Chapter

Introductory Chapter: OCT Enhances Precision Diagnosis and Treatment of Ocular Diseases

Xiaogang Wang

1. Introduction

The eye is the core of the visual system, and any ocular disease can potentially affect vision, thereby impacting quality of life. Common eye diseases include myopia, hyperopia, cataracts, glaucoma, macular degeneration, and diabetic retinopathy. Imaging technologies play a crucial role in ophthalmology. Traditional ophthalmic examinations primarily relied on visual acuity testing and fundus examination. However, with technological advancements, modern imaging techniques such as Optical Coherence Tomography (OCT) and OCT Angiography (OCTA) have greatly improved diagnostic accuracy and efficiency [1, 2].

OCT technology provides high-resolution cross-sectional images of ocular tissues, allowing clinicians to gain an in-depth understanding of the microstructures of the retina, optic nerve head, and associated pathologies. This noninvasive imaging modality enables doctors to obtain detailed pathological information without compromising patient comfort [3]. OCTA further enhances the ability to observe vascular structures and blood flow status, which is particularly important for diagnosing diabetic retinopathy and macular disorders [2].

Through imaging technologies, clinicians can not only identify ocular diseases earlier and more accurately but also monitor disease progression and treatment efficacy. This provides crucial evidence for personalized treatment and management, helping patients achieve better visual outcomes. In the future, as imaging technologies continue to advance, ophthalmic diagnosis and treatment will become more precise, bringing greater benefits to patients.

2. Overview of OCT

2.1 OCT and working principle

OCT, as an advanced imaging technology, is primarily used to obtain high-resolution cross-sectional images of biological tissues. The principle of OCT is based on low-coherence interferometry, which uses the phenomenon of light interference to provide information about the microscopic structure within tissues [3].

An OCT device typically consists of a laser light source, an interferometer, and a detector. First, the light source emits a broad-spectrum beam of light that

IntechOpen

illuminates the tissue being examined. Some of this light is reflected by the tissue, while some penetrates and is reflected by deeper structures. The reflected light combines with light from the reference arm, forming an interference pattern. By analyzing the phase and intensity of this interference pattern, depth information of the reflected signals can be obtained, allowing the reconstruction of cross-sectional images of the tissue.

2.2 Noninvasive and high-resolution imaging advantages of OCT

The noninvasive nature of OCT makes it an essential tool in ophthalmology. Unlike traditional biopsies or other invasive imaging techniques, OCT does not require direct contact with the tissue, meaning patients feel comfortable and safe during examination. This technique not only eliminates the risk of bleeding and infection but also reduces patient anxiety, making it an ideal choice for regular screening and monitoring disease progression.

The high-resolution imaging capability of OCT is another major advantage. By capturing details of microstructures, OCT can identify diseases at an early stage. For example, OCT can clearly display changes in retinal layers, timely detecting conditions such as macular degeneration and diabetic retinopathy. This ability for early diagnosis significantly improves the success rate of treatment.

3. History of OCT development

The development of OCT can be traced back to the 1990s, with the initial concept proposed by Professor David Huang and his team in 1991 [3]. The original OCT technology was primarily based on time-domain imaging principles, utilizing low-coherence interferometry to obtain cross-sectional images of biological tissues. This groundbreaking research marked the beginning of significant applications of optical imaging technology in ophthalmology.

With continuous technological advancements, Time-Domain OCT (TD-OCT) achieved its first clinical application in 1996. Although TD-OCT provided relatively high-resolution, its imaging speed was comparatively slow, limiting its widespread in clinics [4]. Entering the twenty-first century, the emergence of Fourier-Domain OCT (FD-OCT) represented a major breakthrough in OCT technology. FD-OCT significantly improved imaging speed and image quality by simultaneously acquiring signals from multiple depths. This technology enabled clinicians to obtain high-quality images in less time, thereby enhancing clinical diagnosis efficiency [5].

