Review Article for Residents

Anterior segment optical coherence tomography for evaluation of cornea and ocular surface

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Current corneal assessment technologies make the process of corneal evaluation extremely fast and simple. Several devices and technologies allow to explore and manage patients better. Optical coherence tomography (OCT) technology has evolved over the years, and hence a detailed evaluation of anterior segment (AS) structures such as cornea, conjunctiva, tear meniscus, anterior chamber, iris, and crystalline lens has been possible in a noncontact and safe procedure. The purpose of this special issue is to present and update in the evaluation of cornea and ocular surface, and this paper reviews a description of the AS-OCT, presenting the technology and common clinical uses of OCT in the management of diseases involving cornea and ocular surface to provide an updated information of the clinical recommendations of this technique in eye care practice.

Key words: Anterior eye, anterior segment-optical coherence tomography, cornea, dystrophy, keratoconus, ocular surface, tear film

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Optical coherence tomography (OCT) first appeared in 1991 for imaging the posterior segment of the eye,[1] and 3 years later, first anterior segment-OCT (AS-OCT) was proposed as a noncontact and noninvasive imaging technique that captures high-resolution cross-sectional images of the anterior eye segment.[2] AS-OCT has been found to be useful in exploring the AS of the eye, mainly the cornea, anterior chamber, and chamber angle,[3] but other anterior eye structures such as iris and crystalline lens could be assessed as well. OCT imaging is based on measuring the delay of light (typically infrared) reflected from tissue structures.[3] The technology utilizes a Michelson interferometer, which creates a reference beam usually of infrared light against which it measures multiple other beams of light as they return from the variably reflective tissue layers of the eye. The device collects reflected light from the sample at reference beams, thereby creating an interference pattern. Multiple interference patterns are created over the surface of the structure being imaged. As the instrument scans, a series of A-scans is created. These A-scans are combined into a composite cross-sectional image (B-scan). Each A-scan contains information on the strength of the reflected signal as a function of depth. There are currently two major different types of OCTs. Time domain OCT (such as the AS-OCT Visante [Carl Zeiss Meditec, Inc., Dublin, CA, USA]), in which varying the position of the reference mirror produces cross-sectional images and Fourier-domain OCT (such as the three-dimensional (3D)-OCT [Topcon Medical Systems Inc., Paramus, NJ, USA], the slit lamp-OCT [Heidelberg Engineering GmbH, Heidelberg, Germany], and the RTVue (Optovue, Inc., Fremont, California)], in which the reference mirror is fixed and Fourier transformation of the spectral interferogram results in the cross-sectional images. The Fourier domain system provides faster acquisition times than time domain systems and its higher resolution allows visualization of more details.

AS-OCT systems are characterized by wavelength of light sources.[4] Dedicated systems use 1310 nm.[3] where as systems converted from a retinal scanner use 830 nm. Due to different light sources, there are differences between the two groups. A shorter wavelength 830 nm, near infrared system, provides a higher axial resolution, but its imaging depth is limited. On the other hand, the longer wavelength system provides a deeper tissue penetration. A technological change from time domain OCT to spectral domain OCT (SD-OCT) has dramatically increased the image acquisition speed and resolution of OCT devices, allowing for clear delineation of AS tissues. As A-scans are captured in SD-OCT instruments, they provide a higher speed of image acquisition and shorter wavelengths making them capable of improved axial resolution of 4–7 μ. These devices have a horizontal scan width of 3–6 mm. Swept source OCT is slightly different form of SD-OCT having a wavelength of 1310 nm but a horizontal scan width of 16 mm. With a longer

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wavelength light source and increased penetration properties, swept source OCT provides better signals from deeper regions. Ultra-high-resolution OCT technology is characterized by an axial resolution of 1–4 µ allowing more precise imaging of AS. The ultra-high-resolution OCT devices are generally used in academic settings.[5]

A horizontal OCT examination of healthy cornea shows a highly reflective tear film over epithelium, Bowman's layer, stromal layer, Descemet's membrane, and endothelium. The AS-OCT is able to assess a wide range of AS parameters with several uses in different ocular conditions.

