ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, *Vol 10(29), DOI: 10.17485/ijst/2017/v10i29/98625, August 2017* ISSN (Online) : 0974-5645

A Narrative Study of Diagnosing Various Retinal Diseases using Optical Coherence Tomography

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Abstract

Objectives: The aim of the study is to review working principles of Optical Coherence Tomography (OCT), and to describe its use in the diagnosis and management of various retinal diseases in medical field. **Methods/Analysis:** Qualitative analysis such as Morphological alterations, Anomalous structures, 3-D & C-scan studies, increased and decreased reflectivity. Quantitative analysis includes retinal layer thickness measurement, volume and mapping. Interpretations of Spectral Domain OCT (SD-OCT), images to analyze abnormalities in retinal layers in z-depth or 3D scan or C-scan. SD-OCT visualizes ocular structures of retinal diseases in unprecedented 3-D views. It provides an accurate analytic and synthetic study of Retinal Deformations, Retinal edema, Macular Pucker, Macular hole, irregular foveal depression. **Findings:** In 3-D studies of macular cube, B-scan of the retinal profile gives an absolute representation of optical tissue for the study and measurement. The thickness of Fovea is about 160 - 180 microns and the resolving power measured using the A-scan study is under 4 microns. In case of ARMD-Age- related Macular degeneration (Drusen), the yellow deposits in between RPE (Retinal Pigment Epithellium) and Choroid layer is identified clearly. OCT finds that the RPE atrophy is dynamic and also the external membrane or layers of the retina. In case of Pseudo-vitelliform macular degeneration OCT shows a non-transparent yellow-orange sub-retinal deposit and a central retinal detachment. For Glaucoma disease OCT provides accurate images and this allows us to understand the physical structure (morphology) of the optical disc and the peri-papillary nerve strands. In Central Serous Chorio Retinopathy (CSCR) OCT display a little gaps/discontinuity in the RPE at the dispersion location within the serous RPE separation. Various diffusion points shall be visible around the area towards Bruch's membrane around RPE. Cystoid Macular Edema displayed by showing destruction of the Muller glia cells, leading to cystoid cavity formation inside the retina. **Novelty/improvement:** Future work is towards the study of determining and analyzing macular degeneration by SD-OCT tool to diagnose possible symptoms for the disease by identifying affected retinal layers through OCT images using improved mmethodologies like image pre-processing, segmentation and classification based on specific algorithm in neural networks.

Keywords: Interpretation-Retinal SD-OCT Images, OCT Generation, OCT Retinal Layers, OCT Retinal Diseases, OCT in All Fields

1. Introduction

The Optical Coherence Tomography (OCT) principle for imaging by Drexler and Fujimoto was first introduced and demonstrated in 1991 and the entire application is explained and demonstrated. From the past 20 years OCT has developed into an important imaging tool in ophthalmology for the study and examining retina and its surrounding tissue in particularly.

The OCTs are not only applied in ophthalmology field but most of the research is done in other fields as follows. Cardiology, Oncology, and Dermatology, gastroenterology, Neurology, Ovarian imaging and Artwork diagnostics.

Specifically OCT plays a vital role in the field of medicine. In the beginning OCT was demonstrated for retinal imaging and then available commercially in 1996.

OCT is an interferometric imaging technique that

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finds living tissue without involving instruments inside the body. This method maps depth-wise reflections of infrared light from tissue to form micron resolution cross-sectional images of morphological features. OCT empower on 3D imaging i.e., cross sectional view which is needed for various applications from medical applications for tissues testing to the area of manufacturing.

OCT traces its origin to the field of optical coherence–domain reflectometry, a 1-D mapping procedure that was originally developed to concentrate on reflections from faults in fiber optic networks and extended to biological applications[1–3].

2. Principals of OCT Technology

OCT uses a principle called low coherence interferometry to view the internal information of many retinal structures. This interferometry is used to construct a cross-sectional view of ocular images which is less than 10microns.

Interferometry means superimposing more light waves which create an output wave that is different from the input waves.

This is performed by differentiate the time difference in reflected light from the retina at different depths.

