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A COMPREHENSIVE REVIEW OF OPTICAL COHERENCE TOMOGRAPHY (OCT) IN VETERINARY OPHTHALMOLOGY: PRINCIPLES, CURRENT APPLICATIONS, AND FUTURE DIRECTIONS: A REVIEW

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ABSTRACT

Optical coherence tomography (OCT) is a non-invasive imaging technique that enables high-resolution, cross-sectional visualization of ocular tissues in vivo. Since its introduction into ophthalmology, OCT has become an essential diagnostic tool in human clinical practice and has progressively gained importance in veterinary ophthalmology. Its ability to provide near-histological structural information without direct tissue contact makes OCT particularly suitable for use in animal patients, where limited cooperation and the need for repeatable examinations represent common challenges.

This narrative review summarizes the fundamental principles of OCT technology and provides an overview of its current applications in veterinary ophthalmology. The use of OCT for imaging the anterior segment, including the cornea, anterior chamber, iridocorneal angle, and iris, is discussed alongside its applications in the posterior segment, such as retinal layer analysis and optic nerve head evaluation. Special attention is given to technological advances, including spectral-domain OCT and optical coherence tomography angiography, which have expanded the ability to visualize subtle structural changes and ocular microvasculature. Species-specific anatomical considerations, technical limitations, and practical challenges related to image acquisition in veterinary patients are also addressed, together with future perspectives involving artificial intelligence and multimodal imaging approaches. Overall, OCT represents a valuable diagnostic and research tool with expanding potential in veterinary ophthalmology.

Key words: Optical coherence tomography, veterinary ophthalmology, anterior segment, posterior segment, OCT angiography, spectral-domain OCT.

Introduction

Optical coherence tomography (OCT) is an imaging modality based on low-coherence interferometry that allows depth-resolved visualization of biological tissues and has become a cornerstone of modern human ophthalmology since its first description in the early 1990s. The original concept and early clinical potential of OCT were demonstrated by Huang *et al* (1991), who showed that reflected light signals could be used to generate high-resolution cross-sectional images of ocular tissues in vivo. Subsequent advances in light sources, signal processing, and scanning speed led to the development of more sophisticated OCT systems with improved axial resolution and faster image acquisition, enabling detailed visualization of both anterior and posterior ocular structures and establishing OCT as a standard diagnostic tool for retinal and optic nerve diseases in human patients (De Boer *et al*, 2017).

In veterinary medicine, the adoption of OCT has been more gradual but has increased notably over the past decade, reflecting improved technological accessibility and growing demand for advanced diagnostic imaging. Unlike traditional techniques such as slit-lamp biomicroscopy, indirect ophthalmoscopy, or ultrasonography, OCT provides objective, quantitative information on ocular microarchitecture, which is particularly valuable for detecting subtle structural changes that may not be visible during routine ophthalmic examination (Famose, 2013).

Veterinary ophthalmology presents distinct challenges compared to human practice, including species-specific anatomical variability, differences in ocular size and pigmentation, and limited patient cooperation. Despite these constraints, OCT has demonstrated considerable potential across a range of animal species, most commonly dogs and cats, as well as horses and experimental animal models (McLellan & Rasmussen, 2012). Reported applications include assessment of corneal disorders, evaluation of the iridocorneal angle in glaucoma, characterization of iris lesions, and detailed analysis of retinal and optic nerve head morphology.

The aim of this narrative review is to provide a comprehensive overview of OCT technology and its applications in veterinary ophthalmology, integrating clinical and experimental perspectives while highlighting practical considerations, current limitations, and future directions.

Principles and Technical Background of OCT

OCT relies on the detection of backscattered light to generate depth-resolved images of biological tissues. In ophthalmic applications, OCT enables in vivo visualization of ocular microstructures with spatial resolution approaching histological detail, while preserving tissue integrity (Fercher *et al*, 2003). Conceptually, OCT is analogous to ultrasonography, employing low-coherence interferometry to measure the time delay and intensity of backscattered light relative to a reference beam in a Michelson-type interferometer (Brezinski & Fujimoto, 2002).