Dry Eye/Tear Film Evaluation

Tear volume measurement

The assessment of tear volume in dry eye patients helps the clinician in making an accurate diagnosis, develops a differential diagnosis and following up these patients to assess the response to treatment. Conventional diagnostic dry eye tests such as Schirmer's test have some disadvantages highlighting that (1) this is an invasive method that stimulates reflex tearing, (2) their results are variable, and (3) its reliability is low. AS-OCT allows to capture and measure an image of the tear meniscus. Tear meniscus appears as triangular shape of wedge of tear film between the lower lid margin and ocular surface. Three parameters are measured in the image using measurement software; tear meniscus height, tear meniscus depth, and tear meniscus area. Both tear meniscus height and tear meniscus area are found to have the ability to discriminate between healthy and dry eye patients.

Assessment of corneal and conjunctival epithelial thickness

AS-OCT can provide a noninvasive evaluation of epithelial thickness. Tear dysfunction is known to affect corneal, limbal, and bulbar conjunctival epithelial thickness and other diseases and conditions could induce corneal conjuntivalization, for example, limbal stem cell deficiency (LSCD) or ocular burns. In these cases, AS-OCT allows the evaluation of conjunctivalized corneas, helping in determining the surgical treatments reducing corneal graft rejection.[6] This examination helps to assess autologous simple limbal epithelial transplantation (SLET) in patients with LSCD,[7] helping to conduct and intraoperative scanning and pachymetry mapping to guide and assist in the removal of the delicate fibrovascular pannus.[8]

Assessment of Meibomian glands

3D images of Meibomian glands' patient using advanced OCT technology are found to show healthy Meibomian glands as clusters of grapes. The Meibomian glands are found to be parallel to each other, and the saccular acini were clearly visible.

Assessment of Corneal Opacity in Children

AS-OCT has been found to be a valuable tool in diagnostic evaluation of children with congenital corneal opacity.[9] This method can be applied to children even at the age of few days because handheld OCT provides a novel tool to help in pediatric eye diseases' diagnosis and management, which could help in early treatment and optimize visual outcomes in these patients.[10] OCT is helpful in early characterization of the type and the extent of AS disorder. Three distinct phenotypes of congenital corneal opacity were observed.

a. Type-I Peter's anomaly: Central corneal opacity with iridocorneal adhesion
b. Type-II Peter's anomaly: Central corneal opacity with lenticular corneal adhesions
c. Congenital corneal staphyloma: Complete corneal opacity characterized by anterior bulging of ectatic cornea and pigment epithelium cell lining of the posterior corneal surface. Sclerocornea represents limbal vascularized corneal opacity with obscured border between sclera and cornea.

Characterization of type and extent of disorder is essential for the assessment of guidelines for treatment and prognosis. Outcome of surgical intervention depends clearly on the clinical phenotype. Corneal transplantation provides moderate-to-good prognosis in eyes with few iridocorneal adhesions whereas in eyes with lenticulocorneal adhesions, the prognosis is poor.

Anterior Segment Tumors

AS-OCT can penetrate in small hypopigmented tumors, but ultrasound biomicroscopy shows superior ability to penetrate in large tumors, highly pigmented tumors, and ciliary body tumors.[11] However, primary stromal iris cyst could be explored with OCT,[12,13] and recently, OCT angiography has been used to evaluate tumor vasculature in malignant iris melanomas and benign iris lesions providing a dye-free, no-injection, cost-effective method for monitoring these patients.[14]

Diagnosis of Ocular Surface Squamous Neoplasia

On ultra-high-resolution OCT ocular surface squamous neoplasia had these classical features:[5] (a) hyperreflective thickened epithelial layer, (b) abrupt transition from normal to abnormal epithelium, and (c) distinct plane between the lesion and the underlined tissue.

Keratoconus Diagnosis and Treatment

In keratoconus, focal thinning and corneal asymmetry are evaluated on AS-OCT. Focal corneal thinning is a more specific indicator of keratoconus. Several parameters for detecting asymmetry and thinning have been reported.[15] Pachymetric diagnostic parameters include (a) minimum-median, (b) inferior-superior, (c) inferotemporal-superonasal, (d) minimum, and (e) vertical location of the minimum.[16] Focal thinning was captured by minimum-median and minimum parameters. Asymmetric thinning was captured by inferior-superior, inferotemporal-superonasal parameter, and by the vertical location of the minimum locations (superior to the corneal vertex had positive values and locations inferior to the vertex had negative values). Swept source Fourier domain AS-OCT is found to discriminate healthy eyes from subclinical keratoconus.[17] AS-OCT is found useful to find the depth of demarcation following corneal collagen cross-linking.[15] In keratoconus patients, AS-OCT is found useful for qualitative evaluation of the cornea before and after implantation of the intrastromal ring.[18] AS-OCT is found useful to evaluate the Descemet's membrane tear, dimensions of intrastromal clefts, and corneal thickness in acute corneal hydrops of keratoconus [Fig. 1].[19] AS-OCT is also useful in assessing the response of treatment following interventions such as injection of sulfur hexafluoride (SF_6)/perfluoropropane (C_3F_8) gas into the anterior chamber [Figs. 2 and 3].

