Basics for Clinical Veterinary Ophthalmology

Development of the Eye

Revised from "Ocular Embryology and Congenital Malformations," by Cynthia S. Cook, in Kirk N. Gelatt *et al.*, eds., *Veterinary Ophthalmology*, Fifth Edition.

Ocular development has been investigated in some detail in rodents, the dog, and the cow, and demonstrates the sequence of developmental events is very similar across species. When comparing these studies, one should consider differences in duration of gestation, differences in anatomic end point (e.g., presence of a tapetum, macula, or Schlemm's canal), and when eyelid fusion breaks (during the sixth month of gestation in the human versus 2 weeks postnatally in the dog) (Tables 1.1 and 1.2).

Gastrulation and Neurulation

Cellular mitosis following fertilization results in transformation of the single-cell zygote into a cluster of 12–16 cells. With continued cellular proliferation, this morula becomes a blastocyst, containing a fluid-filled cavity. The cells of the blastocyst will form both the embryo proper and the extraembryonic tissues (i.e., amnion and chorion). At this early stage, the embryo is a bilaminar disc, consisting of hypoblast and epiblast. This embryonic tissue divides the blastocyst space into the amniotic cavity (adjacent to the epiblast) and the yolk sac (adjacent to the hypoblast).

Gastrulation (formation of the mesodermal germ layer) begins during day 10 of gestation in the dog (day 7 in the mouse; days 15–20 in the human). The primitive streak forms as a longitudinal groove within the epiblast (i.e., future ectoderm). Epiblast cells migrate toward the primitive streak, where they invaginate to form the mesoderm. This forms the three classic germ layers: ectoderm, mesoderm, and endoderm. **Gastrulation proceeds in a cranial-to-caudal progression; simultaneously, the cranial surface ectoderm proliferates, forming bilateral elevations called the neural folds (i.e., future brain).** The columnar surface ectoderm in this area now becomes known as the neural ectoderm.

As the neural folds elevate and approach each other, a specialized population of mesenchymal cells, the neural crest, emigrates from the neural ectoderm at its junction with the surface ectoderm. Migration and differentiation of the neural crest cells are influenced by the hyaluronic acid-rich extracellular matrix. This acellular matrix is secreted by the surface epithelium as well as by the crest cells, and it forms a space through which the crest cells migrate. The neural crest cells migrate peripherally beneath the surface ectoderm to spread throughout the embryo, populating the region around the optic vesicle and ultimately giving rise to nearly all the connective tissue structures of the eye (Table 1.3).

It is important to note that *mesenchyme* is a general term for any embryonic connective tissue.

Essentials of Veterinary Ophthalmology, Third Edition. Edited by Kirk N. Gelatt.

Companion website: www.wiley.com/go/gelatt/essentials3

Table 1.1. Sequence of Ocular Development in the Human, Mouse, and Dog

Human (approximate post-fertilization age)			*Mouse (day post-fertilization)*	*Dog (day post-fertilization or P = postnatal day)*	*Developmental events*
Month	***Week***	***Day***			
1	3	22	8	13	Optic sulci present in forebrain
	4	24	9	15	Optic sulci convert into optic vesicles
			10	17	Optic vesicle contacts surface epithelium Lens placode begins to thicken
		26			Optic vesicle surrounded by neural crest mesenchyme
2	5	28	10.5		Optic vesicle begins to invaginate, forming optic cup Lens pit forms as lens placode invaginates Retinal primordium thickens, marginal zone present
		32	11	19	Optic vesicle invaginated to form optic cup Optic fissure delineated Retinal primordium consists of external limiting membrane, proliferative zone, primitive zone, marginal zone, and internal limiting membrane Oculomotor nerve present
		33	11.5	25	Pigment in outer layer of optic cup Hyaloid artery enters through the optic cup Lens vesicle separated from surface ectoderm Retina: inner marginal and outer nuclear zones
			11.5	29	Basement membrane of surface ectoderm intact Primary lens fibers form Trochlear and abducens nerves appear Lid fold present
	6	37	12		Edges of optic fissure in contact
			12	30	Tunica vasculosa lentis present Lens vesicle cavity obliterated Ciliary ganglion present
		41	12	32	Posterior retina consists of nerve fiber layer, inner neuroblastic layer, transient fiber layer of Chievitz, proliferative zone, outer neuroblastic layer, and external limiting membrane
			17	32	Eyelids fuse (dog)
	7				Anterior chamber beginning to form
			12.5	40	Secondary lens fibers present
		48	14	32	Corneal endothelium differentiated
	8	51			Optic nerve fibers reach the brain Optic stalk cavity is obliterated Lens sutures appear Acellular corneal stroma present
		54		30–35	Scleral condensation present
	9	57	17	40 –	First indication of ciliary processes and iris Extraocular muscles visible Eyelids fuse (occurs earlier in the dog)
	10			45	Pigment visible in iris stroma Ciliary processes touch lens equator Rudimentary rods and cones appear
				45–1P	Hyaloid artery begins to atrophy to the disc