Subsequently, Swept-Source OCT (SS-OCT) emerged as a novel imaging technology, further enhancing OCT performance. SS-OCT utilizes tunable lasers to image across a wider range of wavelengths, providing information from deeper tissue layers. It has shown unique advantages, particularly in imaging the cornea, retina, and anterior chamber [6].

Today, modern OCT technology has not only improved in resolution and speed but also incorporated advanced technologies such as artificial intelligence, further enhancing image analysis and pathology recognition capabilities [7]. Through continuous exploration and innovation, OCT will continue to play a crucial role in future medical research.

4. Examples of OCT applications in ophthalmology

OCT, as a noninvasive, high-resolution imaging technology, not only provides detailed images of ocular anatomical structures but also effectively assists in early disease diagnosis and treatment evaluation. The following are specific examples of OCT applications in several common ophthalmic conditions.

1. *Diabetic retinopathy (DR):* OCT enables clinicians to observe detailed changes in retinal thickness and microvascular damage (**Figure 1**). By evaluating structural changes in the macular region, OCT can also assess the severity of diabetic macular edema. OCTA can reflect abnormalities in retinal microcirculation to varying degrees, providing a basis for interventional treatment [8, 9].

2. *Glaucoma:* OCT can precisely measure the thickness of the retinal nerve fiber layer (RNFL) and assess structural changes in the optic nerve head, such as the degree of cupping. Additionally, OCTA can visualize the blood supply to the optic nerve head, thereby further evaluating the risk of glaucoma (**Figure 2**) [10].

3. *Cataract:* Anterior segment OCT can provide detailed imaging of the lens, assisting ophthalmologists in identifying the degree and location of lens opacification (**Figure 3**). This is crucial for assessment and treatment planning. Furthermore, postoperative OCT examinations can be used to monitor the occurrence of postoperative complications such as inflammatory reactions, corneal edema, and posterior capsule opacification [11].

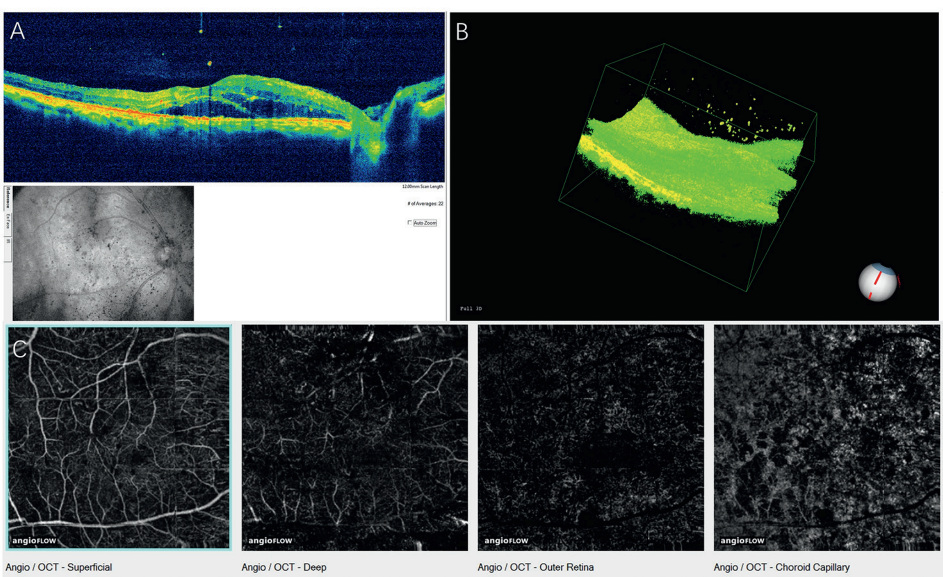

Figure 1.
OCT examination results of the right eye in a patient with diabetic retinopathy (DR). Panel A: Abnormal hyperreflective signals are visible in the vitreous cavity, along with intraretinal exudates and edema. Panel B: Three-dimensional reconstruction of structural OCT reveals distinct hyperreflective signal clusters in the vitreous cavity and morphological changes associated with retinal edema. Panel C: OCTA examination of a 6 mm x 6 mm macular area demonstrates significant perfusion abnormalities across all layers, from the superficial retina to the choriocapillaris.