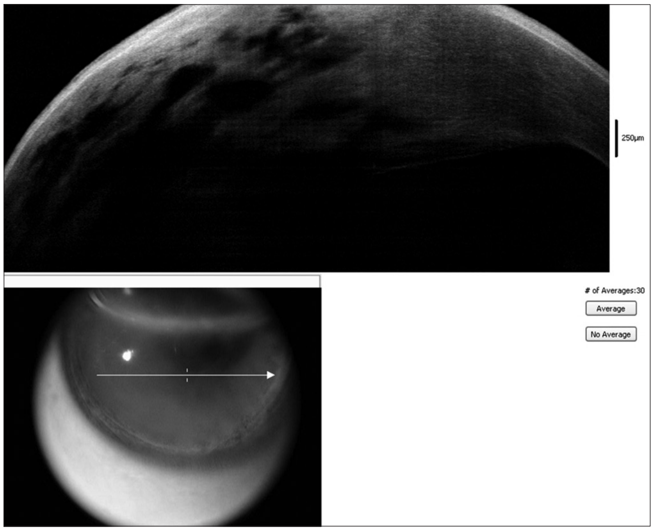

Figure 1: Anterior segment-optical coherence tomography of acute corneal hydrops showing Descemet's membrane tear and intrastromal cleft

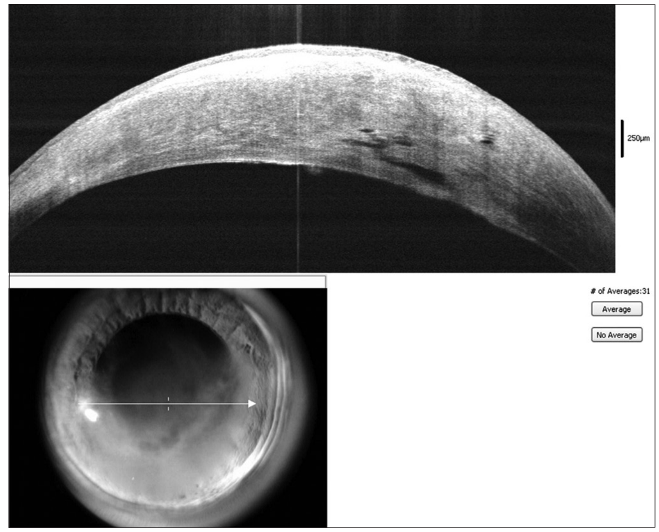

Figure 2: Anterior segment-optical coherence tomography of same patient showing healing in response to injection of C3F8 gas

In Refractive Surgery

AS-OCT is helpful in visualization of flap thickness, flap interface, and look for any flap displacement following LASIK surgery. OCT is useful in measuring residual stromal thickness, following LASIK surgery. Using femtosecond laser, the flaps were more accurate, reproducible, and uniform compared to those created by microkeratome. One week following surgery, LASIK flap thickness can be measured using AS-OCT. During surgery, AS-OCT has been used as a rescue tool for difficult lenticular extraction in SMILE surgery to identify the cause for retained lenticle.[20] Other possible application of the AS-OCT after myopic laser is the calculation of the corneal power to improve the selection of the intraocular lens (IOLs) power in cataract surgeries.[21] AS-OCT is of great utility in other nonlaser refractive surgery techniques, for example, to assess phakic IOLs (pIOLs) implantation, allowing the visualization of the pIOL in the anterior chamber with high-resolution images, measuring pIOL position, distance with crystalline lens, etc.[22,23] AS-OCT, also, provides valuable information in other excimer surgical procedures such as PTK and to assess the morphology of corneal flaps created with femtosecond lasers in LASIK surgery.[24]

