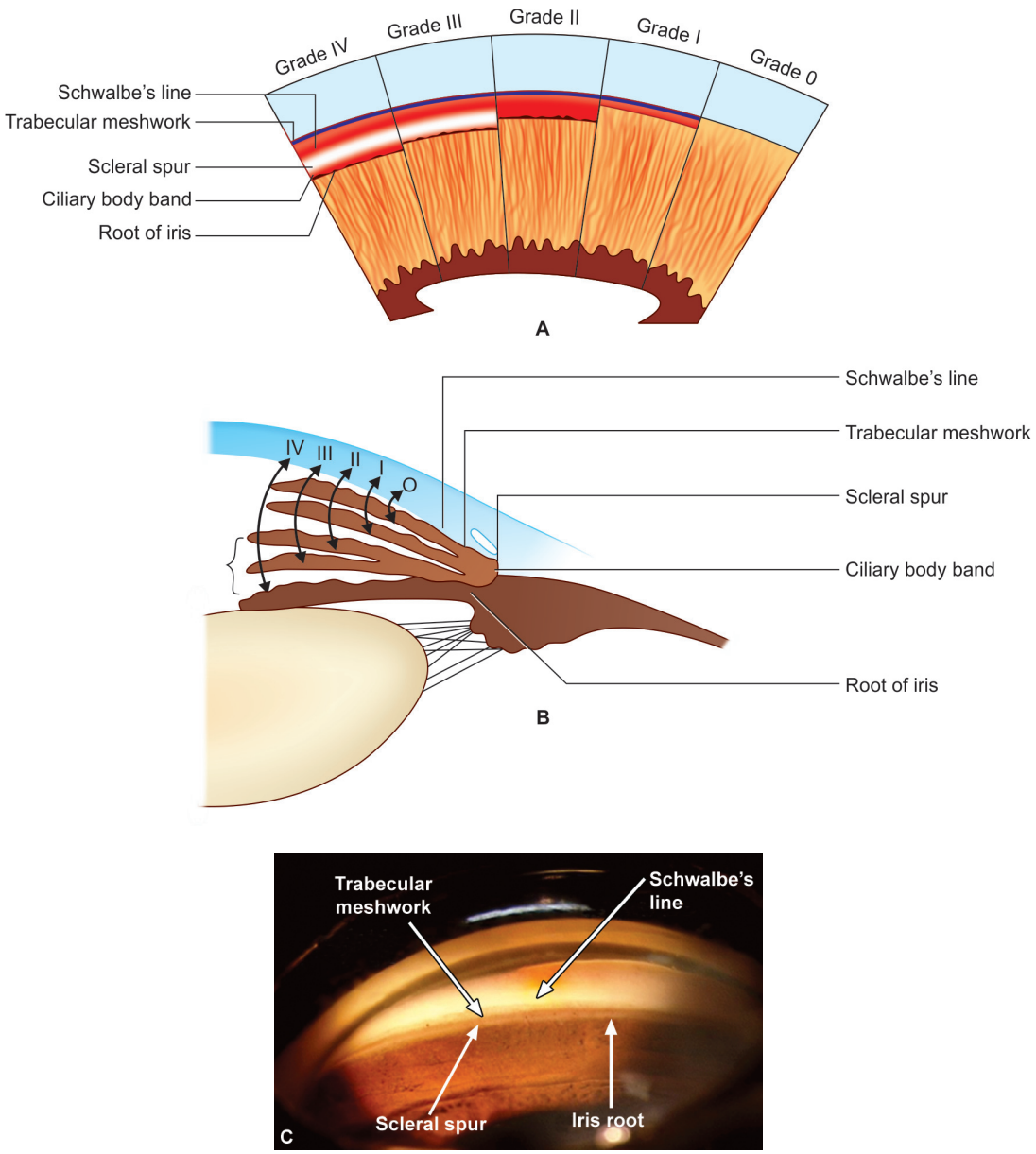

Fig. 2.6 *Depiction of various angle structures as seen in different grades of angle width (Shaffer's grading system): (A) Structures forming angle recess; (B) configuration of the angle in cross-section of anterior chamber; (C) Gonioscopic view.*

anterior chamber. It usually lies in the plane of the posterior corneal surface, but in 15–20% of normal subjects, it may be variably hypertrophied and project as a delicate, glistening ridge into the anterior chamber (posterior embryotoxon).

