Comparative Morphology of the Pectinate Ligaments of Domestic Mammals, as Observed under the Dissecting Microscope and the Scanning Electron Microscope

Paul SIMOENS, Jean-Pierre DE GEEST, and Henri LAUWERS

Department of Morphology, Faculty of Veterinary Medicine, University of Ghent, Casinoplein 24, B-9000 Ghent, Belgium

(Received 8 February 1996/Accepted 11 June 1996)

ABSTRACT. The pectinate ligaments of ten horses, two donkeys, five oxen, five sheep, ten goats, five dogs, five cats, thirty pigs and two rabbits were studied under the stereomicroscope and the scanning electron microscope. In the horse and the donkey, the pectinate ligament was very prominent and was characterized by sturdy interconnected strands and relatively small inter trabecular spaces. The pectinate ligaments of ruminants were composed of shorter strands, separated by relatively larger spaces. Fusion between adjacent strands, resulting in the formation of fenestrated sheets, was regularly observed in these species, in particular in the superior and inferior ocular segments. In the dog and the cat, the pectinate ligament consisted of slender strands that were separated by large inter trabecular spaces. The strands of the pectinate ligaments of the pig and the rabbit were shorter and their diameters were intermediate between those of the herbivores and the carnivores. The clinical relevance of the normal variability in the structure of the pectinate ligament and proposals for a uniform anatomical nomenclature are discussed. — KEY WORDS: eye, iridocorneal angle, morphology, ophthalmology, pectinate ligament.


The pectinate ligament (ligamentum pectinatum) forms the internal boundary of the iridocorneal angle. It consists of radial strands (trabeculae) which connect the inner corneal limbus with the anterior part of the iridal base and it provides mechanical support to the latter. The strands are separated from one another by inter trabecular spaces through which the aqueous humor drains from the anterior eye chamber into the trabecular meshwork (reticulum trabeculare) that is contained within the iridocorneal angle.

The pectinate ligaments of domestic mammals, with the exception of the donkey and the goat, have been described as they appear upon gonioscopy [2, 5, 16, 32] and on histologic sections [3, 4, 16, 18, 20, 21, 24]. Detailed morphologic data are available for the dog in view of the occurrence of glaucoma in this species [1, 2, 5, 6, 14, 24]. The development, structure and pathology of the canine pectinate ligament have also been studied by means of scanning electron microscopy [2, 10–12, 14, 16, 17, 24, 25]. This technique offers images with excellent depth of focus and a wide range of magnifications, combining the advantages of gonioscopy and microscopic anatomy. There are a few reports that include scanning electron micrographs of the pectinate ligament of the horse [3, 16, 19], the cat [25] and the pig [13] but, to our knowledge, no such micrographs have been published for the other domestic mammals. The present study was designed to fill this void by providing a comparative description of the pectinate ligaments of a variety of domestic mammals as seen under the scanning electron microscope. The descriptions are supplemented by data about pigmentation of the pectinate ligament, obtained during sampling of the various specimens under the dissecting microscope.

MATERIALS AND METHODS

Animals: Both eyes of ten horses, two donkeys, five oxen, five sheep, ten goats, five dogs, five cats, thirty pigs and two rabbits were examined. All animals were adult and showed no signs of ocular disorders. The ungulates were slaughtered in an abattoir, and the carnivores and rabbits were killed by an intravenous overdose of pentothal (Nembutal®; Sanofi, Brussels, Belgium).

Preparation of tissue samples: Within 15 min after death, the eyes were enucleated, incised equatorially and immersed either in 10% buffered formalin or in 0.1 M cacodylate buffer that contained 2% formaldehyde, 2.5% glutaraldehyde and 0.02% picric acid. After overnight prefixation, the anterior half of the eye was further subdivided into smaller segments which were thoroughly fixed for at least one week.

Stereomicroscopy: Anterior ocular samples were studied under an epitelescope (Zeiss model OPMI; Oberkochen, Germany) for determination of the general arrangement of the iridocorneal angle and for the presence of pigmentation on the pectinate ligament.

