ESSENTIALS OF
Veterinary Ophthalmology
ESSENTIALS OF
Veterinary Ophthalmology
THIRD EDITION

Edited by

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WILEY Blackwell
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Preface

The Fifth Edition of *Veterinary Ophthalmology*, released in May 2013, serves as the eminent clinical and visual science text and reference in the world in this field and has been referred as the gold standard and the blue bible. The previous four editions (published in 1981, 1991, 1999, and 2007) of *Veterinary Ophthalmology* had both blue and gold covers. The fifth edition was expanded from 1800 pages to 2300 pages, and divided into two volumes to accommodate the continued expansion in knowledge and progression of this discipline. This textbook serves as the base for the Third Edition of the *Essentials of Veterinary Ophthalmology*.

The starting information base essential for a veterinary medical student and most practitioners is addressed in this clinical reference, and presented in a manner similar to the instructional formats of most Colleges of Veterinary Medicine. Most of the 21 chapters represent 50-minute single lecture presentations. Hence, we start with those subjects encountered in the veterinary students’ freshmen year on vision sciences (embryology, anatomy, and physiology), then the sophomore year with pharmacology and therapeutics, then clinical ophthalmology divided by species (offered in either/and the second and third years), and then for the clinical ophthalmology clerkships the entire text and its associated photographs in the text (hard copy and k-copy) and online.

In this Third Edition, the most frequently encountered eye diseases of domestic animals are presented along with their treatment. This book also provides the critical information for a busy general practitioner, small animal practitioner, and equine practitioner who needs a single ophthalmology text that covers their needs. When there is more time, and if the reader seeks additional information on an ophthalmic disorder, the comprehensive Fifth Edition of *Veterinary Ophthalmology* and other references can be consulted.

Relevant chapters from the Fifth Edition have been distilled into this book. As the ophthalmic structures are, for the most part, examined under direct observation, often supplemented with magnification and special illumination, a working knowledge of ocular development and anatomy is important. As most ophthalmic diseases can easily be photographed, nearly all of the illustrations are in color, facilitating transfer of this information to the clinical patient! Algorithms have been included when possible to speed the clinical problem solving process! The complete list of references (often in the hundreds) for these chapters are available in the Fifth Edition of *Veterinary Ophthalmology*. Selected sentences in each chapter are in green to assist with studying; they represent the “silver bullets” or vital information of the more frequently encountered ophthalmic diseases. The appendices (A-X) include the ocular therapy by drug group, available DNA tests for eye diseases in animals, inherited eye conditions (presented in the different chapters) of the dog, cat, horse and food animals, and those lysosomal diseases with ocular manifestations.

Ophthalmology has a unique vocabulary (based on Greek rather than Latin, as the development of ophthalmology paralleled the evolution of medicine), and this often impedes the teaching of veterinary ophthalmology. As a result, a brief glossary is included, summarizing those
ophthalmic words used most frequently in veterinary ophthalmology, often with some adaptation to animals.

If you have suggestions to improve *Essentials*, by all means, please feel free to contact me with your comments. As learning for veterinarians is a life- and career-long process, *Essentials* may be your first contact with veterinary ophthalmology. I hope you benefit and build upon this *Essentials of Veterinary Ophthalmology*.