Table 1.1. (*Continued*)

Human (approximate post-fertilization age)			***Mouse (day post-fertilization)***	***Dog (day post-fertilization or P = postnatal day)***	***Developmental events***
Month	***Week***	***Day***			
3	12			–	Branches of the central retinal artery form
4				51	Pupillary sphincter differentiates Retinal vessels present
—				56	Ciliary muscle appears
				–	Tapetum present (dog)
5				40	Layers of the choroid are complete with pigmentation
6				–	Eyelids begin to open, light perception
				1P	Pupillary dilator muscle present
7				1–14P	Pupillary membrane atrophies
				1–16P	Rod and cone inner and outer segments present in posterior retina
				10–13P	Pars plana distinct
9				16–40P	Retinal layers developed
				14P	Regression of pupillary membrane, tunica vasculosa lentis, and hyaloid artery nearly complete Lacrimal duct canalized

Table 1.2. Sequence of Ocular Development in the Cow

Ocular part or event	***Gestational size (mm)***	***Ocular part or event***	***Gestational size (mm)***
Lens		*Ciliary body*	
Optic vesicle	6	Ciliary processes	125
Lens placode	6	Ciliary processes touch lens equator	230
Optic cup and lens placode	10	Pars plana (distinct)	200
Separation of lens vesicle from surface ectoderm	10	Pars plana fully developed	410
Primary lens fibers	15	*Choroid*	
Lens vesicle cavity disappears	24	Choroidal net in posterior pole	33
Completion of lens capsule	50	Choroidal net throughout	50
Secondary lens fibers	58	Outermost large choroidal vessels	40
Perilenticular vascular mesoderm		Choriocapillaris	90
Extension of primary vitreous (hyaloid artery) to lens	15	Pigmentation of choroid	90
Tunica vasculosa lentis	33	*Retina – posterior third*	
Disappearance of posterior lenticular vascular network	410	Inner and outer nucleated zones	10
Disappearance of tunica vasculosa lentis	410	Multilayer outer cup of optic vesicle forms single cells	20
Iris		Nerve fiber layer	20
Major arterial circle of iris	90	Optic nerve well formed	24
Iris reaches front of lens	200	Inner/outer neuroblastic layers	14
Pigment in stroma	200	Transient layer of Chievitz	14
Sphincter muscle	410	Inner plexiform layer	180
Dilator muscle	410	Retinal vessels	180
		Tapetal cells	410

Table 1.3. Embryonic Origins of Ocular Tissues

Neural retina	Stroma of iris, ciliary body, choroid, and sclera
Retinal pigment epithelium	Ciliary muscles
Posterior iris epithelium	Corneal stroma and endothelium
Pupillary iris sphincter and dilator muscles	Perivascular connective tissue and smooth muscle cells
(Mammalian species)	Striated muscle cells in avian species
Bilayered ciliary epithelium	Meninges of optic nerve
	Orbital cartilage and bone
	Connective tissue of extrinsic ocular muscles
	Endothelium of the trabecular meshwork
Surface ectoderm	***Mesoderm***
Lens	Extraocular myoblasts
Corneal and conjunctival epithelium	Vascular endothelium
Lacrimal gland	Schlemm's canal (man)
	Posterior sclera (?)