Differences between the reflected light and the reference standard give us the structural information in the form of A-scans. This shown in the below (Figure 1). In this figure more number of scans named (A) is combined into one image to produce a single scan called B. The former scans are the intensity of reflected light at various retinal depths at a single point of retina.

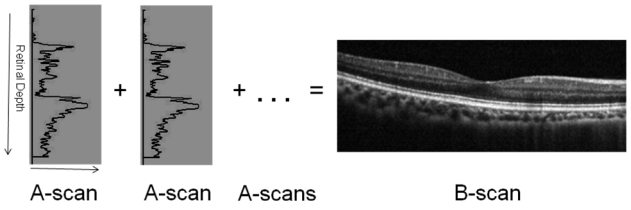

Figure 1. Combining many A-scans produces a B-scan.

2.1 Resolution

Multiple (A) type scans are combined to form a single image which constitutes a resolution capacity of around 10 to 20 microns vertically and planarity that graphically pictured in (Figure 2). This figure compares OCT imaging with standard imaging that explains the penetration depth of OCT. Contrast that with the resolving power of a best ophthalmic ultrasound at 100 microns.

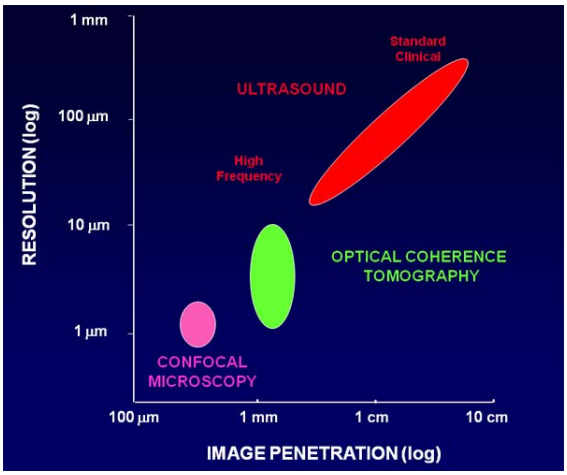

Figure 2. Resolution range (OCT vs. standard imaging)[18].

2.2 Practical Realizations of OCT

Different practical realizations are categorised into first, second, third generations. Based on limitations in each type of OCT, the next generation is introduced.

2.2.1 The First Generation- Time Domain OCT (TD-OCT)

The structure of TD-OCT enables coherence at different possible depth positions in the arm of the equipment thereby repositioning the reference mirror, e.g. In Full-Field OCT, the intrusion model for a 2-D collection is observed simultaneously by a 2D detector structure. It consists of 1- Detector and each A type scan needs the movement of a few mechanical parts. TD-OCT drawbacks are,

- Very complexity i.e., this OCT will produce ~ 400 A-scans per sec.
- It will take much time to capture the image.
- Tend to produce poor image quality in movement artifacts and when patient flickering.
- In some circumstances there may be error in quantitative and qualitative measurements.

2.2.2 The Second Generation: FD-OCT or Spectral-Domain OCT (SD-OCT)

Here the reference mirror is fixed and the intervention model is found and changed to geographical data by the

Fourier Transformation (FT). Further this OCT branched into Spectrometer based OCT (Sp-OCT).

It is a high speed high resolution OCT and its frequency swept light source at around 850-1040 nm. For some difficult cases, retinal specialists use this image for decision making. The produced OCT 3-D projection image can be then aligned with the actual fundus image to provide pixel-to-pixel registration. Mainly helpful in applications of some disease such as neovascular AMD[4,5].

2.2.2.1 SD-OCT Problems

- Lack of movable parts in reference arm of the interferometer[6].
- Signal strength and depth resolution is dependent on the path difference between the retina and the reference mirror
- Expensive

2.2.2.2 Anterior Segment (AS)-OCT

Is a well known and frequently used technology to image the posterior segment? AS-OCT was ideal for detailed imaging of structures from the surface of the eye to the iris plane.

AS-OCT is used for enhancing the process of surgical planning and postoperative care. AS-OCT applications include identifying and evaluating abnormalities and variations in the anterior angle of cornea, iris and lens.