Corneal Infections

AS-OCT helps in evaluation of microbial keratitis and assessing treatment response objectively.[25,26] Infiltrate is seen as hyperreflective areas in corneal stroma on high-resolution scans [Fig. 4]. Retrocorneal pathologic features, anterior chamber inflammation, and width of endothelial plaque can be assessed by AS-OCT. In full thickness infiltrate using slit-lamp biomicroscope, the details of infiltration are not clearly visible. In fungal keratitis, two unique patterns of early localized and diffused necrotic stromal cystic spaces are seen on AS-OCT.[26] AS-OCT has been found for localizing microcystic edema and keratic precipitates in patients with herpes simplex virus stromal keratitis. Cytomegalovirus corneal endotheliitis on AS-OCT showed protruding structures from the posterior cornea.[27] These structures exhibited dendritic, doom-shaped, quadrangular, saw-tooth appearance, and reflectivity of posterior corneal images from the endothelium and deep stromal corneal regions was also high. These high-intensity regions resolved after antiviral treatment.

Corneal Deposits

AS-OCT would be extremely useful to see early drug deposits and early Kayser–Fleischer rings of Wilson disease which is missed by slit-lamp biomicroscope. Kayser–Fleischer ring was seen as hyperreflectivity at the level of Descemet's membrane in the peripheral cornea [Fig. 5].[28] Amiodarone-induced keratopathy was observed as highly reflective and bright intracellular inclusions in the epithelial basal layer.[29]

Descemet's Membrane Detachment and Keratoplasty

AS-OCT is found to demonstrate various types of Descemet's membrane detachment including planar/nonplanar, local/extensive detachment, and rupture.[30] AS-OCT is valuable for selecting appropriate treatment and monitoring the treatment outcomes when corneal edema is present [Fig. 6]. Anecdotal reports of intraoperative use of OCT-assisted descemetopexy for nonresolving Descemet's membrane detachments are available in literature.[30] AS-OCT has been found to provide useful information after keratoplasty surgeries including penetrating keratoplasty, Descemet's stripped endokeratoplasty, and Descemet's membrane endokeratoplasty (DMEK) surgeries, automated lamellar therapeutic keratoplasty, and others.[31-33] OCT is extremely useful in detecting early graft detachment after DMEK surgery and also to find interface fluid between the host cornea and the graft. Intraoperative use of OCT for corneal surgery has been reported with enthusiasm.[31-33] Finally, this technology could be of great utility in keratoprosthesis patient management, helping in monitoring anatomical stability of an implanted keratoprosthesis (evaluating the anterior keratoprosthesis cornea interface).[34] AS-OCT, also, helps in quantitative evaluation of AS and angle after keratoprosthesis, to identify changes that are sometimes difficult to appreciate

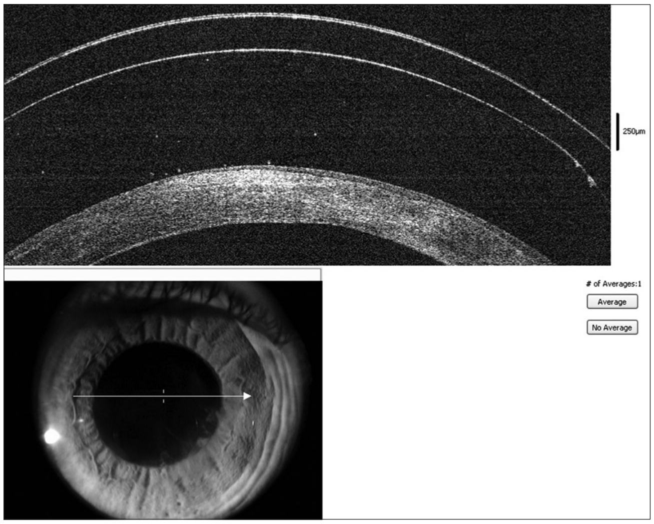

Figure 3: Anterior segment-optical coherence tomography of the same patient following healing of Descemet's membrane tear. Note the scleral contact lens

