REVIEW ARTICLE

An insight into Principle and Practice of Anterior Segment Optical Coherence Tomography

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ABSTRACT

Proper visualization of the eye structures is the hallmark of diagnosis in eye diseases. With advent of newer techniques and instruments, the significance of anterior segment eye structures is further elaborated. This article explores the basic working principle of optical coherence tomography (OCT) and also provides a list of commonly available instruments and their advantages over one another. It then sheds light upon the use of anterior segment OCT in the observation of cornea, conjunctiva, lacrimal gland and other anatomic structures of eye within the living subject. Anterior segment OCT is also helpful in the demonstration of dynamics involving aqueous flow system. The application of this advanced technique in diagnosis of dry eye disease, keratoconus, anterior segment eye tumors and other diseases is also explained. The examination of normal cornea along with all its layers is possible with anterior segment OCT and it can also point out any abnormality in corneal epithelium, edema or any other change that may occur after intra ocular lens placement or corneal transplantation. Anterior chamber angle measurement is an essential step in the diagnosis of angle closure glaucoma and quite accurate results are provided by this technique. The data was searched from PubMed and Google Scholar, from the articles published during 2014 and 2020, using the keywords "optical coherence tomography", "glaucoma" and "anterior segment of eye". A few of the limitations of OCT are also discussed along with the future perspectives of this powerful instrument.

Keywords: Anterior Eye Segment; Optical Coherence Tomography; Glaucoma; Anterior Chamber Angle.

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INTRODUCTION

Anterior segment of the eye refers to the portion of eye present in front of the lens, and it comprises of two cavities; anterior chamber between cornea and iris and posterior chamber between iris and lens[1]. The two chambers are connected by the pupil and are filled with aqueous humor. Aqueous humor is secreted by ciliary body, it flows from the posterior chamber to the anterior chamber, and there it is drained into canal of Schlemm after passing through trabecular meshwork. Anterior segment can be considered as a dynamic area nourishment of which is maintained by constant formation and absorption of aqueous humor and is actively involved in the refraction of light. Assessment of anterior segment is important in diseases related to the cornea, iris, conjunctiva, corneoscleral junction, iridocorneal angle and ciliary body[2]. There are different imaging modalities available for visualization of anterior segment which include ultrasound bimicroscopy, specular microscopy, corneal topography and optical coherence tomography[3]. All these techniques have their own advantages and disadvantages. Anterior segment optical coherence tomography offers non-contact, non-invasive inspection of anterior segment of human eye. The objective of this review article is to focus on the significance of OCT and its preference over other modalities.

DISCUSSION

In this segment, we will explain the basic working principle of Anterior Segment OCT using some easy-to-understand diagrams and put light on some OCT modules commonly used in the clinics.

Optical Coherence Tomography

It is a noninvasive, noncontact technique, which allows accurate anatomical imaging of the eye in cross sections.

Basic Principle

The light emitting from a superluminescent diode is shone on to the eye. Some light rays are scattered back by the eye structures, which are then collected by a light detector. This back-scattered beam of light is compared with a reference beam that is reflected by a reference mirror. The coherence between these two beams is calculated by the computer[4,5]. As different tissues have different refractive indices, the light collected at the detector shows different refractive patterns when compared to the reference light. The light coming from the eye gives valuable information about the size, shape and depth of the eye structures in terms of intensity distribution of the reflecting light. The principle of OCT is similar to Ultrasonography but differ in type of waves used; Ultrasonography uses sound waves whereas OCT involves near-infrared light interferometry[6].

Types of Optical Coherence Tomography

Depending upon the type of reference mirror and the detector (Table 1, Figure 1), there are three types of OCT:

a. Time Domain OCT: Historically the first OCT machine designed, used a mechanically fast moving reference mirror; but the time delay in moving this mirror was too much[5]. To obtain the depth resolution, the mirror has to be moved at a constant velocity[4]. A complete travel of reference mirror is termed as A Scan. However, as pointed out it took far less A Scans per second.

b. Spectral/ Fourier Domain OCT: In this type of OCT, the point detector for the reference arm is replaced by a spectrophotometer. The reference mirror is static and the spectrophotometer simultaneously collects modulations with all the spectral components of the source spectrum. This results in a rapid production of A Scans.

c. Swept-Source OCT: This most advanced type of OCT uses a wavelength-changing laser as a light source. In this, a static mirror like SD-OCT is employed, but instead of spectrophotometer, a light detector is used. The laser with changing wavelength allows taking as much A Scans as possible i.e., up to a million per second[7].

Table 1: Comparison of commercially available anterior segment optical coherence tomography (OCT)[4,8].