2.2.2.3 Ultra-High Resolution OCT

In UHR-OCT even the microstructure of the retinal tissues can be visualized with higher resolving power. This type of OCT enables us to view the inner part of retinal layers and non-transparent tissues with high resolution. Thus this technology has been explored in clinical settings to survey its clinical utility.

2.2.3 The Third Generation: Swept-Source OCT (SS-OCT)

In this type detection is performed by a single photodiode. Here inference septra is measured by changing the wavelengths of the monitoring light with time. This is accomplished by using a Sweep Source laser (SS) as the light source. This device has ability in change of the wavelength generated over a range of 100nm within a couple of microseconds[7–11].

This type of OCT quickly scans using its enabled source and the spectral dimension and replication of the interferometer is identified by a uniform detector.

But generally there might be various assets and liabilities for these above said techniques, making them highly or moderate useful for certain applications.

3. Retinal OCT

3.1 Description

OCT is a non-invasive ocular perceiver testing, works without making any physical contact with the eye (ocular perceiver). This instrument beams light through eye tissue and accumulates the reflected light signal and constructs three-dimensional (3D) color images that enable us by seeing and analyzing any abnormalities in the layers and structure of the retina.

The retina is a sensitive two-layered membrane which is at back of the eye. Retina changes lights and images that enter the eye into nerve signals that are sent to the cerebrum of the brain. A part of the retina called the macula makes vision sharper and more detailed

Image of the retina viewed in the OCT scan is seems like performing a biopsy of the retinal layers vertically, but this efficient technique make use of light rather than using knife as biopsy done using this. The OCT images visible here in "false-color" with a high resolution capacity. This method is equivalent to ultrasound, whereas we use light waves rather than sound.

The overall retinal OCT profile of normal fovea through OCT imaging is shown in the below (Figure 3). In this image the OCT identified fovea by its normal depth (depression). i.e., the normal foveal profile is a slight break or hollow like in the middle surface of the retina, as pictured below.

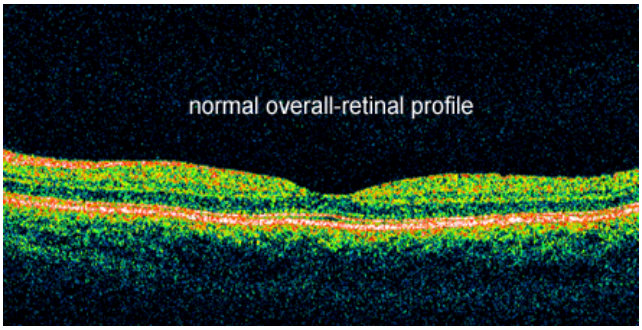

Figure 3. The overall retinal profile[19].

3.2 How OCT Scans the Retinal Layers

OCT gives target proof to treatment choices for different retinal ailments. OCT uses the light upon the macular and retinal into cross-section view of all its layers so unobtrusive issues introducing themselves in any of its layers underneath the layered surface area that might effectively be missed by other equipment's or by specialist's perspective, can be identified easily by the OCT image.

Let us assume the retina as a piece of some desserts. The Optomap machine gives only the surface or the upper layer on the dessert, while the OCT views the layers below in-depth and in addition it gives perfect resolution views for detecting various underneath of the item pictured.

By this method OCT detect appropriately some of the general retinal diseases and its layers affected diseases such as Macular Holes, Diabetic Macular Edema, Choroidal Neo-Vascular Membranes, CSCR (Central Serous Chorioretinopathy), Epi-Retinal Membranes, Glaucoma, Age-related Macular degeneration (Drusen), etc. can easily be detected by the OCT, but may be more difficult to notice in other techniques. Additionally, OCT give a clear view of the NFL (Nerve Fiber Layer) and the ganglion cell complex layer in the macular for detection of glaucoma disease to the earliest.

3.3 Retinal Vs OCT Pathology in Layers

Retina pathology in layers

Inner retina

- Diabetic Retinopathy (DR)
- Retinal vein occlusion

Outer retina

- AMD (Age-related Macular Degeneration)
- CSR (Central Serous Retinopathy)

OCT pathology in layers

Retinal surface

- Vitreo-macular traction
- Epi-retinal membrane

Inner retina

- DR
- Retinal vein occlusion

Outer retina

- AMD
- CSR

3.4 OCT Vs Fluorescein Angiography (FA) in Retinal Diagnosis

3.4.1 Fluorescein Angiography (FA)

FA provides incredible representation of retinal circulatory system (blood stream) over time, and in addition size of data on the 2D (x and y) axis (east-west, north-south).

