close relationship with the macula playing critical roles in stabilizing the microenvironment of the macula. However, macular homeostasis depends on sophisticated specific arrangement of neuronal cells and blood supply. Knowledge of macular anatomy and histology is essential for understanding macular function and management of macular diseases.

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