Principle	Time Domain OCT		Fourier-Domain OCT					
			Spectral Domain OCT				Swept Source OCT	
Examples	Visante (Carl Zeiss Meditec, Dublin CA)	Heide-berg Slit-lamp OCT	Cirrus (Carl Zeiss Meditec)	Spectralis	3D-OCT (Topcon, Japan)	NidekRS-3000 Advanced (Nidek, Japan)	Casia (Tomey, Japan)	Triton (Topcon)
Light Source	Beam		Broad band Light Source (Spectrometer)				Swept-Source Laser	
Wavelength (nm)	1310	1310	840	820	850	880	1310	1050
Resolution (µm) Axial ×Transverse	18×60	25×20-100	5×15	3.9×14	6×20	7×15	10×30	2.6×20
Imaging speed (A-Scans /sec)	2,000	200	27,000 - 68,000	40,000	50,000	53,000	30,000	100,000

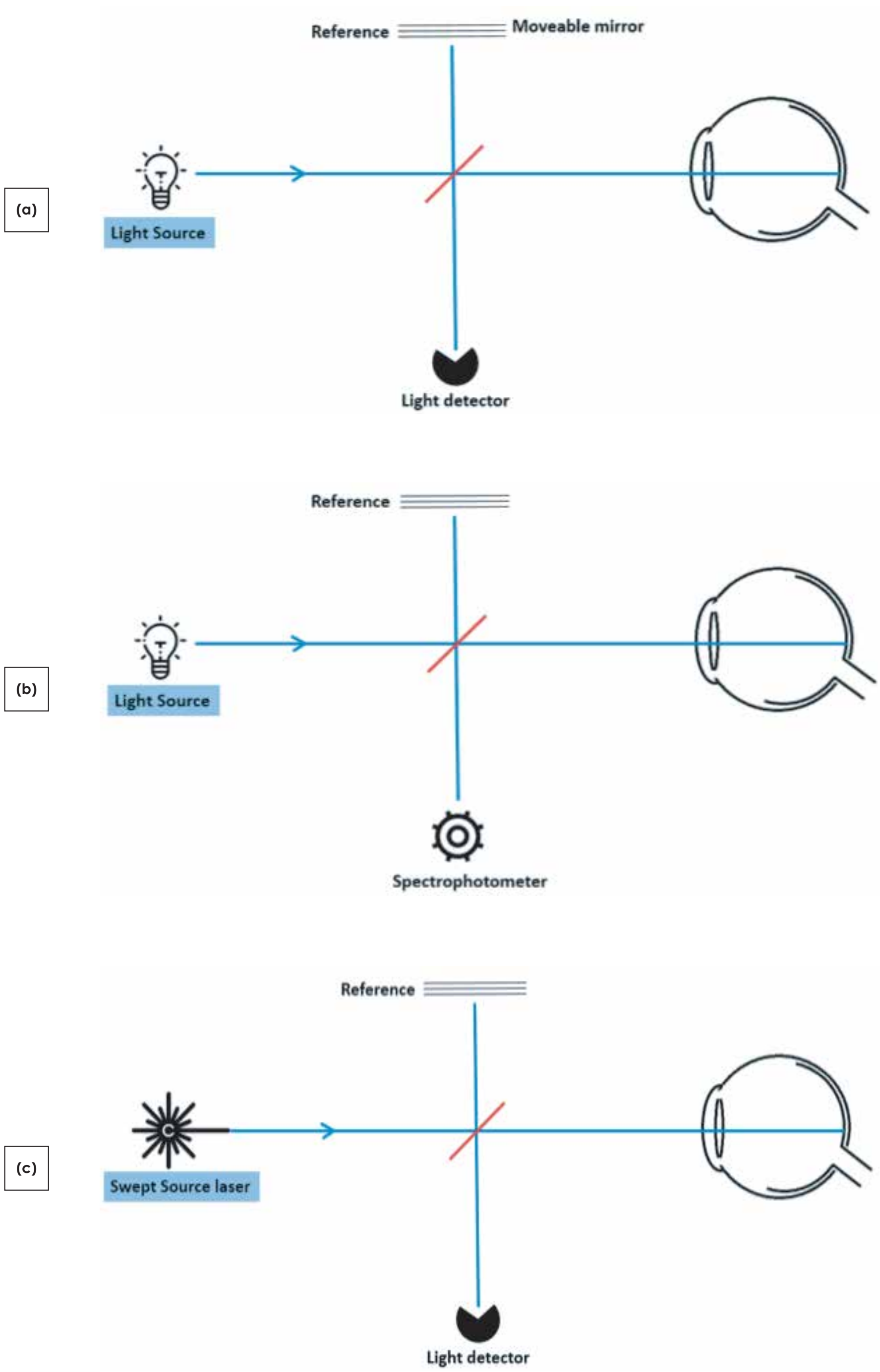

Figure 1: Basic working principle of three types of optical coherence tomography (OCT): (a) Time Domain OCT, (b) Spectral Domain OCT and (c) Swept Source OCT[5].