In the image given below (Figure 4), the OCT scan gives information in the third depth axis called z-axis, giving us the affected layers of the retina and for imaging and measurement of various ocular structures in-depth by identifying all retinal layers accurately.

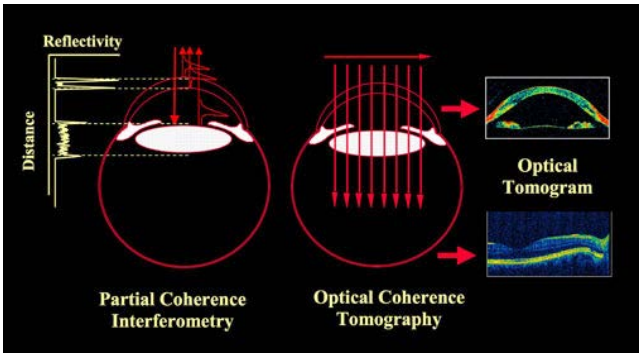

Figure 4. OCT- allows for imaging and measurement of various ocular structures in-depth by identifying retinal layers accurately[18].

For analyzing retinal layers the OCT image can be again divided into four regions

- the pre-retinal layer
- the epi-retinal layer
- the intra-retinal layer
- the sub-retinal layer

3.4 OCT Layers- Retinal Labeled Layers

The primary layers of the retina from innermost surface to outermost surface through OCT as shown in (Table 1).

The below table gives the 10 micro layers of retina from inner layer ILM to outer layer RPE and its characteristics

Table 1. Retinal OCT layers (from inner to outer region)

No.	Layers	Characteristics
10	Inner limiting membrane	End point of muller cells & their basement layer
9	Optic nerve fibers	Unmyelinated (fibres having no myelin sheath covering) axons of ganglion cells
8	Ganglion cell layer	Nuclei of ganglion cells
7	Inner plexiform layer	Neural connections between axons of bipolar cells
6	Inner plexiform layer	Nuclei of horizontal, bipolar, amacrine, & muller cells
5	Outer plexiform layer	Neural connections between axons of bipolar and dendrites of ganglion, retinal veins might reach out to this layer
4	Outer nuclear layer	Nuclei of rods & cones
3	External limiting membrane	Zonula adherens between rods/cones & muller cells
2	Photoreceptor layer	External segment with membrane disks, associating cilium & internal segment of rods & cones
1	Retinal pigment epithelium (RPE)	Has tight intersections at apical border to form blood-retina barrier

by how each retinal layers with its characteristics is identified through OCT scanning.

3.4.1 Retina

The 10 layered retina are described above and the retina has a number of specialized areas which include,

3.4.2 Optic Disk

The site where optic nerve fibers converge to form the optic nerve. It lacks rods and cones and so it is called a blind spot.

3.4.3 Macula

Is a small yellow area (due to the presence of Xanthophil pigment) located lateral to the optic plate or disk. Center part of the macula is the fovea, which is composed of cons linked to a single ganglion cell, there by producing the highest visual acuity and colour vision.

4. OCT Diagnosis Retinal Images

4.1 OCT Permits both Qualitative and Quantitative Study of the Retinal Layers

4.1.1 Qualitative Analysis

Includes distinguishing or depicting morphological changes and anomalous structures in the retina. Morphology is the analysis of structures of living creatures.

4.1.2 Quantitative Analysis

Involves evaluation of the retina, especially retinal layer thickness and volume, and NFL thickness.

This is possible only by the OCT tool because OCT able to diagnose and make track of a pair retinal layers, the NFL and RPE (Retinal Pigmented Epithelium)[12].

4.2 OCT Retinal Scan-Qualitative Analysis

- Fast Macular Thickness Scan / FMT
- Line Scan
- Cross Hair Scan

(Figure 5) demonstrates the OCT scanning for Qualitative analysis for retina. In this figure there are 3 types of OCT Scan viewed in different scanning methods and patient positions.