Initially developed for posterior segment retinal imaging using wavelengths around 820 nm, OCT was subsequently adapted for anterior segment imaging through the use of longer wavelengths (approximately 1310 nm), which provide improved penetration through highly scattering tissues and enable visualization of the iridocorneal angle (Goldsmith *et al*, 2005; Radhakrishnan *et al*, 2005). In veterinary ophthalmology, this adaptability allows imaging of both superficial and deeper ocular structures across species with varying ocular anatomy.

Spectral-domain OCT (SD-OCT) and ultrasonography are conceptually similar in that both generate cross-sectional images of internal tissue structures (Konstantopoulos *et al*, 2007), however, they differ fundamentally in physical principles and image acquisition. Ultrasonography relies on acoustic waves transmitted through direct probe–tissue contact, whereas SD-OCT uses near-infrared light delivered without physical contact, enabling superior axial resolution, albeit with more limited penetration in highly opaque or pigmented structures (Brezinski & Fujimoto, 2002).

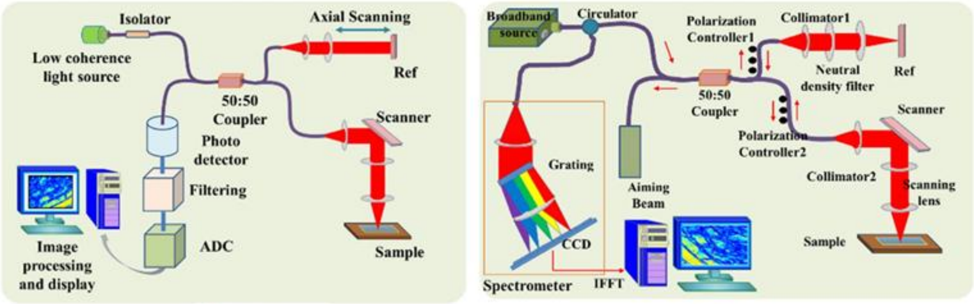
SD-OCT achieves axial resolution of approximately 2–4 µm and lateral resolution of about 20–25 µm, markedly exceeding the axial resolution of high-frequency ultrasonography at 50 MHz, which is typically around 50 µm (Siahmed *et al*, 2004; Famose, 2013; Hayashi *et al*, 2019). In contrast, computed tomography provides submillimeter spatial resolution and is primarily used for evaluation of orbital anatomy and osseous structures (Tsukagoshi *et al*, 2007), while magnetic resonance imaging offers superior soft tissue contrast and is valuable for assessment of the globe, optic nerve, and orbital contents, despite lower spatial resolution than OCT (Boroffka *et al*, 2008; Mortier *et al*, 2023).

Table 1: Comparison of imaging methods in veterinary ophthalmology

Imaging modality	*Spatial resolution*	*Main advantages*	*Typical applications*
Spectral-domain OCT	~2–4 μm (axial), ~20–25 μm (lateral)	Very high resolution, non-contact imaging	Cornea, retina, optic nerve head
High-frequency ultrasound (20–50 MHz)	~50–80 μm	Real-time imaging, good penetration	Anterior segment, lens
Ultra-high-frequency utrasound (70–100 MHz)	~30 μm	Extremely high superficial resolution	Fine anterior segment structures
Computed tomography (CT)	~0.5–1.0 mm	3D anatomy, bone detail	Orbit, skull, mineralized lesions
Magnetic resonance imaging (MRI)	~0.3–1.0 mm	Excellent soft tissue contrast	Optic nerve, orbit, neuro-ophthalmic diseases