Kirk N. Gelatt

*Florida, 2014*
ACKNOWLEDGMENTS

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Chapter 10.3 Diagnostic Ultrasonography (Ursula M. Dietrich)
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Chapter 21  Diseases of the Lens and Cataract Formation (Michael G. Davidson and Susan R. Nelms)
Chapter 22  Surgery of the Lens (David A. Wilkie and Carmen M.H. Colitz)
Chapter 23  Diseases and Surgery of the Canine Vitreous (Michael H. Boevé and Frans C. Stades)
Chapter 24  Diseases of the Canine Ocular Fundus (Kristina Narfström and Simon M. Petersen-Jones)
Chapter 25  Surgery of the Canine Posterior Segment (Samuel J. Vainisi, Joseph C. Wolfer, and Allison R. Hoffman)
Chapter 26  Diseases of the Canine Optic Nerve (Bianca C. Martins and Dennis E. Brooks)
Chapter 27  Feline Ophthalmology (Jean Stiles)
Chapter 28  Equine Ophthalmology (Brian C. Gilger)
Chapter 29  Food Animal Ophthalmology (Jacqueline W. Pearce and Cecil P. Moore)
Chapter 30  Ophthalmology of New World Camelids (Juliet R. Gionfriddo)
Chapter 31  Laboratory Animal Ophthalmology (David L. Williams)
Chapter 32  The Rabbit (David L. Williams, with contribution by Glenwood G. Gum)
Chapter 33  Exotics Animal Ophthalmology (Thomas J. Kern and Carmen M. H. Colitz)
Chapter 34  Neuro-ophthalmology (Aubrey A. Webb, Cheryl L. Cullen)
Chapter 35  Ocular Manifestations of Systemic Disease (Cheryl L. Cullen and Aubrey A. Webb)
About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/gelatt/essentials3

The website includes:
- Interactive MCQs
- All figures from the book
BASICS FOR CLINICAL VETERINARY OPHTHALMOLOGY
Development of the Eye

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 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.
<table>
<thead>
<tr>
<th>Month</th>
<th>Week</th>
<th>Day</th>
<th>Human (approximate post-fertilization age)</th>
<th>Mouse (day post-fertilization)</th>
<th>Dog (day post-fertilization or ( P = ) postnatal day)</th>
<th>Developmental events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>8</td>
<td>13</td>
<td></td>
<td>Optic sulci present in forebrain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9</td>
<td>15</td>
<td></td>
<td>Optic sulci convert into optic vesicles</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>10</td>
<td>17</td>
<td>Optic vesicle contacts surface epithelium</td>
<td>Lens placode begins to thicken</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>26</td>
<td></td>
<td>Optic vesicle surrounded by neural crest mesenchyme</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>10.5</td>
<td></td>
<td>Optic vesicle begins to invaginate, forming optic cup</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Lens pit forms as lens placode invaginates</td>
<td>Retinal primordium thickens, marginal zone present</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Retinal primordium invaginated</td>
<td>Retinal primordium consists of external limiting membrane, proliferative zone, primitive zone, marginal zone, and internal limiting membrane</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>P = postnatal day</td>
<td>Oculomotor nerve present</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Pigment in outer layer of optic cup</td>
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<td></td>
<td></td>
<td>Hyaloid artery enters through the optic cup</td>
<td></td>
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<td></td>
<td></td>
<td>Lens vesicle separated from surface ectoderm</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Retina: inner marginal and outer nuclear zones</td>
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<td></td>
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<td></td>
<td></td>
<td>Basement membrane of surface ectoderm intact</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Primary lens fibers form</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Trochlear and abducens nerves appear</td>
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<td></td>
<td></td>
<td></td>
<td>Lid fold present</td>
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<td></td>
<td></td>
<td>Anterior chamber beginning to form</td>
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<td></td>
<td></td>
<td></td>
<td>Secondary lens fibers present</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Corneal endothelium differentiated</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Optic nerve fibers reach the brain</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Optic stalk cavity is obliterated</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lens sutures appear</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Acellular corneal stroma present</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Sceral condensation present</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>First indication of ciliary processes and iris</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Extraocular muscles visible</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>Eyelids fuse (occurs earlier in the dog)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rudimentary rods and cones appear</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hyaloid artery begins to atrophy to the disc</td>
<td></td>
</tr>
</tbody>
</table>
### Table 1.2. Sequence of Ocular Development in the Cow

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

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

<table>
<thead>
<tr>
<th>Table 1.3. Embryonic Origins of Ocular Tissues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neural retina</td>
</tr>
<tr>
<td>Retinal pigment epithelium</td>
</tr>
<tr>
<td>Posterior iris epithelium</td>
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<tr>
<td>Pupillary iris sphincter and dilator muscles</td>
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<tr>
<td>(Mammalian species)</td>
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<tr>
<td>Bilayered ciliary epithelium</td>
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**Surface ectoderm**  |  **Mesoderm**
---|---
Lens | Extraocular myoblasts
Corneal and conjunctival epithelium | Vascular endothelium
Lacrimal gland | Schlemm’s canal (man)
| Posterior sclera (?)