FMT scan Line scan Cross-hair scan

Figure 5. OCT scan for qualitative analysis..

4.2.1 The FMT Scan

This study consists of 6 spiral lines which scan with low resolving power that was predetermined for quantitative analysis. Scanning the macula through FMT scan involves in a simple way by making the patient to look at the obsession focus point. Generally the midpoint of the

scan lines up with the fixation focus. For further process the acquired scan picture is stored and then examined with any of the available retinal diagnosing tools.

4.2.2 The Line Scan

The main advantage of line scan is its flexibility. In line scan the length and point of the line can be altered and the line can be moved to any point or angle on the video display.

4.2.3 The Cross Hair Scan

This sweep attempts to give a high determination flat line and afterward actually bends to a steep line scan without leaving the convention. This is a common strategy used in B type of scan in ultra-sonography.

4.3 Optical Biopsy of Retinal Layers

The fovea of the retina can be determined by the normal depression as shown in the below (Figure 6). This image shows the optical biopsy of retinal layers. i.e., the retinal layers are viewed accurately through OCT scanning. In the given image,

- The NFL or Optic nerves and the RPE are very easily identifiable layers due to their high reflective nature compared to other retinal layers.
- The visibility due to reflection is described by the shades like red, yellow, orange and white in the illustration of the OCT image.
- The layers between NFL and RPE are less effectively perceptible in the scan.
- OCT is also capable of detecting small, fluid-filled, cystic spaces inside the macula.

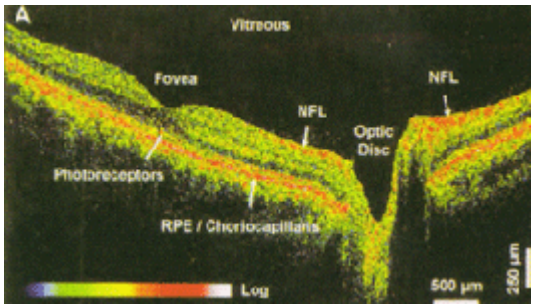

Figure 6. Retinal OCT layers (layers of retina through OCT)[20].
(This higher reflectivity is shown by the "hotter" colors [red, yellow, orange, white] in the false color representation of the OCT).

4.4 OCT Macula

OCT macular scan- report actually is like an Optical Biopsy of the 10 Retinal Layers. OCT macula examines the retina and its sub-layers for its integration of structures, Macular atrophy (macular decay), Macular edema, Macular traction, Macular holes (openings), Sub-retinal liquid, RPE anomaly.

Clinical signs for macular/retinal OCT are diagnosis of various retinal conditions such as.

- DR - when changes are not yet clearly seen on fundoscopy or on fluoroscein angiography.
- Age Related Macular Degeneration (ARMD)
- Post cataract surgery Cystoid Macular Edema (CME)
- CSCR
- Macular holes
- Epi-retinal membranes
- Pigment epithelial on neurosensory detachments at the macula,

Overall OCT used to monitoring screen movements, to help in treatment planning, to monitor response to therapy.

4.5 Spectral Domain OCT Images-Interpretation

Spectral Domain OCT (SD-OCT) – helps to analyze retinal layers in-depth there by producing higher accurate images and information's with enhanced efficiency. A 3-D display with anterior segment of retina is viewed through SD-OCT. while compared with other scanning technique such as ultrasound diagnosis, SD-OCT has improvised resolution of 5 microns, but the former is about 150 microns. In case of delivering information both ultrasound and SD-OCT are analogous. Thus SD-OCT retinal images permit us to analyze retinal diseases like macular degeneration, glaucoma, DR accurately and guide treatment effectively.

OCT permits clinical perception, measurement and identification of the structures of External Limiting Membrane (ELM) and the intersection of the photoreceptor layers. I.e. Internal and External. Obtained images display many ranges of lesions with morphological changes, differences in reflections and blank regions. SD-OCT performs the operations such as,

- Evaluating Retinal size and density.
- Retinal Nerve Fiber Layer (RFNL)/NFL analysis.