Clinical Applications of Anterior Segment-OCT

Since anterior segment OCT illuminates the anterior segment of eye, this segment discusses its uses in the study and evaluation of tear film, conjunctiva, cornea and anterior segment tumors.

Anterior Segment-OCT and Tear Film

Anterior segment-OCT has been successfully used to find the area, height, depth, curvature and even the volume of tear meniscus[5]. Tear film plays an essential role in protection and nourishment of the cornea. Between the blinks, the tear film is thinned and this involves many complex mechanisms[9]. Dry eye disease is a very common condition and it may lead to ocular discomfort and visual disturbances. The tear film thinning dynamics are cleared with the

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help of AS-OCT which enables the researchers to take multiple images of the tear film over time and used to make a sort of time-lapse photography of the tear film[10,11]. AS-OCT is also employed in the evaluation of meibomian glands[12]. The lacrimal gland anatomy along with all its ducts, lobules and parenchyma have been observed by the OCT[13].

Anterior Segment-OCT and Conjunctiva

Pinguecula is an extremely common condition in adults and manifests as yellowish nodules on conjunctiva on both sides of cornea. If left untreated, it may lead to pterygium in which a pinguecula encroaches on to the healthy cornea from nasal side[14]. AS-OCT plays an important role in identification of both pinguecula and pterygium which appear as edge-shaped hyper reflective masses just under the epithelium[15,16].

AS-OCT is also useful in diagnosis of conjunctiva related tumors. In case of conjunctival lymphoma, the lesion appears as hypo-reflective sub-epithelial structure surrounded by a hyper-reflective uninvolved epithelial lining[15]. In case of nevi or melanoma, the cystic space inside the lesion is also observeable[17,18].

Anterior Segment-OCT and Cornea

Cornea is the avascular and transparent part of the outer coat of the eye. It also adds to the refractive power of human eye. This segment explores the applications of anterior segment OCT in the normal as well as diseased cornea.

Anterior Segment-OCT and Normal Cornea

The cornea is the anterior most layer of the refractive system and along with tear film it provides about two third of the optical power of the eye[4]. Histologically, the cornea is composed of five layers including surface epithelium, Bowmans' layer, stroma of cornea, Descemet's membrane and the inner most being corneal endothelium[2]. Of these, stroma is the thickest. It is an acellular layer made up of interconnecting keratocytes and collagen fibers[19]. The endothelium is a single layer responsible for the transfer of the nutrients and other excretory materials. The average corneal thickness varies from 500-800 microns[20]. It is now possible to visualize all the layers with the help of AS-OCT[4].

Anterior Segment-OCT and Diagnosis of Corneal Diseases

Ectasia refers to dilatation of tubular structures, and in case of cornea the most common and most dangerous ectasia is the Keratoconus[21,22]. Keratoconus is a disorder in which the corneal stroma is progressively thinned. It results in loss of normal refractive power of the cornea and culminates in blindness[5,6]. AS-OCT has shown accurate results with improved reproducibility in determining the corneal thickness compared with Placido-Scheimflug imaging[23]. The progression of keratoconus is also observed using longitudinal AS-OCT studies[24].

AS-OCT has also shown promising results in the study of anterior segment pathology even in the presence of corneal edema. It successfully overcomes the use of slit-lamp microscopy in observing the infectious keratitis led corneal infiltrates[25]. In case of neoplasia of the ocular surface, AS-OCT provides clear images of thickened, hyper-reflective epithelium and also indicates the area of transition from normal to abnormal epithelium[15].

Anterior Segment-OCT and Corneal Surgery

While planning a cataract surgery on a patient with astigmatism of more than 1.0 diopter, Toric Intra ocular lens are often prescribed. In addition to spherical powers, these lenses have a cylindrical power as well[22]. Post operative care in these patients includes the evaluation of the tilt of these toric lens and AS-OCT is the instrument of choice in this regard[26]. AS-OCT has also shown changes in the iridocorneal angle after implantation of IOL[27].

Diseases of cornea are the second leading cause of non-refractive blindness in the world[28], therefore corneal transplantation remains the main method of treatment and restoration of vision[29]. In recent years, the advanced instruments and surgical techniques has allowed surgeons to replace only the diseased layer of cornea instead of entire corneal transplantation. These techniques have shown better corneal graft survival and improved post surgical outcomes[30]. Thus AS-OCT has been found helpful in determining the layers of cornea to be transplanted[20]. Similarly, AS-OCT is also employed to detect early graft detachment after corneal surgeries[31]. In case of corneal dystrophy, clinical decisions are also made easier by the use of AS-OCT regarding surgical technique required to remove scar tissue and corneal debris[27,32].