Gonioscopic grading of the angle width

Various systems have been suggested to grade the angle width. The most commonly used is modified Shaffer's system of grading. The grading of angle width is given in Table 2.1 and is shown diagrammatically in Fig. 2.6.

Ultrafiltration accounts for 20% and osmosis 10%. The various constituents of the aqueous humour reach the posterior chamber from the plasma within the capillary network of ciliary processes as follows:

1. Formation of stromal pool

It is the first step in the formation of aqueous. By ultrafiltration, most substances pass easily from the capillaries of the ciliary processes, across the stroma and between the pigmented epithelium cells before accumulating behind the tight junctions of the non-pigmented epithelium. Protein is to be expected in the filtrate because of the fenestrated nature of the ciliary capillaries.

2. Active transport of stromal filtrates

The tight junctions between the non-pigmented epithelial cells create part of blood–aqueous barrier. Evidence of active transport occurring across these non-pigmented epithelial cells, especially in the cell membrane of the lateral interdigitations, comes from observations of the following in these areas:

- Abundant Na^+–K^+-active ATPase,
- Presence of more mitochondria,
- Higher adenyl cyclase activity,
- Higher specific activity for glycolytic enzymes, and
- Preferential incorporation of labelled sulphate into macromolecules (primarily glycolipids and glycoproteins).

Until recently, active aqueous secretion was thought to be carried out solely by the mitochondria rich non-pigmented epithelium as described above. However, recent studies have shown that the pigmented epithelium also plays an active role in the aqueous production. The basolateral membranes of the pigmented epithelial cells contain numerous Na^+ ion dependent cotransporters and exchangers (Fig. 2.12) and carbonic anhydrase activity is also present in these cells. The net effect of these ion transport systems is a low level of Na^+ in both epithelial layers (facilitated by numerous gap junctions between the pigmented and non-pigmented cells), a high level of ascorbate and K^+, and control of intracellular pH.

Following substances from the stromal filtrate are actively transported across epithelial cells:

- *Sodium:* Approximately 70% of the sodium found in the posterior chamber is actively transported by a specific secretory pump. Remaining 30% enters the posterior chamber by diffusion or ultrafiltration. The active transport of sodium is ATPase-dependent but does not appear to be related to the concentration of sodium in plasma.

  Whether carbonic anhydrase works on the sodium pump as a facilitator, as a catalyst or as part of a parallel but related process remains to be demonstrated. It is possible that carbonic anhydrase acts to maintain the proper pH for the Na^+–K^+-ATPase system.
- *Chloride:* A smaller percentage of the chloride ion is actively transported and this appears to be dependent upon the presence of sodium as well as pH. The remaining amount of Cl^- enters into lateral intercellular space by diffusion.
- *Potassium* is transported by secretion and diffusion.
- *Ascorbic acid* is secreted against a large concentration gradient.
- *Amino acids* are secreted by at least three carriers, one each for acidic, basic and neutral molecules.
- *Bicarbonate:* Its formation is catalysed by carbonic anhydrase. The rapid interconversion between bicarbonate and CO_2 makes it difficult to determine the relative proportions of these two substances. It influences fluid transport through its effect on sodium, possibly by regulating the pH for optimum active transport of sodium.