Types of OCT Systems

Several technological variants of OCT have been developed, primarily differing in acquisition speed and image resolution. Early time-domain OCT systems (TD-OCT) have largely been replaced due to relatively slow scanning and limited image quality (Huang *et al*, 1991). In contrast, SD-OCT captures depth-resolved data simultaneously from the wavelength-dependent interference spectrum using Fourier transformation, resulting in faster acquisition and improved sensitivity (Leitgeb *et al*, 2003). In contemporary veterinary ophthalmology, SD-OCT represents the most widely used platform, offering sufficient resolution and speed for imaging fine ocular structures such as individual retinal layers and subtle corneal changes (Thomas & Duguid, 2004).



a) TD-OCT b) SD-OCT

Figure 1: Basic schematic representation (Fan *et al*, 2018).

Swept-source OCT (SS-OCT) represents a more recent advancement, utilizing a tunable laser source that enables deeper tissue penetration and higher scanning speeds (Vira *et al*, 2020). Although less frequently reported in veterinary studies, SS-OCT may be particularly useful for imaging deeper posterior segment structures, including the choroid and optic nerve head (Hernandez-Merino *et al*, 2011; Sekiryu, 2022). In veterinary practice, the selection of an OCT system is often influenced by availability and clinical purpose rather than strict technological superiority.

Optical Coherence Tomography Angiography

Optical coherence tomography angiography (OCTA) is a functional extension of conventional OCT that enables non-invasive visualization of ocular microvasculature by detecting motion-based contrast generated by circulating erythrocytes (Koustenis *et al,* 2017; Javed *et al,* 2023). By eliminating the need for intravenously administered contrast agents, OCTA allows in vivo reconstruction of retinal and choroidal vascular networks and enables repeated imaging of the same regions. In veterinary ophthalmology, OCTA remains a relatively recent and evolving modality, with applications that are still largely exploratory compared to those of structural OCT (Beckmann *et al*, 2022). Nevertheless, its ability to depict retinal and choroidal vascular networks in vivo as a fast and non-invasive three-dimensional alternative to dye-based angiography has generated increasing interest in both experimental and clinical settings (Ivanova *et al*, 2018; Ripolles-Garcia *et al*, 2021).

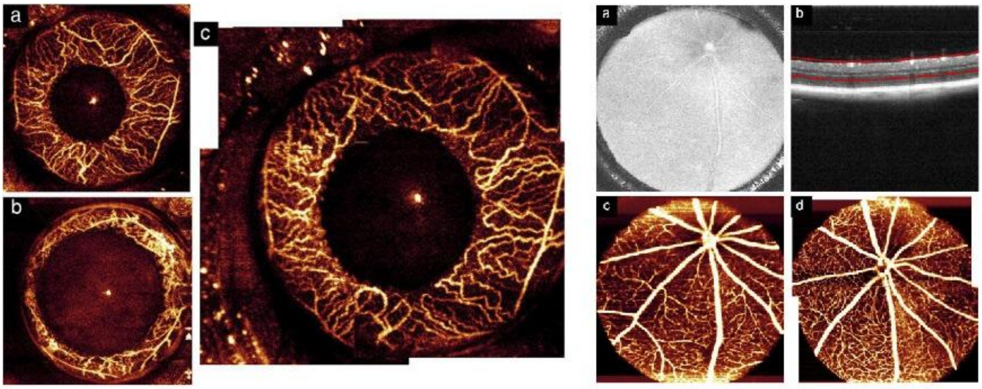


Figure 2: OCTA images acquired from the mouse iris (on the left) and single volume 50° wide-field (a) OCT en face, (b) OCT B-scan, and (c) inner retinal OCTA (Wei *et al,* 2022).

OCTA provides depth-resolved, layer-specific visualization of retinal and choroidal vasculature, permitting separate assessment of superficial and deep retinal capillary plexuses and the choriocapillaris (Choi *et al*, 2014). This capability may support investigation of vascular alterations associated with retinal degeneration, inflammatory disease, and ischemic processes (Hagag *et al*, 2017). Interpretation in veterinary patients remains challenging due to species-specific vascular anatomy, limited normative reference data, and susceptibility to motion artifacts. OCTA holds promise as a complementary imaging modality for advancing research in posterior segment disease and comparative ophthalmology (Ripolles-Garcia *et al*, 2021; Meleppat *et al*, 2022).