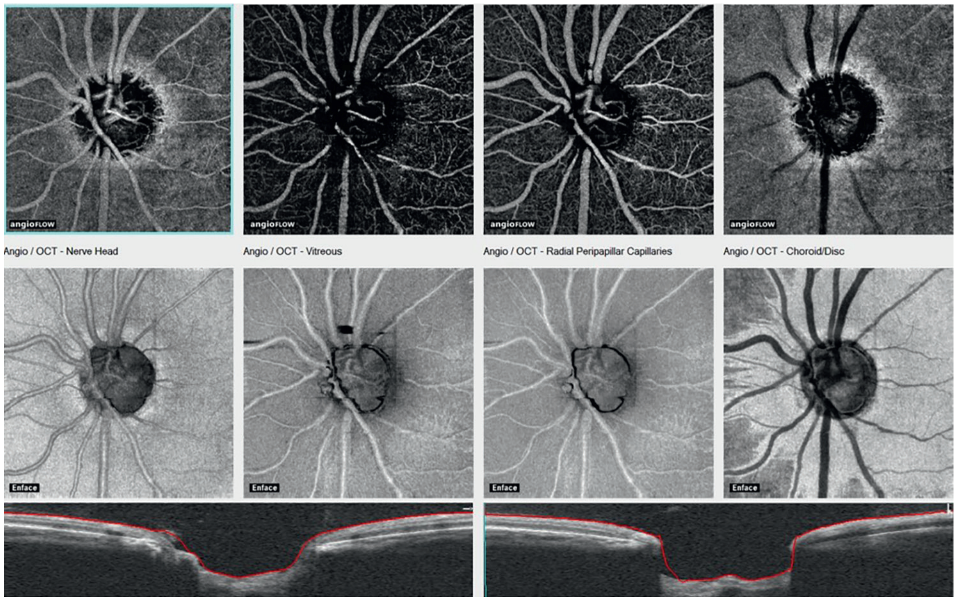

Figure 2.
OCTA scan results of a 4.5 x 4.5 mm optic disk area in the left eye of a glaucoma patient. First row: OCTA examination reveals only large vessel information remaining in the optic disk area. Due to long-term elevated intraocular pressure, the microvascular circulation is significantly compromised. Second row: Corresponding en-face images at various levels demonstrate marked enlargement of the optic cup. Third row: OCT cross-sectional images show deep excavation of the optic disk with significant expansion of the cup margins.