3. Passive transport across non-pigmented ciliary epithelium

Active transport of the substances as described above, across the non-pigmented ciliary epithelium results in an osmotic and electrical gradient. To maintain the balance of osmotic and electrical forces, water, chloride and other small plasma constituents move into the posterior chamber by ultrafiltration and diffusion; sodium is primarily responsible for movement of water into the posterior chamber and its secretion is a

3. Suction cup method

This method is no better than tonography and so not used clinically. In this technique, a suction cup is applied to the perilimbal area, which occludes the episcleral vein and thus, trabecular outflow from the eye, and results in rise of IOP. After the suction cup is removed, the rate of return to normal IOP is noted. The faster the return to baseline IOP, the greater the outflow facility; and conversely, the slower the return to baseline, the lower the outflow facility.

INTRAOCULAR PRESSURE

GENERAL CONSIDERATIONS

Features of normal intraocular pressure

Intraocular pressure refers to the pressure exerted by intraocular contents on the coats of the eyeball. The normal level of IOP is essentially maintained by a dynamic equilibrium between the aqueous humour formation, aqueous humour outflow, and episcleral venous pressure. IOP is distributed evenly throughout the eye, so that the pressure is always the same in the posterior vitreous as it is in the aqueous humour. The intraocular pressure is important in maintaining the shape of the eyeball and thus also the optical integrity.

- Normal IOP varies between 10.5 and 20.5 mm Hg with a mean pressure of 15.5 ± 2.57 mm Hg.
- IOP is created by aqueous formation which has two components: First, a hydrostatic component from the arterial blood pressure and ciliary body tissue pressure, and second, an osmotic pressure induced by the active secretion of sodium and other ions by the ciliary epithelium.
- IOP serves as the tissue pressure of the vascularized internal structures of the eye, and is thus, much higher than the tissue pressure elsewhere in the body (5 mm Hg).
- Normal IOP is pulsatile, reflecting in part its vascular origin and the effects of blood flow on the internal ocular structures.

The IOP is a dynamic function. Any single measurement of IOP is just a momentary sample and may or may not reflect the average pressure for the patient in that hour, day or week.

Frequency distribution of IOP in the population

Several population-based studies have been done to comment upon the frequency distribution of the normal IOP. Despite the use of different instruments and differing ethnic groups, the studies show remarkably close correlation. The most frequently cited population study is that of Leydhecker and associates, in which 10,000 persons with no known eye disease were tested with Schiotz tonometer. The conclusions drawn from the study regarding frequency distribution of IOP in the population are as follows:

- The distribution of pressures observed resembled a Gaussian curve, but was skewed towards the right (Fig. 2.16).
- It has been assumed that perhaps two different population groups account for the skewed distribution: a large 'normal' group (having a true Gaussian-shaped curve) and a smaller group that was felt to be glaucomatous without optic nerve head damage (causing a long tail on the right hand side of the distribution curve).
- The mean IOP of normal group was 15.5 ± 2.57 mm Hg.
- 95% of the population had an IOP between 10.5 and 20.5 mm Hg.
- If one chooses a point 2 SD above the mean as the upper limit of normal (about 20.5 mm Hg),

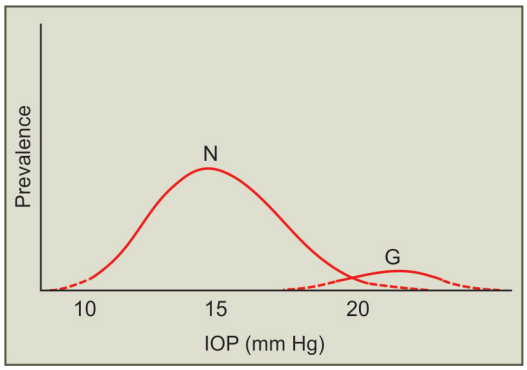

Fig. 2.16 *Distribution of intraocular pressure in non-glaucomatous (N) and glaucoma (G) populations, showing overlap between the two groups (dotted lines represent uncertainty of extreme value in both populations*