Scanning electron microscopy: Samples were dehydrated in acetone, critical-point dried with carbon dioxide, fixed on aluminium specimen mounts with conductive carbon paint, coated with gold in a sputtering device (Polaron, Sussex, England) and examined under the scanning electron microscope (SEM; Philips model 505, Eindhoven, the Netherlands).

Photography: For comparative purposes, all scanning electron micrographs were printed of the same magnification (white bars=200 μm) and with similar orientation (iris at the upper margin and cornea at the lower margin of the picture).
RESULTS

Horse (Fig. 1): The equine pectinate ligament was very prominent and was inserted almost perpendicularly onto the corneal limbus. It consisted of numerous, large and interwoven strands that were arranged as a dense flat network which encircled the iridocorneal angle as a fenestrated membrane. This compact arrangement was most obvious in the superior and the inferior ocular segments. By contrast, in the nasal and temporal segments, the strands had fewer mutual connections and were arranged radially. The strands had an average diameter of 150 μm (100–200 μm) and a mean radial length of 1.2 mm (1–1.5 mm). The radial length of the strands was somewhat shorter in the superior and inferior ocular segments than in the nasal and temporal segments. The pectinate ligament was strongly pigmented, the pigmentation being most prominent at the iridial insertions and decreasing towards the cornea. The intertrabecular spaces of the pectinate ligament were relatively small and irregularly dispersed. They varied considerably in size and had an average diameter of 100–250 μm. The total area of all intertrabecular spaces was about one-third of the total area of the pectinate ligament sheet.

Donkey (Fig. 2): The strands of the asinine pectinate ligament had an average diameter of 100 μm and a mean radial length of 0.6 mm. The intertrabecular spaces were larger than in the horse and, therefore, the general arrangement of the ligament was less compact in the donkey.

Ox (Fig. 3): As in the horse, the pectinate ligament of the bovine eye was inserted almost perpendicularly onto the corneal limbus and also contained numerous melanocytes. By contrast, the general appearance of the ligament was less prominent because of its shorter radial length. Most strands of the pectinate ligament were broad and conical, having iridial insertions that were broader than the corneal attachments. Some strands were, however, somewhat prismatic, columnar or irregular in shape. Adjacent strands either fused at their iridial extremities or at their corneal insertions. This fusion was quite prominent in the superior and the inferior ocular segments and resulted in large membranes that were perforated by a few, small flow-holes. In the nasal and temporal segments of the eye, the strands were less densely packed, shorter and thicker. The width of

Fig. 1. HORSE. Anterior SEM view of the inferior segment of the pectinate ligament, as seen from within the anterior eye chamber. The numerous and robust strands form a compact meshwork with relatively few intertrabecular holes (white bar=200 μm).

Fig. 2. DONKEY. Anterior SEM view of the superior segment of the pectinate ligament (white bar=200 μm).
the inter trabecular spaces reached as much as 1 mm. The large flow-holes were most obvious at the borders of the membranous sheets that had been formed by fusion of the strands in the superior and the inferior segments of the pectinate ligament.

Sheep and goat (Figs. 4–7): In these small ruminants, the morphological features of the pectinate ligament were similar to those in the ox eye. The strands were conical or columnar but they were shorter, thinner and less pigmented in the ovine and the caprine eyes than those in the ox. Membranes formed by fusion between adjacent strands were observed frequently in the superior and inferior ocular segments but only rarely in the nasal and temporal segments. The flow-holes at the borders of fused strands were narrower in the small ruminants than those in the ox.