Mesenchymal cells generally appear stellate and are actively migrating populations with extensive extracellular space. In contrast, the term *mesoderm* refers specifically to the middle embryonic germ layer. In the eye, mesoderm probably gives rise only to the striated myocytes of the extraocular muscles and vascular endothelium. Most of the craniofacial mesenchymal tissue comes from neural crest cells.

Formation of the Optic Vesicle and Optic Cup

The optic sulci are visible as paired evaginations of the forebrain neural ectoderm on day 13 of gestation in the dog (Figure 1.1). **The transformation from optic sulcus to optic vesicle is considered to occur concurrent with the closure of the neural tube (day 15 of gestation in the dog).** The optic vesicle enlarges and, covered by its own basal lamina, approaches the basal lamina underlying the surface ectoderm. The optic vesicle appears to play a significant role in the induction and size determination of the palpebral fissure and of the orbital and periocular structure. An external bulge indicating the presence of the enlarging optic vesicle can be seen at approximately day 17 of gestation in the dog.

The optic vesicle and optic stalk invaginate through differential growth and infolding. Local apical contraction and physiologic cell death have been identified during invagination. **The surface ectoderm in contact with the optic vesicle thickens to form the lens placode, which then invaginates with the underlying neural ectoderm. The invaginating neural ectoderm folds onto itself as the space within the optic vesicle collapses, thus creating a double layer of neural ectoderm, the optic cup.**

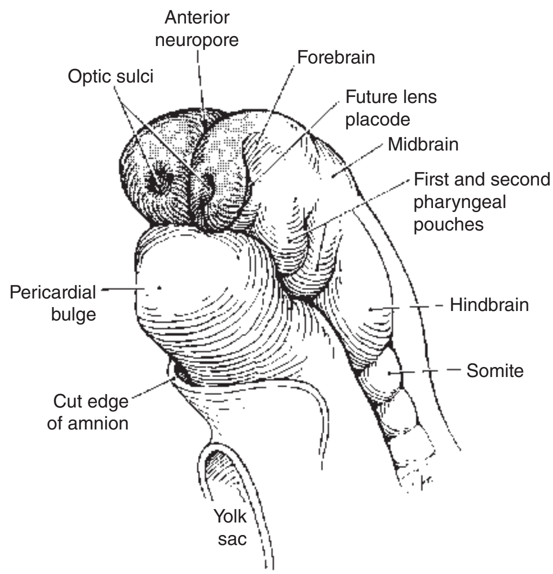

Figure 1.1. Development of the optic sulci, which are the first sign of eye development. Optic sulci on the inside of the forebrain vesicles consist of neural ectoderm (shaded cells). The optic sulci evaginate toward the surface ectoderm as the forebrain vesicles simultaneously rotate inward to fuse. (Source: Cook C, Sulik K, Wright K. Embryology. In: Wright KW and Spiegel PH, eds. *Pediatric Ophthalmology and Strabismus*. St. Louis: Mosby–Year Book, 2003:3–53. Reproduced with permission of Elsevier.)

This process of optic vesicle/lens placode invagination progresses from inferior to superior, so the sides of the optic cup and stalk meet inferiorly in an area called the optic (choroid/retinal) fissure. **Mesenchymal tissue (of primarily neural crest origin) surrounds and fills the optic cup, and by day 25 of gestation in the dog, the hyaloid artery develops from mesenchyme in the optic fissure. This artery courses from the optic stalk (i.e., the region of the future optic nerve) to the developing lens.** The two edges of the optic fissure meet and initially fuse anterior to the optic stalk, with fusion then progressing anteriorly and posteriorly. This process is mediated by glycosaminoglycan-induced adhesion between the two edges of the fissure. Apoptosis has been identified in the inferior optic cup prior to formation of the optic fissure and is, transiently, associated with its closure. Failure of this fissure to close normally may result in inferiorly located defects (i.e., colobomas) in the iris, choroid, or optic