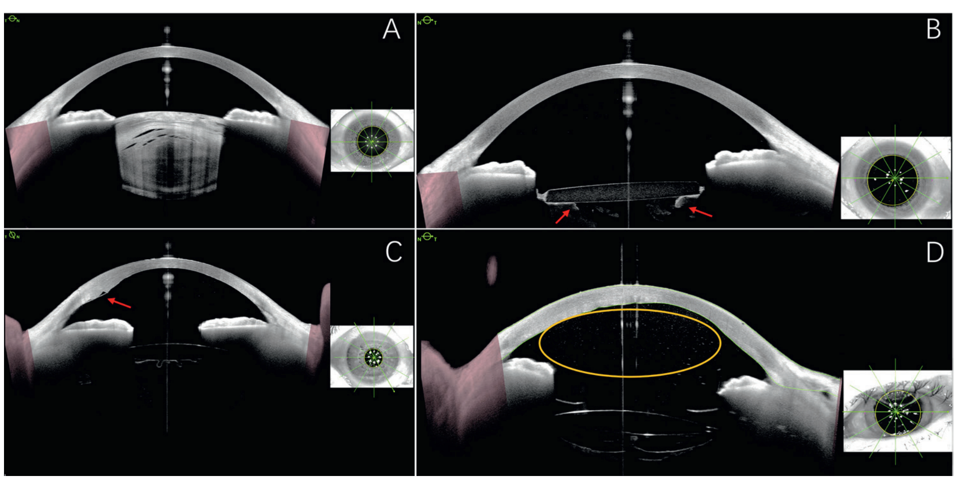

Figure 3.
Various OCT images related to cataract surgery. Panel A: Preoperative cataract OCT image showing a significant lens opacity. Panel B: Post-laser treatment for posterior capsular opacification (PCO), demonstrating discontinuity of the posterior lens capsule. The curling of the capsule edges is visible at both ends of the opening (red arrows). Panel C: Postoperative OCT image showing wound gaping and Descemet's membrane detachment at the main incision site (red arrow). Panel D: Postoperative OCT image revealing varying degrees of corneal edema and anterior chamber inflammatory reaction (yellow circle).

5. Future prospects

The widespread application of OCT technology in ophthalmology has made significant progress, but its future development still holds great potential, primarily in the integration with new imaging technologies, the application of artificial intelligence, and its potential in personalized medicine and treatment monitoring.

5.1 Integration with new imaging technologies

In recent years, OCT Angiography (OCTA) has emerged as a novel imaging technique that has been successfully integrated with OCT. OCTA enables noninvasive observation of ocular vascular structure and function, providing crucial reference information for diagnosing ophthalmic diseases such as diabetic retinopathy and wet age-related macular degeneration [9, 12]. The combination of OCT with other imaging technologies (e.g., fluorescein angiography and ultrasonography) will allow clinicians to obtain more comprehensive information about ocular health. This multimodal imaging strategy can not only improve early disease detection rates but also support the development of personalized treatment plans.

5.2 Application of artificial intelligence in OCT image analysis

The rapid development of AI has brought revolutionary changes to OCT image analysis. Through deep learning algorithms, AI can automatically identify and classify lesions in OCT images, improving the speed and accuracy of image analysis [13]. In the future, the application of AI is expected to reduce subjective bias in the diagnostic process, providing more objective assessments. Furthermore, AI can help researchers identify new biomarkers through the analysis of large-scale OCT datasets, promoting the development of novel treatment methods.

5.3 Potential of OCT in personalized medicine and treatment monitoring

With the rise of personalized medicine, the prospects for OCT in treatment monitoring and disease management are becoming increasingly broad. OCT can provide real-time information on the ocular structure and function, offering a basis for clinicians to formulate personalized treatment plans. Through regular OCT examinations, doctors can dynamically monitor changes in a patient's condition and adjust treatment plans in a timely manner. Additionally, with the development of telemedicine and mobile smart health technologies, OCT technology is expected to integrate with these emerging technologies to achieve more convenient patient management. Patients may be able to conduct preliminary screenings at home, with OCT images transmitted to doctors for analysis via cloud platforms, thereby improving the accessibility of medical services [14].

6. Summary

This book will compile the various aspects mentioned above, selecting key anterior segment and fundus diseases to delve into the application and analysis of OCT imaging technology in specific disease contexts. It emphasizes the importance of OCT in early diagnosis, treatment monitoring, and evaluation. Additionally, the book will focus on the application of artificial intelligence (AI) in the analysis of OCT images, exploring how to enhance the speed and accuracy of image processing and analysis, thereby aiding physicians in making more precise diagnoses. The introduction of AI will transform the traditional methods of ophthalmic diagnosis, making them more objective and intelligent.

We hope that readers will absorb the necessary knowledge from the chapters of this book, enabling them to contribute to global eye health from a perspective of wisdom and precision. By combining the latest advancements in OCT technology with AI, we anticipate that this book will provide valuable references and insights for ophthalmologists, researchers, and readers interested in ocular health, promoting further development and innovation in the field of ophthalmology. The ultimate goal is to improve the early detection rates and treatment outcomes of ocular diseases, thereby enhancing overall patient health and quality of life.