OCT in Veterinary Ophthalmology: General and Technical Considerations

The application of OCT in veterinary ophthalmology differs substantially from its use in human clinical practice due to pronounced species-specific anatomical variability, differences in ocular size, corneal curvature, and degree of ocular pigmentation, as well as limited patient cooperation (McLellan & Rasmussen, 2012; Espinheira Gomes *et al*, 2019). These factors directly influence scan alignment, image quality, and interpretation, particularly when imaging protocols and devices originally designed for the human eye are applied to animal patients (Ripolles-Garcia *et al*, 2021; Sekiryu, 2022)

OCT has been most extensively applied in dogs and cats, reflecting both their prevalence as companion animals and the availability of reference data for these species (Vanore & Benoit-

Biancamano, 2023). Successful imaging has also been reported in horses and experimental animal models, where OCT has proven valuable for longitudinal, in vivo assessment of retinal and optic nerve morphology (Blanchard *et al*, 2019; Chen *et al*, 2017).

Most commercially available OCT systems, including automated segmentation and thickness analysis algorithms, are optimized for the human eye and are not calibrated for veterinary anatomy. Consequently, examination results require cautious interpretation, and qualitative structural assessment often remains more reliable than automated quantitative measurements (Ripolles-Garcia *et al*, 2021; Sekiryu, 2022). Limited patient cooperation further contributes to motion artifacts, sometimes necessitating mild sedation or physical restraint (Espinheira Gomes *et al*, 2019; Beckmann *et al*, 2022). Despite these challenges, ongoing improvements in scanning speed and image stabilization continue to enhance the feasibility of OCT examinations in veterinary clinical practice.

Anterior Segment Optical Coherence Tomography (AS-OCT)

AS-OCT is among the most widely applied OCT modalities in veterinary ophthalmology, enabling detailed imaging of the cornea, anterior chamber, iridocorneal angle, and iris. Cross-sectional views provided by AS-OCT complement slit-lamp biomicroscopy and ultrasound-based techniques and support objective assessment of tissue morphology and spatial relationships within the anterior segment (Beckmann *et al*, 2022). Although AS-OCT cannot replace histopathological examination, it provides valuable in vivo information that may assist in clinical monitoring and decision-making when invasive sampling is not immediately indicated.

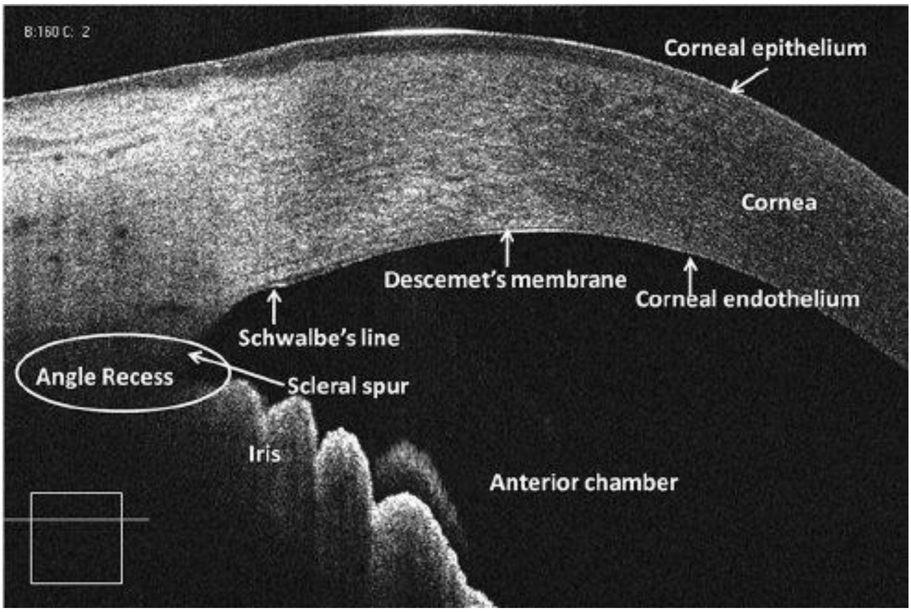


Figure 3: Anterior segment optical coherence tomography image (Tian *et al*, 2011).