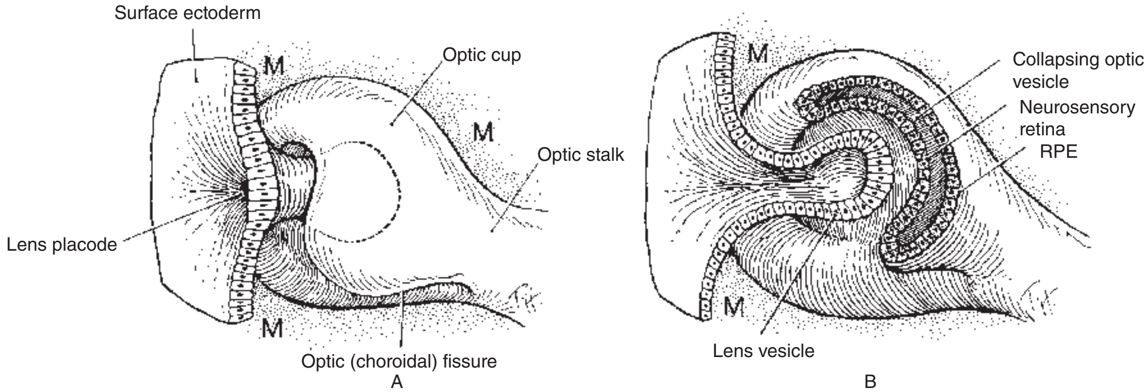

Figure 1.2. Formation of the lens vesicle and optic cup. Note that the optic fissure is present, because the optic cup is not yet fused inferiorly. (**A**) Formation of the lens vesicle and optic cup with inferior choroidal or optic fissure. Mesenchyme (M) surrounds the invaginating lens vesicle. (**B**) Surface ectoderm forms the lens vesicle with a hollow interior. Note that the optic cup and optic stalk are of surface ectoderm origin. RPE, retinal pigment epithelium. (Source: Cook C, Sulik K, Wright K. Embryology. In: Wright KW and Spiegel PH, eds. *Pediatric Ophthalmology and Strabismus*. St. Louis: Mosby–Year Book, 2003:3–53. Reproduced with permission of Elsevier.)

nerve. Colobomas other than those in the "typical" 6-o'clock location may occur through a different mechanism and are discussed later. **Closure of the optic cup through fusion of the optic fissure allows intraocular pressure (IOP) to be established.**

Lens Formation

Before contact with the optic vesicle, the surface ectoderm first becomes competent to respond to lens inducers. Inductive signals from the anterior neural plate give this area of ectoderm a "lens-forming bias." Signals from the optic vesicle are required for complete lens differentiation, and inhibitory signals from the cranial neural crest may suppress any residual lens-forming bias in head ectoderm adjacent to the lens. Adhesion between the optic vesicle and surface ectoderm exists, but there is no direct cell contact. The basement membranes of the optic vesicle and the surface ectoderm remain separate and intact throughout the contact period.

Thickening of the lens placode can be seen on day 17 of gestation in the dog. A tight, extracellular matrix-mediated adhesion between the optic vesicle and the surface ectoderm has been described. **This anchoring effect on the mitotically active ectoderm results in cell crowding and elongation, and the formation of a thickened placode.** This adhesion between the optic vesicle and lens placode also assures alignment of the lens and retina in the visual axis.

The lens placode invaginates, forming a hollow sphere, now referred to as a lens vesicle (Figures 1.2 and 1.3). The size of the lens vesicle is determined by the contact area of the optic vesicle with the surface ectoderm and by the ability of the latter tissue to respond to induction. **Aplasia may result from failure of lens induction or through later involutions of the lens vesicle, either before or after its separation from the surface ectoderm.**

Lens vesicle detachment is the initial event leading to formation of the chambers of the ocular anterior segment. This process is accompanied by active migration of epithelial cells out of the keratolenticular stalk, cellular necrosis, apoptosis, and basement membrane breakdown. Induction of a small lens vesicle that fails to undergo normal separation from the surface ectoderm is one of the characteristics of the teratogen-induced anterior segment dysgenesis described in animal models.