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.)
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 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.

**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.)
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 regress, 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 (PIGF) 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 Mitten-dorf’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.
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 remolds 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 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.

**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

In folding 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 neuroblast 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 Druart, or Druart's bundle. Druart'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.
This chapter does not present the complete anatomy of the eye and surrounding tissues, but describes those ophthalmic structures important to the clinician confronted with ophthalmic patients. The analogue to the eye is the camera or video camera, which results in a continuous image! There is a huge range of variations in the ophthalmic structures, probably modified by evolution and the animal species’ need to survive. Adaptations to light intensity and duration have resulted in the division of vertebrates among the animal kingdom into three broad categories: diurnal, nocturnal, and arrhythmic. Diurnal animals are essentially active during the day. They possess optimal visual acuity at that time and “poor” or least effective vision at night. Nocturnal animals are essentially active during the night, and they possess most effective vision under dimly lit conditions. Many animals such as larger representatives of the ungulates and carnivores comprise a third group, the arrhythmic animals, which can be active during the day as well as night. Included in this group are crepuscular animals that optimally use the twilight hours of morning and evening. Time of visual activity and feeding behavior have played profound roles in the evolution of the eye and modification of its components. Species of teleostean fishes, birds, and mammals have eyes with very good vision.

Commonly used diagnostic equipment for ophthalmology such as the biomicroscope and the direct ophthalmoscope afford sufficient magnification to approach the histologic level; newer diagnostics such as the optical coherence tomograph (OCT) and high-frequency biomicroscopic ultrasonography (UBM) can examine noninvasively the patient’s eye at resolutions up to 10–20 μm, thereby exceeding the light histology limits. As a result, veterinarians should have a good working knowledge of gross and microanatomy. In ophthalmic surgery, there is the requirement for the exactness of incision depth to the level of micrometers, or of incision location and length to the level of millimeters.

**Adnexa: Protective Apparatus**

**Orbit**

The orbit is the bony fossa that separates the eye from the cranial cavity, surrounds and protects it, and provides several pathways through foramina for the various blood vessels and nerves involved in eye function. The size, shape, and position of the orbit are closely associated with the same two factors, time of visual activity and feeding behavior, that have markedly influenced global anatomy. While the depth of the orbit may contribute to some
extent to the protection and appearance of the eye, it is the location of the orbit within the skull that largely governs expanse of the visual field as well as the depth of field for a given species or breed. In domestic carnivores such as the cat and dog, the axes of the eyes are set rostrolaterally, approximately 10° and 20° from their midlines, respectively, and possess enhanced binocular vision. In contrast, the orbits in horses and ruminants are positioned more laterally, being approximately 40° from the midline in horses and 50° in cattle, and result in monocular vision and a strong panoramic line of vision, which serves to scan effectively as possible for potential predators.

Orbits in animals are also divided into: (1) enclosed, i.e., completely encompassed by bone (e.g., horse, ox, sheep, cow, and goat); and (2) open or incomplete, i.e., partially surrounded by bone (mostly carnivores to accommodate their ability to open their jaws widely, e.g., dogs and cats). Among the domesticated animal species, the orbital dimensions vary widely.

The bony fossa typically consists of five to seven bones, depending on the species (Figures 2.1 and 2.2). The orbit in the dog is composed of five, and sometimes six, bones, the supraorbital ligament which extends from the frontal to the zygomatic bones, and the periosteum. Most of the orbital rim is formed by the frontal, lacrimal, and zygomatic bones, but laterally, the rim is formed by a fairly extensive supraorbital ligament which is contiguous with a fibroelastic connective tissue sheath for much of the floor of the orbit; the latter is incomplete, being partially formed by the sphenoid and palatine bones. Cats, domestic and wild, have a very similar construction. In animals with enclosed orbits, closure of the temporal side of the orbit is accomplished by union of the zygomatic process of the frontal bone with the frontal process of the zygomatic bone. The arrangement of the bones of the orbital rim and lateral wall limit the different surgical approaches to the orbital tissues to through the orbital fissure, lateral and/or dorsal orbital walls, and the caudal mouth.