Corneal Imaging

AS-OCT allows precise evaluation of corneal architecture, including epithelial, stromal, and endothelial layers. Applications include assessment of corneal thickness, structural integrity, and lesion depth (Famose, 2013; Alario & Pirie, 2014). Quantitative pachymetric measurements are particularly useful for monitoring corneal edema, dystrophies, and healing processes (Jeong *et al*, 2023). The non-contact nature of AS-OCT is advantageous in painful or compromised corneas, minimizing patient discomfort and reducing the risk of iatrogenic trauma (Gupta *et al*, 2022).

Anterior Chamber and Iridocorneal Angle Assessment

AS-OCT enables visualization and measurement of anterior chamber depth and angle configuration, which are important parameters in the evaluation of glaucoma and predisposition to angle closure (Craven *et al*, 2022). Unlike gonioscopy, AS-OCT allows objective assessment of angle anatomy without direct contact. Studies in dogs have demonstrated its ability to identify anatomical variations of the iridocorneal angle, although interpretation requires caution due to limited breed-specific reference values (Shim *et al*, 2022; Kim *et al*, 2023).

Iris and Anterior Segment Lesions

AS-OCT has also been applied to the evaluation of iris morphology and anterior segment lesions. Cross-sectional imaging enables assessment of iris thickness, structural heterogeneity, and lesion margins, supporting differentiation of benign and malignant processes (Hau *et al*, 2015). In cats, AS-OCT has been explored as a supportive tool in the evaluation of pigmented iris lesions, where subtle structural changes may precede clinically evident progression (Komatsu *et al*, 2024).

Posterior Segment Optical Coherence Tomography (PS-OCT)

PS-OCT enables detailed in vivo assessment of retinal organization and optic nerve head morphology in veterinary patients. Cross-sectional visualization of retinal layers supports evaluation of the neurosensory retina and its supporting structures, while assessment of optic nerve head configuration and peripapillary retinal nerve fiber layer appearance provides clinically relevant information in optic neuropathies (Khodeiry *et al*, 2025) and glaucomatous changes (Tatham & Medeiros, 2017).

In veterinary practice and research, PS-OCT allows structural characterization of the posterior segment that is not attainable through routine ophthalmoscopic examination alone. This capability is particularly valuable for the detection of early structural alterations and for longitudinal monitoring of disease progression in both clinical and experimental settings (McLellan & Rasmussen, 2012).

Retinal Imaging

SD-OCT supports qualitative and quantitative assessment of retinal morphology in veterinary patients. In dogs and cats, OCT has been used to describe normal retinal layer organization and establish reference patterns for comparison with pathological conditions (Mischi *et al*, 2022). Reliable visualization of the nerve fiber layer, nuclear layers, and photoreceptor complex has been demonstrated in vivo (Grozdanic *et al*, 2019). OCT has also been widely applied in experimental research to monitor retinal changes over time, particularly in models of inherited retinal degeneration (Nakazawa *et al*, 2019; Arrigo *et al*, 2023).

Optic Nerve Head Evaluation

OCT enables visualization of optic disc contour and peripapillary retinal nerve fiber layer, providing structural information relevant to optic neuropathies and glaucoma (Sakata *et al*, 2009). Although normative quantitative data in veterinary species remain limited, qualitative assessment of optic nerve head morphology has been reported as feasible and clinically informative in experimental models (Schuman *et al*, 2007; Strouthidis *et al*, 2011).