Dog (Fig. 8): The strands of the canine pectinate ligament were less numerous and slenderer than those in the ungulates. They exhibited large variations in size and thickness in different individuals. The majority of the strands were single strands, but some were fused with adjacent strands or ramified in a characteristic branching pattern before attaching to the corneal limbus. In general, the corneal insertions of the pectinate ligament were thinner (60 μm) than the iridal attachments (100–150 μm). The strands were inserted obliquely onto the corneal limbus and were usually heavily pigmented over their entire length. The inter trabecular spaces were very wide since the strands were slender and few in number. Through these wide spaces, the anterior strands of the trabecular meshwork inside the iridocorneal angle were easily visible from within the anterior eye chamber. These strands (which represented the so-called accessory or secondary pectinate ligament) were less numerous, thinner and much less heavily pigmented than those of the actual (or primary) pectinate ligament.

Cat (Fig. 9): The strands of the feline pectinate ligament were fewer in number, longer (radial length ≥ 1 mm), much finer and more uniform than those in the dog. Lateral connections between adjacent strands were almost completely absent. Although the corneal limbus was heavily pigmented in the area in which the pectinate ligament was attached, only the stouter strands of the ligament were somewhat pigmented. This slight pigmentation was sometimes distributed evenly over the entire length of the strands, but usually it was more pronounced at their iridal extremities. Because the strands were very thin, the inter trabecular spaces were proportionally much larger than in all other domestic animals examined, and their total area accounted for the major part of the area of the pectinate ligament. The trabecular meshwork inside the iridocorneal angle was easily visible from within the anterior eye chamber through these wide inter trabecular spaces.

Pig (Fig. 10): The strands of the porcine pectinate ligament were very short (radial length < 0.5 mm), slender and slightly pigmented. The iridal origins of the strands could hardly be distinguished from the iridal stroma and they were much broader than the corneal ends. Many adjacent strands had a common iridal origin but were separately attached to the cornea. The inter trabecular spaces were round or oval, giving the porcine pectinate ligament a characteristic cribiform appearance. The total area of all the inter trabecular spaces accounted for about half of the area of the pectinate ligament.

Rabbit (Fig. 11): The pectinate ligament of the rabbit was very similar to that of the pig, with the exception that the iridal insertions of the strands were more distinctly separated from the iridal base in the rabbit than in the pig.

DISCUSSION

The present study confirms and extends previous reports of morphologic differences between the pectinate ligaments of various mammalian species [18–23]. In the horse, the strands of the pectinate ligament are sturdy and insert almost perpendicularly onto the corneal limbus. This firm arrangement is requisite for the normal outflow of aqueous humor, as it prevents the wide iridocorneal angle from collapsing. On the other hand, the density of the strands is inversely proportional to the size of the inter trabecular spaces through which the aqueous humor passes into the spaces of the iridocorneal angle, but the total area of the flow-holes in the equine pectinate ligament is large enough to permit the free passage of the aqueous humor [3]. A similar situation is present in the donkey, where the strands of the pectinate ligament are even stouter, but the inter trabecular spaces are proportionally larger than in the horse. In the ruminants, the pectinate ligaments are characterized by an extensive fusion of adjacent strands, but aqueous humor outflow is ensured by large flow-holes at the borders of these membranous sheets. In contrast with the prominent pectinate ligaments of the domestic herbivores, the strands of the pectinate ligaments in the carnivores are slenderer and insert obliquely onto the corneal limbus. These morphologic characteristics are indicative of their weak mechanical support of the iridocorneal angle. In the carnivores, however, the ciliary muscle surrounding the iridocorneal angle is far better developed than in the herbivores and may provide additional support to prevent the collapse of the iridocorneal angle [6, 21]. The present study has further demonstrated that the pattern of the pectinate ligaments in the porcine and rabbit eyes is intermediate between the sturdy herbivore type and the delicate carnivore type.

In addition to the large interspecies variation, the appearance of the pectinate ligament also varies among breeds and among individual animals, as clearly demonstrated in the dog [2, 11, 25]. The strands of the canine pectinate ligament range from thread-like to columnar and are either single or ramified; they make connections with adjacent strands with various resultant degrees of inter weaving and even form solid sheets. The size and shape of the pectinate ligament are also subject to local variations in different parts of the same eye. These local differences have been described in the dog [6, 11], horse
Fig. 3. OX. Anterior SEM view of the inferior segment of the pectinate ligament. Fusion between strands has led to the formation of a trabecular sheet with only a few, very small flow-holes. The presence of few and small intertrabecular spaces is balanced by the presence of a few large, adjacent flow-holes (asterisk; white bar=200 µm).