Following detachment from the surface ectoderm (day 25 of gestation in the dog), the lens vesicle is lined by a monolayer of cuboidal cells surrounded by a basal lamina, the future lens capsule. The primitive retina promotes primary lens fiber formation in the adjacent lens epithelial cells. Thus, while the retina develops independently of the lens, the lens appears to be dependent on the retinal primordium for its differentiation. The primitive lens filled with primary lens fibers is the embryonic lens nucleus. In the adult, the embryonic nucleus is the central sphere inside the "Y" sutures; there are no sutures within the embryonal nucleus.

At birth, the lens consists almost entirely of lens nucleus, with minimal lens cortex. Lens

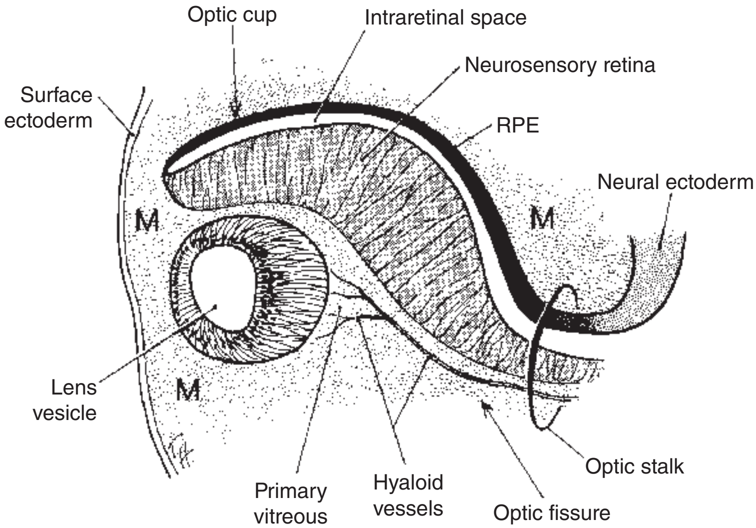

Figure 1.3. Cross-section through optic cup and optic fissure. The lens vesicle is separated from the surface ectoderm. Mesenchyme (M) surrounds the developing lens vesicle, and the hyaloid artery is seen within the optic fissure. RPE, retinal pigment epithelium. (Source: Cook C, Sulik K, Wright K. Embryology. In: Wright KW and Spiegel PH, eds. *Pediatric Ophthalmology and Strabismus*. St. Louis: Mosby–Year Book, 2003:3–53. Reproduced with permission of Elsevier.)

cortex continues to develop from the anterior cuboidal epithelial cells, which remain mitotic throughout life. Differentiation of epithelial cells into secondary lens fibers occurs at the lens equator (i.e., lens bow). Lens fiber elongation is accompanied by a corresponding increase in cell volume and a decrease in intercellular space within the lens.

The zonule fibers are termed the *tertiary vitreous*, but their origin remains uncertain. **The zonules may form from the developing ciliary epithelium or the endothelium of the posterior tunica vasculosa lentis (TVL).**

Vascular Development

The hyaloid artery is the termination of the primitive ophthalmic artery, a branch of the internal ophthalmic artery, and it remains within the optic cup following closure of the optic fissure. The hyaloid artery branches around the posterior lens capsule and continues anteriorly to anastomose with the network of vessels in the pupillary membrane (Figure 1.4). The pupillary membrane consists of vessels and mesenchyme overlying the anterior lens capsule. This hyaloid vascular network that forms around the lens is called the anterior and posterior TVL. The hyaloid artery and associated TVL provide nutrition to the lens and anterior segment during its period of rapid differentiation. Venous drainage occurs via a network near the equatorial lens, in the area where the ciliary body will eventually develop. There is no discrete hyaloid vein.

Once the ciliary body begins actively producing aqueous humor, which circulates and nourishes the lens, the hyaloid system is no longer needed. The hyaloid vasculature and TVL reach their maximal development by day 45 of gestation in the dog and then begin to regress. As the peripheral hyaloid vasculature regresses, the retinal vessels develop. Spindle-shaped mesenchymal cells from the wall of the hyaloid artery at the optic disc form buds (*angiogenesis*) that invade the nerve fiber layer.