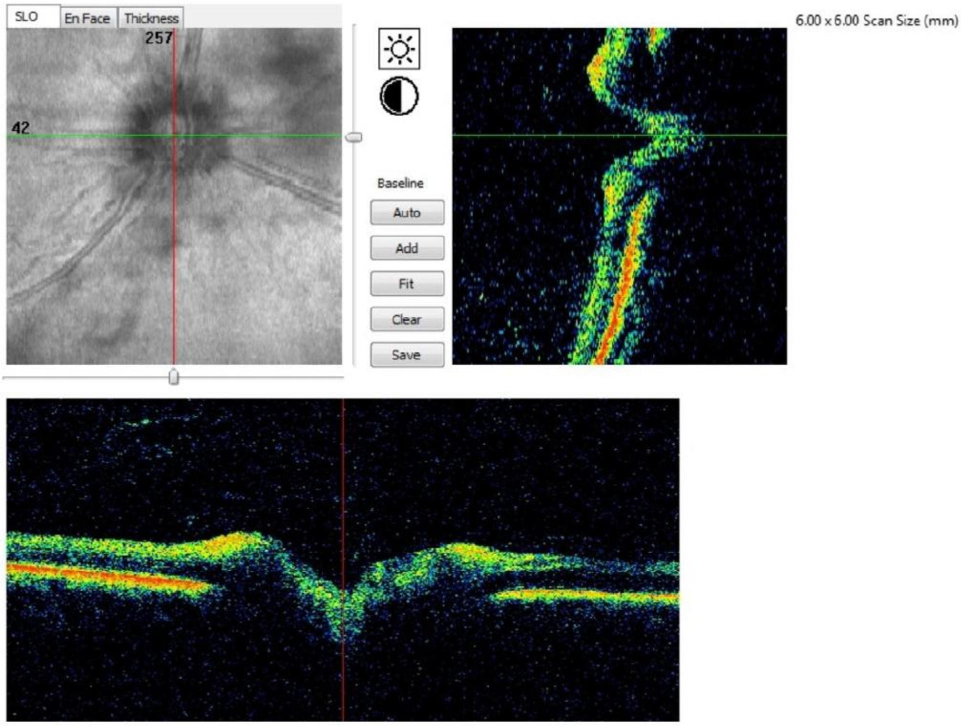


Figure 4: Optic nerve head 3D analysis (Graham *et al*, 2020).

Clinical and Research Implications

In clinical veterinary practice, PS-OCT is most applied in dogs and cats, reflecting accessibility and available reference data. Its value extends beyond routine diagnostics, particularly in experimental ophthalmology, where OCT serves as a key tool for in vivo retinal phenotyping (Mowat *et al*, 2017). Despite limitations related to eye size, pigmentation, and patient cooperation, PS-OCT provides structural detail that complements indirect ophthalmoscopy and fundus imaging techniques (Annear *et al*, 2021).

Limitations and Challenges of OCT in Veterinary Ophthalmology

Despite its expanding role, OCT is associated with several limitations affecting both clinical and research applications. Pronounced species-specific anatomical variability can influence signal penetration, image quality, and interpretation (Hernandez-Merino *et al*, 2011), complicating direct comparison across individuals and species in the absence of standardized acquisition protocols (Nurjanah *et al*, 2025).

Although OCT is widely applied in anterior segment imaging, its role in the evaluation of lens pathology remains comparatively limited. In human ophthalmology, AS-OCT has been used in the perioperative assessment of cataract patients, including measurement of anterior chamber depth and lens thickness, evaluation of corneal incisions, and postoperative intraocular lens positioning (Hamzeh *et al*, 2015; Kato *et al*, 2022; Wang *et al*, 2025). However, the optical properties of the crystalline lens, particularly in advanced cataractous change, reduce signal penetration and image contrast within the lens substance itself (Van Velthoven *et al*, 2006). As a result, OCT is not considered a primary modality for direct assessment of lens disease but rather a complementary tool supporting anterior segment evaluation and surgical planning. In veterinary patients, these limitations may be further accentuated by anatomical variability and iris pigmentation, which can additionally restrict visualization of deeper intraocular structures.