- Producing map view for retinal dimensions.
- ILM (Inner Limiting Membrane) and RPE detachment and generation of maps.
- Indicates 3-D views and provides classic C-scan, developing horizontal tissue sections.

The acquired images possibly measured, interpreted, preserved and compared with other different outcomes, and overlaid on Fluorescein Angiography (FA), indocyanine green, and microperimetry.

Scanning through SD - OCT a clinicians can,

- Detect disease accurately
- Measures thickness and volume of injured tissue
- Track disease spread and development
- Evaluate post-operative condition

4.5.1 Reading an OCT Report Involves (Analysis and Synthesis)

- Qualitative analysis involves all dimensional images and mapping
- Quantitative analyses study the thickness and mapping of retina and study the volumetric analysis.
- By connecting and examining all the investigated results such as retinal layer dimension, semantic changes, hyper and hypo reflectivity and abnormal structures are clear with fluorescein and indocyanine green .With this data, we can complete the diagnosis.

5. Detecting 2-D Cross Sectional SD-OCT Scan, the B-Scan

5.1 Analysis and Synthesis using OCT

While detecting an OCT scan, it is necessary to follow a logical sequence. At first, each of the components – hyper-reflective lesions, hypo-reflective abrasion, biological alterations, significant changes, retinal guide and thickness must be studied thoroughly to arrive at a clarification.

In SD-OCT tool we would view a sequence of alterations in the acquired reflection, because this software allocates a shade for each and every level of its reflection, allowing us to view the considerable changes in the colours obtained.

6. Results and Discussions

6.1 Analytic Study

6.1.1 Qualitative Analysis

6.1.1.1 Morphology

6.1.1.1.1 Morphological Modifications

- Deformation of the entire retina
- Alterations of the retinal profile
- Intra-retinal structural modification
- Morphological (Physical structure) changes

6.1.1.2 Anomalous Structures

- Pre-retinal
- Epi-retinal
- Intra-retinal
- Sub-retinal

6.1.1.3 3-D and C-scan studies

- Serous RPE detachment
- Cystoid oedema
- Serous neuro-epithelium separation / tear
- Neovascular membrane
- Lamellar hole
- Macular hole

6.1.1.4 Reflectivity

6.1.1.4.1 Increased Reflectivity

- Apparent
- Intra-retinal
- Depth

6.1.1.4.2 Decreased Reflectivity

- Outward
- Intra-retinal
- Deep
- Anterior

6.1.2 Quantitative Analysis

- Retinal Thickness
- Volume
- Map

6.2 Synthesis Study

With the evaluation and comparison of findings obtained in OCT interpretation, it is used in checking and comparing the data with the patient's early medical information, clinical investigation and other reports, the specialists shall arrive at analysis and judge the response of the patient to medicine and treatment.

SD-OCT has benefits in automatically selecting the range of reflection for a particular colour. This advantage helps to guide and discuss with the patients in an efficient manner. The macular hole is abnormal due to its thickness range usually known as full-thickness macular hole. In this image RPE seems to be precisely sub-divided in to 3 layers and the ELM is clearly visible there by investigating and observing it more simply and[13].

6.3 Retinal Deformations

6.3.1 Concavity

Concavity is also known as Myopia. In high myopia cases and posterior myopic staphyloma (sclera) shown in (Figure 7), the OCT software will display a considerable depression called concavity. Certain injuries in the part of sclera are available in the depressed retinal layers throughout its thickness.

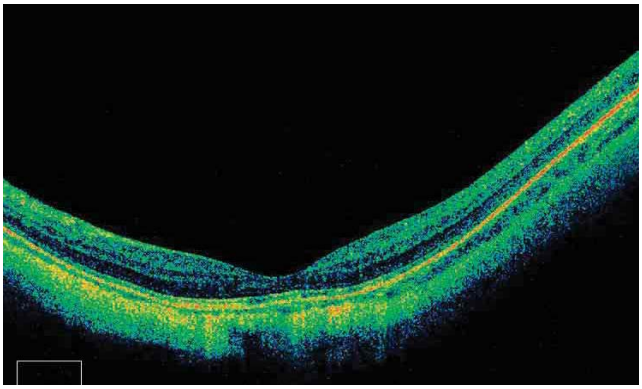

Figure 7. Deformation of entire retina- small staphyloma[21].
Note the abnormally concave structure of this highly myopic eye.