Branches of the hyaloid artery become sporadically occluded by macrophages prior to their gradual atrophy. Placental growth factor (PlGF) and vascular endothelial growth factor (VEGF) appear to be involved in hyaloid regression. Proximal arteriolar vasoconstriction at birth precedes regression of the major hyaloid vasculature. **Atrophy of the pupillary membrane, TVL, and hyaloid artery occurs initially through apoptosis and later through cellular necrosis, and is usually complete by the time of eyelid opening 14 days postnatally in the dog.**

The clinical lens anomaly known as Mittendorf's dot is a small (1 mm) area of fibrosis on the posterior lens capsule, and it is a manifestation of incomplete regression of the hyaloid artery at the point where it was attached to the posterior lens

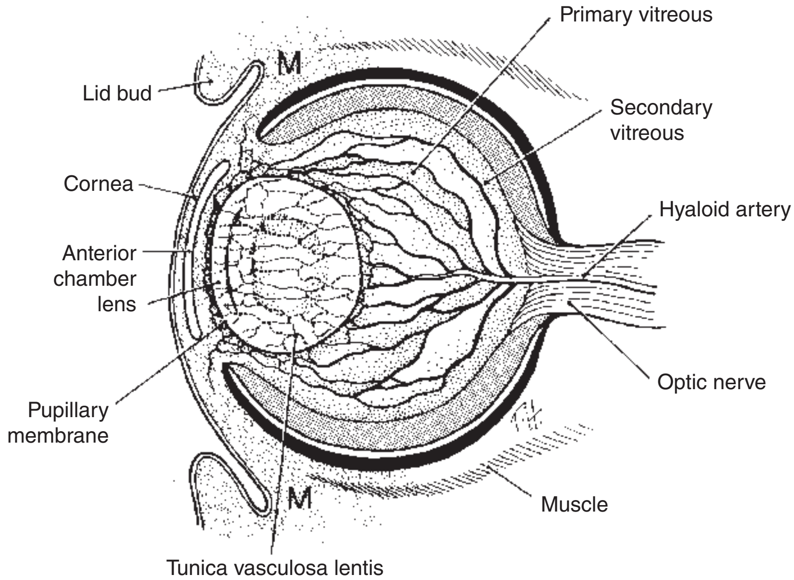

Figure 1.4. The hyaloid vascular system and tunica vasculosa lentis. M, mesenchyme. (Source: Cook C, Sulik K, Wright K. Embryology. In: Wright KW and Spiegel PH, eds. *Pediatric Ophthalmology and Strabismus*. St. Louis: Mosby–Year Book, 2003:3–53. Reproduced with permission of Elsevier.)

capsule. Bergmeister's papilla represents a remnant of the hyaloid vasculature consisting of a small, fibrous glial tuft of tissue emanating from the center of the optic nerve. Both are frequently observed as incidental clinical findings.

Development of the Cornea and Anterior Chamber

The anterior margins of the optic cup advance beneath the surface ectoderm and adjacent neural crest mesenchyme after lens vesicle detachment (day 25 of gestation in the dog). The surface ectoderm overlying the optic cup (i.e., the presumptive corneal epithelium) secretes a thick matrix, the primary stroma. Mesenchymal neural crest cells migrate between the surface ectoderm and the optic cup, using the basal lamina of the lens vesicle as a substrate. This loosely arranged mesenchyme fills the future anterior chamber, and it gives rise to the corneal endothelium and stroma, anterior iris stroma, ciliary muscle, and most structures of the iridocorneal angle. **The presence of an adjacent lens vesicle is required for induction of corneal endothelium, identified by its production of the cell adhesion molecule, N-cadherin.** Patches of endothelium become confluent and develop zonulae occludens during days 30–35 of gestation in the dog, and during this period, Descemet's membrane also forms.