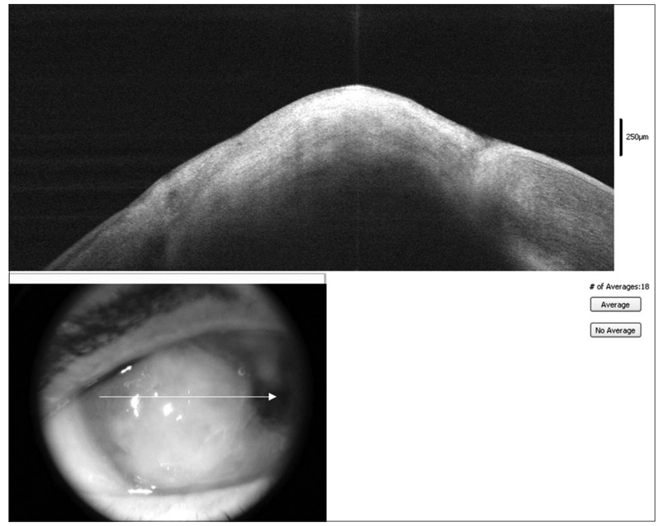

Figure 4: Anterior segment-optical coherence tomography of fungal keratitis

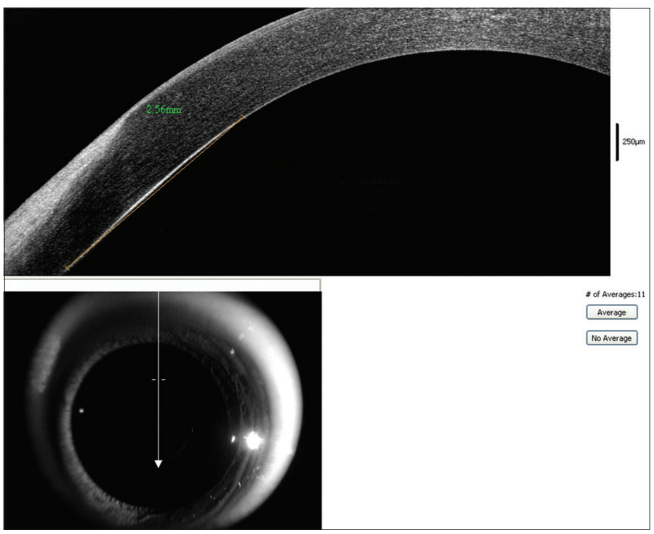

Figure 5: Anterior segment-optical coherence tomography of a patient with Wilson disease showing Kayser–Fleischer ring as hyperreflectivity of peripheral Descemet's membrane

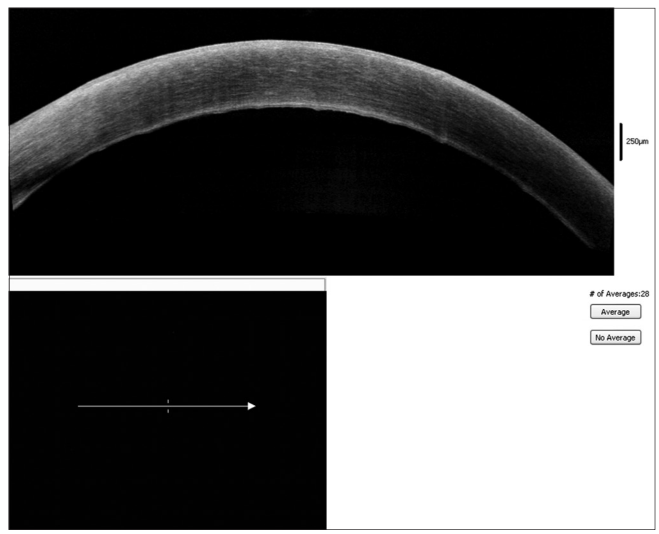

Figure 6: Anterior segment-optical coherence tomography of patient with systemic sclerosis showing Descemet's membrane scarring and corneal edema

by clinical evaluation because majority of eyes show shallow anterior chamber depth, extensive angle closure, and synechiae formation.[35,36]