Fig. 4. SHEEP. Anterior SEM view of the nasal segment of the pectinate ligament. The strands in the horizontal meridian have a regular radial orientation and are well-separated from each other (white bar=200 µm).

Fig. 5. GOAT. Panoramic anterior SEM view of the superior segment of the pectinate ligament (white bar=200 µm).

Fig. 6. GOAT. Anterior SEM view of the superior segment of the pectinate ligament, showing strands that are shorter and broader than those in the nasal and temporal ocular segments (compare with Fig. 7; white bar=200 µm).

Fig. 7. GOAT. Anterior SEM view of the relatively long and well-separated strands in the nasal segment of the pectinate ligament (white bar=200 µm).

[3], pig, ox and sheep [23], and they were also observed in the present study in the goat. Further variations in the pectinate ligament are caused by developmental and age-related changes [10, 17].

The normal variability of the pectinate ligament must be taken into account by clinicians investigating the iridocorneal angle for the detection of pathological conditions, such as congenital mesodermal goniodysgenesis or dysplasia of the pectinate ligament, which can interfere with the drainage of aqueous humor and lead to glaucoma [1, 5, 6, 12, 24]. Experience, judgment and caution are necessary in the attribution of pathological significance to an apparently aberrant structural appearance of the pectinate ligament [10]. Therefore, morphometric methods for
objective evaluation have been proposed [6, 24]. These methods should further be refined in view of the wide variations found in the normal pectinate ligaments of domestic mammals.

The comparative study of the meshwork at the iridocorneal angle is complicated by nomenclature confusion about the terms "ligamentum pectinatum" and "reticulum trabeculare". According to official gross-anatomical nomenclature, the former term is a synonym [7] or a substitute [8] for the latter. In accordance with these directives, several authors have used the term pectinate ligament to indicate the entire trabecular meshwork that fills the iridocorneal angle [15, 23]. According to most veterinary ophthalmologists, however, the term pectinate ligament is attributed only to the anteriormost strands of the meshwork at the iridocorneal angle, whereas the more peripheral parts of the network are called the trabecular meshwork. This differentiation is made because the anterior strands are of particular clinical importance as they are directly visible from within the anterior chamber, and because morphological aberrations in this ligament can interfere with the outflow of the aqueous humor [1, 5, 6, 12, 24]. The differentiation between the pectinate ligament and the trabecular meshwork is recognized in the veterinary edition of Nomina Histologica [9] and we recommend that it be included in the official veterinary gross anatomical nomenclature in order that the terminology used by veterinary anatomists, histologists and ophthalmologists be uniformly consistent.

Despite the apparent need for a separate nomenclature for the pectinate ligament and the deeper parts of the trabecular meshwork, it must be remarked that both
structures have connections with each other. These connections have been described in the horse, ox, sheep and pig [18, 19], and are most manifest in the canine eye, in which they are readily visible from within the anterior chamber through the wide flow-holes of the pectinate ligament [2, 11, 17]. This arrangement has been emphasized by some authors who indicated the anteriormost strands that form the actual pectinate ligament by the term "primary fibres", and the deeper strands by the name "accessory or secondary fibers" [2, 11, 17]. Other authors have used the plural term "pectinate ligaments" to designate the separate anterior strands of the iridocorneal angle [5, 13, 14]. We feel that these terminological elaborations are complicating and redundant, and they are therefore not recommended for general use.

ACKNOWLEDGMENTS. This study was supported by the Belgian National Fund for Scientific Research (Grant no. 31547888). The authors are grateful to Mr. R. De Moor and Mr. M. Verdonck for their technical assistance and to Mrs. D. Bracke for secretarial support.

REFERENCES