Neural crest migration anterior to the lens to form the corneal stroma and iris stroma also results in formation of a solid sheet of mesenchymal tissue, which ultimately remodels to form the anterior chamber. The portion of this sheet that bridges the future pupil is called the pupillary membrane. Vessels within the pupillary membrane form the TVL, which surrounds and nourishes the lens. These vessels are continuous with those of the primary vitreous (i.e., hyaloid). **The vascular endothelium is the only intraocular tissue of mesodermal origin; even the vascular smooth muscle cells and pericytes, that originate from mesoderm in the rest of the body, are of neural crest origin.** In the dog, atrophy of the pupillary membrane begins by day 45 of gestation and continues during the first 2 postnatal weeks. Separation of the corneal mesenchyme (neural crest cell origin) from the lens (surface ectoderm origin) results in formation of the anterior chamber.

Development of the Iris, Ciliary Body, and Iridocorneal Angle

The two layers of the optic cup (neuroectoderm origin) consist of an inner, nonpigmented layer and an outer, pigmented layer. Both the pigmented and nonpigmented epithelium of the iris and the ciliary body develop from the anterior aspect of the optic cup; the retina develops from the posterior optic cup. The optic vesicle is organized with all cell apices directed toward the center of the vesicle. During optic cup invagination, the apices of the inner and outer epithelial layers become adjacent. Thus, the cells of the optic cup are oriented apex to apex.

A thin, periodic acid-Schiff–positive basal lamina lines the inner aspect (i.e., vitreous side) of the nonpigmented epithelium and retina (i.e., inner limiting membrane). **By approximately day 40 of gestation in the dog, both the pigmented and nonpigmented epithelial cells show apical cilia that project into the intercellular space. These changes probably represent the first production of aqueous humor.**

The iris stroma develops from the anterior segment mesenchymal tissue (neural crest cell origin), and the iris pigmented and nonpigmented epithelia originate from the neural ectoderm of the optic cup. **The smooth muscles of the pupillary sphincter and dilator muscles ultimately differentiate from these epithelial layers, and they represent the only mammalian muscles of neural ectodermal origin.** In avian species, however, the skeletal muscle cells in the iris are of neural crest origin, with a possible small contribution of mesoderm to the ventral portion.

Differential growth of the optic cup epithelial layers results in folding of the inner layer, representing early, anterior ciliary processes. The ciliary body epithelium develops from the neuroectoderm of the anterior optic cup, and the underlying mesenchyme differentiates into the ciliary muscles. **Extracellular matrix secreted by the ciliary epithelium becomes the tertiary vitreous and, ultimately, develops into the lens zonules.**

The three phases of iridocorneal angle maturation include: (1) the separation of anterior mesenchyme into corneoscleral and iridociliary regions (i.e., trabecular primordium formation), followed by differentiation of ciliary muscle and folding of the neural ectoderm into ciliary processes; (2) the enlargement of the corneal trabeculae and development of clefts in the area of the trabecular meshwork; and (3) the postnatal remodeling of the drainage angle, associated with cellular necrosis and phagocytosis by macrophages, and resulting in opening of clefts in the trabecular meshwork and outflow pathways.

In species born with congenitally fused eyelids (i.e. the dog and cat), development of the anterior chamber continues during this postnatal period before eyelid opening. **At birth, the peripheral iris and cornea are in contact, with maturation of pectinate ligaments by 3 weeks and rarefaction of the uveal and corneoscleral trabecular meshworks to their adult state during the first 8 weeks after birth.**

Retina and Optic Nerve Development

Infolding of the neuroectodermal optic vesicle results in a bilayered optic cup with the apices of these two cell layers in direct contact. Primitive optic vesicle cells are columnar, but by day 20 of gestation in the dog, they form a cuboidal layer containing the first melanin granules in the developing embryo. **The neurosensory retina develops from the inner, nonpigmented layer of the optic cup, and the retinal pigment epithelium (RPE) originates from the outer, pigmented layer.** Bruch's membrane (the basal lamina of the RPE) is first seen during this time, and becomes well developed over the next week, when the choriocapillaris is developing. By day 45 of gestation, the RPE cells take on a hexagonal cross-sectional shape and develop microvilli that interdigitate with projections from photoreceptors of the nonpigmented (inner) layer of the optic cup.