Technical constraints further limit routine application, as most OCT systems and analysis algorithms are designed for the human eye and are not optimized for veterinary anatomy (McLellan & Rasmussen, 2012). Automated segmentation and quantitative measurements, therefore, require cautious interpretation. Motion artifacts related to limited patient cooperation represent an additional challenge, particularly during posterior segment and angiographic imaging.

At the same time, OCT has demonstrated substantial value in experimental animal models. By enabling cross-species evaluation of ocular anatomy and disease-related structural changes, OCT has contributed to comparative ophthalmology and improved understanding of ocular pathophysiology (Zwolska *et al*, 2023). The ability to obtain repeated, in vivo assessments has been particularly important for longitudinal investigation of disease processes (Hernandez-Merino *et al*, 2011), supporting the role of OCT as a central imaging tool in experimental ophthalmic research.

Future Directions of OCT in Veterinary Ophthalmology

Future developments in OCT are expected to further expand its role in veterinary ophthalmology. Advances in imaging hardware, including faster scanning speeds, improved image stabilization, and enhanced depth penetration, are likely to improve the reliability of posterior segment imaging and reduce motion-related artifacts (Beckmann *et al*, 2022).

Progress in image analysis represents another important direction. Artificial intelligence–assisted interpretation may enhance OCT analysis through automated segmentation, pattern recognition, and quantitative assessment of subtle structural changes, improving objectivity and reducing interobserver variability (Zeppieri *et al*, 2023; Devine *et al*, 2025). Such approaches may improve objectivity, reduce interobserver variability, and support more consistent longitudinal evaluation, particularly in the context of chronic ocular disease (Lan *et al*, 2025).

In veterinary ophthalmology, AI-assisted OCT analysis may be especially valuable given pronounced anatomical diversity between species and the limited availability of normative reference datasets (Maqbool *et al*, 2025). Algorithms trained on veterinary-specific data could assist in distinguishing normal anatomical variation from pathological change across species and breeds (Rahmoun *et al*, 2025).

Multimodal imaging strategies are also expected to gain increasing importance. Integration of OCT with complementary imaging techniques, including fundus photography, autofluorescence imaging, angiographic methods, and OCT angiography, is also expected to provide a more comprehensive assessment of ocular structure and function (Devine *et al*, 2025). Together, continued technological refinement and veterinary-specific adaptation are likely to strengthen the role of OCT in both clinical and comparative ophthalmology.

Conclusion

Optical coherence tomography has become an important adjunctive imaging modality in veterinary ophthalmology, expanding structural assessment of both anterior and posterior segment pathology. Although its clinical implementation has progressed more gradually than in human ophthalmology (Beckmann *et al*, 2022), OCT has demonstrated clear value in the evaluation of corneal disease, anterior chamber configuration, retinal architecture, and optic nerve head morphology.

Species-specific anatomical variability, technical limitations of human-designed systems, and restricted reference data remain important challenges. Nevertheless, ongoing technological refinement and growing veterinary-specific experience continue to enhance the feasibility and interpretative value of OCT. Beyond clinical diagnostics, OCT has assumed a significant role in experimental and comparative ophthalmology by enabling longitudinal, in vivo assessment of ocular structure.

With continued veterinary-specific adaptation, OCT complements conventional ophthalmic examination techniques, including slit-lamp biomicroscopy, indirect ophthalmoscopy, and ultrasonography, and is expected to play an increasingly important role in the diagnosis, monitoring, and understanding of ocular disease across animal species.

Declaration of conflicting interests

The authors confirm that there are no conflicts of interest related to the authorship or publication of this review article.

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