Within the orbit, various foramina and fissures provide an osseous pathway through which blood vessels and nerves pass from the cranial cavity and alar canal into the orbital region. The foramina of rather constant position in domestic animals are the rostral alar, ethmoidal, lacrimal, orbital, ovale, optic, rotundum, and supraorbital.

**Orbital Fascia**

The orbital fascia consists of a thin, tough, connective tissue lining that envelopes all the structures within the orbit, including the bony fossa itself. This fascia can be subdivided into three anatomic entities: (1) periorbita; (2) fascia bulbi or Tenon’s capsule, and (3) fascial sheaths of the extraocular muscles (Figure 2.3). The periorbita is a conically shaped, fibrous membrane that lines the orbit and encloses the eyeball with its muscles, blood vessels, and nerves. Its apex is at the exit of the optic nerve from the orbit. At this point, it is continuous with the dural sheath of the optic nerve; in the orbit, it is thin, attaches firmly to the orbital bones, and forms their periosteum. In animals with an incomplete lateral orbital wall, the periorbita is thicker laterally next to the orbital ligament. Anteriorly, in the

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Figure 2.1. Canine orbit. Bones of the orbit shown: F, frontal; L, lacrimal; M, maxilla; S, sphenoid; T, temporal; Z, zygomatic. Orbital foramina shown: A, rostral alar; E, ethmoidal; Op, optic; Or, orbital fissure.

Figure 2.2. Equine orbit. Bones of the orbit shown: F, frontal; L, lacrimal; S, sphenoid; T, temporal; Z, zygomatic. Orbit foramina shown: A, rostral alar; E, ethmoidal; Op, optic; Or, orbital fissure; So, supraorbital.
The three sheets of orbital fascia are separated by condensations of adipose tissue, i.e., orbital fat, that fill the dead space in the orbit and act as a protective cushion for the eye and adjacent muscles. The amount of orbital fat varies to some extent from individual to individual and to a greater extent from one animal species to another. Some animals, including birds and many reptiles, e.g., turtles and snakes, possess very little orbital fat, having relatively small orbits almost entirely filled by their globes. With regard to contraction of the retractor oculi muscle, orbital fat may become displaced against glandular tissue associated with the third eyelid, resulting in the latter's forward superior and lateral movements over the cornea.

The extraocular muscles suspend the globe in the orbit and provide ocular motility. There are four rectus muscles: the dorsal, ventral, medial, and lateral recti. They originate from the orbital apex (i.e., annulus of Zinn) and insert, in the dog, approximately 5 mm posterior to the limbus medially, 6 mm ventrally, 7 mm dorsally, and 9 mm laterally (Figure 2.4). They move the eye in the direction their names suggest. The retractor oculi (bulbi) muscle originates at the orbital apex and continues forward to form a cone surrounding the optic nerve and inserting posterior and deep to the recti muscles. This muscle bundle serves to retract the globe into the orbit. The retractor oculi muscle is ubiquitous among mammals, but it is absent in various nonmammalian groups, including birds and snakes. In instances of cetaceans, the retractor oculi muscle is highly developed, and as the eye is withdrawn into the orbit by the massive musculature, the anterior half of the globe may alter in shape, allowing the rounded lens to be displaced forwardly along the anteroposterior axis.

Upper and Lower Eyelids

The eyelids (palpebrae) are upper (superior or dorsal) and lower (inferior or ventral) folds of skin continuous with the facial skin, which is usually thin in domestic species. The free edges of the upper and lower eyelids meet to form the lateral and medial canthi (sing. canthus). The opening formed by the free edges is the palpebral fissure. The fissure is prevented from assuming a circular shape by medial (nasal) and lateral (temporal) palpebral ligaments that attach each canthus to the orbital rim. The medial ligament inserts into the periosteum of the nasal bones, whereas laterally it inserts into the temporal fascia and bones associated with the lateral