At the time of lens placode induction, the retinal primordium consists of an outer, nuclear zone and an inner, marginal (anuclear) zone. This process forms the inner and outer neuroblastic layers, separated by their cell processes that make up the transient fiber layer of Chievitz. **Cellular differentiation progresses from inner to outer layers and, regionally, from central to peripheral locations.** Peripheral retinal differentiation may lag that occurring in the central retina by 3–to 8 days in the dog. Retinal ganglion cells develop first within the inner neuroblastic layer, and axons of the ganglion cells collectively form the optic nerve. Cell bodies of the Müller and amacrine cells differentiate in the inner portion of the outer neuroblastic layer. Horizontal cells are found in the middle of this layer; the bipolar cells and photoreceptors mature last, in the outermost zone of the retina.

Significant retinal differentiation continues postnatally, particularly in species born with fused eyelids. At birth, the canine retina has reached a stage of development equivalent to that in the human at 3–4 months of gestation. In the kitten, all ganglion cells and central retinal cells are present at birth with proliferation in the peripheral retina continuing during the first 2–3 postnatal weeks in dogs and cats.

Sclera, Choroid, and Tapetum

These neural crest-derived tissues are all induced by the outer layer of the optic cup (future RPE). Normal RPE differentiation is a prerequisite for normal development of the sclera and choroid. **The choroid and sclera are relatively differentiated at birth, but the tapetum in dogs and cats continues to develop and mature during the first 4 months postnatally.**

Vitreous

The primary vitreous forms posteriorly, between the primitive lens and the inner layer of the optic cup. In addition to the vessels of the hyaloid system, the primary vitreous also contains mesenchymal cells, collagenous fibrillar material, and macrophages. Primitive hyalocytes produce collagen fibrils that expand the volume of the secondary vitreous.

The tertiary vitreous forms as a thick accumulation of collagen fibers between the lens equator and the optic cup. These fibers are called the marginal bundle of Drualt, or Drualt's bundle. Drualt's bundle has a strong attachment to the inner layer of the optic cup, and it is the precursor to the vitreous base and lens zonules. The early lens zonular fibers appear to be continuous with the inner, limiting membrane of the nonpigmented epithelial layer covering the ciliary muscle. Atrophy of the primary vitreous and hyaloid leaves a clear, narrow central zone, which is called Cloquet's canal.

Optic Nerve

Axons from the developing ganglion cells pass through vacuolated cells from the inner wall of the optic stalk. A glial sheath forms around the hyaloid artery. As the hyaloid artery regresses, the space between the hyaloid artery and the glial sheath enlarges. **Occasionally these remnants of the hyaloid vasculature combined with some glial tissue may emanate from the center of the optic disc postnatally and can be viewed ophthalmoscopically (termed Bergmeiter's papilla).** Glial cells migrate into the optic nerve and form the primitive optic disc. The glial cells around the optic nerve and the glial part of the lamina cribrosa come from the inner layer of the optic stalk, which is of neural ectoderm origin. Later, a mesenchymal (neural crest origin) portion of the lamina cribrosa develops. **Myelinization of the optic nerve begins at the chiasm, progresses toward the eye, and reaches the optic disc after birth.**

Eyelids

The eyelids develop from surface ectoderm, which gives rise to the epidermis, cilia, and conjunctival epithelium. Neural crest mesenchyme gives rise to deeper structures, including the dermis and tarsus. The eyelid muscles (i.e., orbicularis and levator) are derived from craniofacial condensations of mesoderm called somitomeres. The upper eyelid develops from the frontonasal process; the lower eyelid develops from the maxillary process. The lid folds grow together and elongate to cover the developing eye. **The upper and lower lids fuse on day 32 of gestation in the dog. Separation occurs 2 weeks postnatally.**

Extraocular Muscles

The extraocular muscles arise from mesoderm in somitomeres (i.e., preoptic mesodermal condensations). Spatial organization of the developing eye muscles is initiated before they interact with the neural crest mesenchyme. From studies of chick embryos, it has been shown that the oculomotor-innervated muscles originate from the first and second somitomeres, the superior oblique muscle from the third somitomere, and the lateral rectus muscle from the fourth somitomere. The entire length of these muscles appears to develop spontaneously rather than from the orbital apex anteriorly.