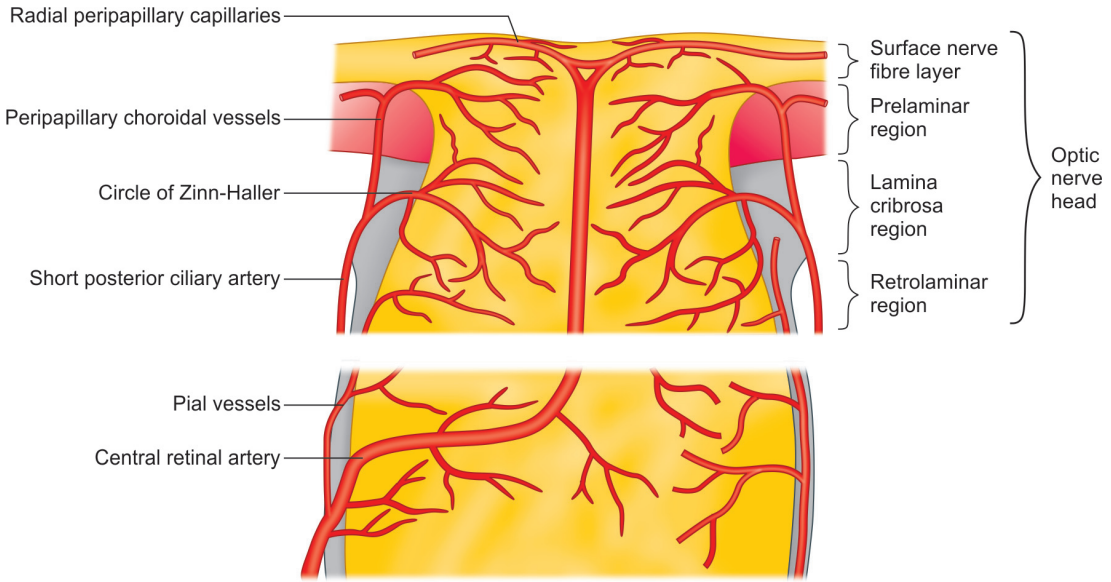

Fig. 3.5 *Blood supply of the optic nerve head*

whether these vessels are derived primarily from the peripapillary choroidal system or from separate branches of the short posterior ciliary arteries.

- *The lamina cribrosa region* is also supplied by the ciliary vessels which are derived from the short posterior ciliary arteries and arterial circle of Zinn-Haller.
- *The retrolaminar region* is supplied by both the ciliary and retinal circulations with the former coming from recurrent pial vessels. The central retinal artery provides centripetal branches from the pial plexus and also centrifugal branches.

Capillaries

Although derived from both the retinal and ciliary circulations, the capillaries of the optic nerve head resemble more closely the features of retinal capillaries than of the choriocapillaries. These characteristics include:

- Tight junctions,
- Abundant pericytes, and
- Non-fenestrated endothelium

They represent a *blood–nerve barrier*. The capillaries decrease in number posterior to the lamina, especially along the margins of the larger vessels.

The rich capillary beds of each of the 4 anatomic regions within the anterior optic nerve are anatomically confluent.

Venous drainage

The venous drainage from the optic nerve head is almost entirely through the central retinal vein, although a small portion may occur through the choroidal system. Occasionally, these communications are enlarged as *retinociliary veins*, which drain from the retina to the choroidal circulation, or *cilio-optic veins*, which drain from the choroid to the central retinal vein.

PATHOPHYSIOLOGY OF GLAUCOMATOUS OPTIC NEUROPATHY

The pathogenesis of glaucomatous optic atrophy has remained a matter of controversy since the mid-19th century. In 1858, Müller proposed that the elevated IOP led to direct compression and death of the neurons. The same year, von Jaeger suggested that a vascular abnormality was the underlying cause of the optic atrophy. In 1892, Schnabel proposed another concept in the pathogenesis, suggesting that atrophy of neural