Corneal Dystropies

AS-OCT has allowed us to detect depth, extent, and distribution of material in different corneal layers in patients with corneal dystrophies.[37] This information helps to make decisions between superficial laser treatment and corneal surgery. The reported AS-OCT features in different corneal dystrophies are as follows: (a) Epithelial basement membrane dystrophy where AS-OCT imaging has showed irregularities of the basement membrane with protrusions into the corneal epithelium. The epithelium is found to be thin. (b) Meesmann corneal dystrophy where AS-OCT imaging revealed disseminated hyporeflective cysts of the epithelium and thickening of the basement membrane. (c) Gelatinous drop-like corneal dystrophy where AS-OCT imaging has showed dense, hyperreflective, nodular formations on the level of the basal epithelial layer. Epithelium had irregularities and sometimes seemed to be disrupted. (d) Reis-Buckler's corneal dystrophy where AS-OCT images have found revealed dense hyperreflective material at the level of the Bowman layer, which is thinner in the periphery. (e) Thiel–Behnke corneal dystrophy where AS-OCT imaging has showed typical saw-toothed, hyperreflective deposits on the Bowman layer. (f) Lattice corneal dystrophy where AS-OCT imaging has showed spread out material at the level of the Bowman's layer extending to the anterior stroma. The epithelium is partially thinned and atrophic. The Bowman layer is disrupted or absent. (g) Granular corneal dystrophy Type I where an AS-OCT image has showed large, lattice-like, and superficial dense and hyperreflective deposits, especially in the anterior stroma and epithelium. The Bowman layer is irregular and sometimes found disrupted. (h) Granular corneal dystrophy Type II where AS-OCT images show large, lattice-like, and superficial dense and hyperreflective deposits, especially in the anterior stroma and epithelium. The Bowman layer is irregular and sometimes found disrupted. (i) Macular corneal dystrophy where AS-OCT has depicted distinct and disseminated hyperreflective small areas in the whole corneal stroma and a generally increased hyperreflectivity in between the stromal collagen lamellae. (j) Schnyder corneal dystrophy where AS-OCT has demonstrated dense and hyperreflective organized material in the anterior corneal stroma, not involving the epithelium or Bowman layer. (k) Congenital stromal corneal dystrophy where AS-OCT imaging has showed diffuse hyperreflective material in the whole corneal stroma. (l) Fuchs 'endothelial corneal dystrophy where AS-OCT images show a thickened Descemet's membrane and small nodular formations of the endothelial cells. (m) Posterior polymorphous corneal dystrophy where OCT has showed a thickened Descemet's membrane as well as amorphous hyperreflective material and deposits on the back of the cornea, protruding into the anterior chamber. (n) Congenital hereditary endothelial dystrophy where AS-OCT imaging has revealed diffuse corneal edema and haze, thickened Descemet's membrane, and irregularities of the Bowman layer.

Crystalline Lens Assessment and Cataract Surgery

High-resolution OCT allows to evaluate the anterior lens capsule in pseudoexfoliation patients (thicker than in normal patients)[38,39] and predict postoperative (IOL) tilt, and assist in IOL (toric) power calculations to improve visual outcome after cataract surgery.[40] Moreover, AS-OCT has been useful to evaluate the wound characteristics of clear corneal incisions of cataract surgery, analyzing incision angle, incision length, corneal thickness, epithelial side closure of the incision or epithelial gaps, endothelial side closure or endothelial gaps, and Descemet's membrane detachment, helping in detecting a high rate of structural abnormalities.[41,42] AS-OCT should help cataract surgeons in the selection of appropriate corneal incision instruments and surgical techniques.[41]

In Glaucoma Drainage Implant Surgery

AS-OCT has been used for bleb imaging after Ahmed glaucoma valve implantation to assess internal structure, facilitating the investigation of surgical outcomes and pathogenesis in after surgery patients follow-up.[43]

In Contact Lens Practice

AS-OCT has been used to monitor corneal swelling in continuous contact lens wear without contact lens removal.[44] Moreover, this technology is of great utility in scleral gas permeable contact lens fitting in irregular corneal patient management to improve vision and comfort.[45]

Conclusions

AS-OCT has become an important tool in the evaluation of cornea and AS. This technology is helping the clinician to see corneal pathology better when slit-lamp biomicroscope and other techniques cannot give enough details. AS-OCT is found useful in understanding deep corneal and retrocorneal pathology better. AS-OCT is becoming a routine tool in cornea and anterior eye practice including contact lens practice. Moreover, this technique is of paramount importance in several surgical procedures (corneal and noncorneal refractive surgery, cataract surgery, corneal keratoplasty, Glaucoma drainage implant surgery, and others).

Current reported use of AS-OCT in corneal disorders can be remembered by 7 Ds: (1) determining the thickness of cornea and corneal flaps, (2) depth of corneal lesions including dystrophies, (3) details of corneal inflammation, (4) Descemet's membrane assessment, (5) deposits in cornea, (6) dry eyes assessment, and (7) diagnosis of surface neoplasia in early stages.

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Conflicts of interest

There are no conflicts of interest.

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