Anterior Segment-OCT and Aqueous Outflow System

The capillaries within the ciliary processes produce the aqueous humor, which then flows though the pupil and enters the anterior chamber. About ninety percent of reabsorption of aqueous humor is performed by trabecular meshwork[5]. From here, it is drained into lymphatic like channels called Schlemm's Canal (SC). The trabecular meshwork provides sufficient resistance to produce intraocular pressure[2].

The use of AS-OCT to assess trabecular meshwork is quite recent; the first study being published in 2008[4]. They used a customized SS-OCT system for this purpose. Later FD-OCT was used to assess the cross sectional area of Schlemm's canal[33]. Later studies extensively focused on the relationship between Schlemm's canal area and IOP[34-36].

The surgical options for glaucoma include Canaloplasty and Trabeculotomy, in which the surgeon tries to increase the drainage of aqueous humor[22]. AS-OCT has been found to be helpful in exactly determining the size of Schlemm's canal and it's correlation with IOP and anterior chamber width[30,37,38]. This information may prove helpful for the surgeon to find an appropriate surgical option for glaucoma patients.

Anterior Segment-OCT and Anterior Chamber Angle

It is the angle formed between the posterior surface of peripheral cornea and the anterior surface of iris, hence also termed as "iridocorneal angle"[39]. This peripheral part of cornea is also referred to as the corneoscleral limbus[2]. It is the drainage angle for aqueous humor and differences in this angle morphology are important for development of primary angle closure glaucoma. This angle is measured with traditional methods like gonioscopy and ultrasound bimicroscopy examination, but the accuracy of these methods was highly dependent upon the practitioners' experience and technique[40]. AS-OCT provides accurate, high-resolution non-contact cross-sectional images of anterior segment of the eye including iridocorneal angle[41].

The parameters that can be easily measured using AS-OCT include anterior chamber angle, angle opening distance (AOD) and trabecular-iris apace area (TISA). The built-in algorithms in AS-OCT allows accurate measurement of the parameters at different distances from scleral spur; most commonly at 500 or 750µm[42]. AS-OCT has shown significantly higher sensitivity in ACA measurement when compared with gonioscopy[43]. Many other risk factors for angle closure has been found with the help of AS-OCT like anterior chamber width, anterior chamber volume/area, iris thickness and lens vault[44,45].

Anterior Segment-OCT and Anterior Segment Tumors

The ability of OCT to show reflected light in different densities allows the surgeon to differentiate between the diseased or abnormal growth from a normal healthy tissue. For example, the ocular surface squamous neoplasia (OSSN) presents on AS-OCT as thickened, hyper-reflective epithelium and the transition from normal to abnormal is easily appreciable [15,46]. On the other hand, hypo-reflective sub-epithelial masses are identified as lymphoma. And if the cysts are found in this sub-epithelial mass, it will be regarded as nevi[5]. If the sub-epithelial lesion is hyperreflective and dense and present on the Bowman's layer, it is diagnosed as Salzmann's nodular degeneration[15,46]. Although ultrasound bimicroscopy is traditionally used for the assessment of ocular surface tumors, AS-OCT has shown far better sensitivity since it can provide exact extent, depth, location and anatomic relationship with surrounding structures[5,6].

Limitations of Anterior Segment-OCT

Since the basic principle of OCT depends upon the reflection of light from eye structures, its use may be limited when the cornea is pigmented because of some disease. In this case, successful reflection of light is inhibited. In such scenarios ultrasound bimicroscopy finds superiority because it uses ultrasound waves but the image quality is compromised[5].

Future of Anterior Segment-OCT

Currently available AS-OCT systems provide limited 5-20µm axial resolution of cornea[20]. Work is being carried out to obtain higher resolution and greater width with OCT. Few studies has shown resolution of 1-4µm[47,48]. In order to overcome, low intensity imaging of current OCT systems, a conical scan pattern is also used[49]. Similarly more sophisticated computer programs are being designed to obtain automated and accurate parameters from the anterior segment. The intra-operative use of OCT is also being advocated which has shown great help for the eye surgeon to make timely decisions.

CONCLUSION

Although the use of anterior segment-optical coherence tomography in Pakistan is very limited due to its unavailability at most tertiary care eye hospitals owing to its high price, this technique is explored all around the world and is being used for examination of normal eye structures as well as its associated diseases. Despite a few limitations, anterior segment OCT is rapidly proving to be a very useful tool and is definitely going to help in understanding of anterior segment eye structures and diagnosis of their pathologies.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

IU carried out the data mining and manuscript writing, KJJB brought forward the main idea, NH worked upon the content coherency of the article and SNNS provided comparative intellectual input.

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