Author details

Xiaogang Wang
Shanxi Eye Hospital Affiliated to Shanxi Medical University,
Taiyuan, Shanxi Province, China

*Address all correspondence to: movie6521@163.com

References

[1] Kashani AH, Chen CL, Gahm JK, Zheng F, Richter GM, Rosenfeld PJ, et al. Optical coherence tomography angiography: A comprehensive review of current methods and clinical applications. Progress in Retinal and Eye Research. 2017;**60**:66-100. DOI: 10.1016/j.preteyeres.2017.07.002

[2] Pandya BU, Grinton M, Mandelcorn ED, Felfeli T. Retinal optical coherence tomography imaging biomarkers: A review of the literature. Retina. 2024;**44**(3):369-380. DOI: 10.1097/IAE.0000000000003974

[3] Huang D, Swanson EA, Lin CP, Schuman JS, Stinson WG, Chang W, et al. Optical coherence tomography. Science. 1991;**254**(5035):1178-1181. DOI: 10.1126/science.1957169

[4] Tsang SH, Sharma T. Optical coherence tomography. Advances in Experimental Medicine and Biology. 2018;**1085**:11-13. DOI: 10.1007/978-3-319-95046-4_3

[5] Bouma BE, Yun SH, Vakoc BJ, Suter MJ, Tearney GJ. Fourier-domain optical coherence tomography: Recent advances toward clinical utility. Current Opinion in Biotechnology. 2009;**20**(1):111-118. DOI: 10.1016/j.copbio.2009.02.007

[6] Mirzayev I, Gündüz AK, Aydın Ellialtıoğlu P, Gündüz ÖÖ. Clinical applications of anterior segment swept-source optical coherence tomography: A systematic review. Photodiagnosis and Photodynamic Therapy. 2023;**42**:103334. DOI: 10.1016/j.pdpdt.2023.103334

[7] Kapoor R, Whigham BT, Al-Aswad LA. Artificial intelligence and optical coherence tomography imaging. Asia-Pacific Journal of Ophthalmology. 2019;**8**(2):187-194. DOI: 10.22608/APO.201904

[8] Waheed NK, Rosen RB, Jia Y, Munk MR, Huang D, Fawzi A, et al. Optical coherence tomography angiography in diabetic retinopathy. Progress in Retinal and Eye Research. 2023;**97**:101206. DOI: 10.1016/j.preteyeres.2023.101206

[9] Szeto SK, Lai TY, Vujosevic S, Sun JK, Sadda SR, Tan G, et al. Optical coherence tomography in the management of diabetic macular oedema. Progress in Retinal and Eye Research. 2024;**98**:101220. DOI: 10.1016/j.preteyeres.2023.101220

[10] Geevarghese A, Wollstein G, Ishikawa H, Schuman JS. Optical coherence tomography and glaucoma. Annual Review of Vision Science. 2021;**7**:693-726. DOI: 10.1146/annurev-vision-100419-111350

[11] Ahmed TM, Siddiqui MAR, Hussain B. Optical coherence tomography as a diagnostic intervention before cataract surgery-a review. Eye (London, England). 2023;**37**(11):2176-2182. DOI: 10.1038/s41433-022-02320-y

[12] Vidal-Oliver L, Montolío-Marzo E, Gallego-Pinazo R, Dolz-Marco R. Optical coherence tomography biomarkers in early and intermediate age-related macular degeneration: A clinical guide. Clinical and Experimental Ophthalmology. 2024;**52**(2):207-219. DOI: 10.1111/ceo.14337

[13] Li D, Ran AR, Cheung CY, Prince JL. Deep learning in optical coherence tomography: Where are the gaps? Clinical and Experimental

Ophthalmology. 2023;**51**(8):853-863. DOI: 10.1111/ceo.14258

[14] Willis ET, Kim JE, Schneider EW. Home optical coherence tomography monitoring for Neovascular age-related macular degeneration: Transformative technology or cool toy? Ophthalmology and Therapy. 2024;**13**(6):1407-1416. DOI: 10.1007/s40123-024-00953-8