6.3.2 Convexity

Convexity is known as sub-retinal tumours or cysts. In most of the serous detachment cases i.e., separation of the Retinal pigment epithelium layer, OCT always displays a bulging shape (Convex). In rare cases convexity of the retina could be due to the reason of cysts formations in some scenarios as shown in (Figure 8). In these types, the convexity is less noticeable and consists of the sub-retinal layers (the epithelium and choriocapillaris).

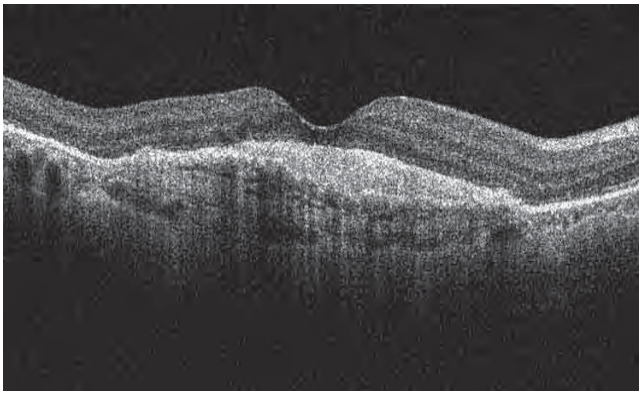

Figure 8. Deformation of entire retina-convexity[21].
(In cases of sub-retinal cysts or choroidal tumors, a convex retina that also involves the RPE and the choriocapillaris may be observed. In this case of fibro-vascular scarring and neo-vascularization, retinal edema and small serous detachments of the retina are seen. The retina is deformed and convex).

In the case of cysts or sub-retinal tumours, the entire retinal layers may be bulged leads to convexity so that identifying the tumour from other diseases is a difficult job Particularly displaying these images through colour scale are more difficult rather it is better to view in grey scale which is pictured in Figure 8.

6.4 Abnormal Retinal Profile

In normal retina, the OCT scan displays a regular continuous foveal depression. OCT can find abnormalities such as,

6.4.1 Vitreo-Retinal Traction

In this type of abnormality the normal foveal depression misshaped, becoming bulged or irregular in shape. This stage leads to holes formation in the foveal region of retina.

6.4.2 Retinal Edema

In this case, foveal depression might be small in size or destroyed, and the overall retinal shall become flat or irregular in shape. The absence of foveal depression is an indication of clinically huge retinal edema which is called as diffuse retinal edema.

6.4.3 Macular Pucker

Here the retinal surface is misshaped by waves and twisted by traction caused by the Epi-Retinal Membrane (ERM).

6.4.4 Enlarged and Irregular Foveal Depression

Macular Pseudohole

In the below (Figure 9), it shows an expanded foveal depression which replicates a retinal macular hole. The presence of tissue at all retinal layers over the RPE is a pseudohole. A true lamellar hole is identified and described by an absence of some retinal layers above the RPE as shown in figure.

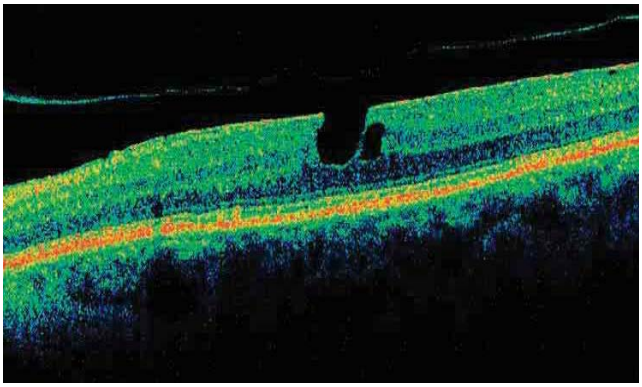

Figure 9. Qualitative analysis –lamellar hole[21].

6.4.5 Macular Hole

OCT gives distinguishing proof, evaluation, and categorization of macular holes in agreement with the Gass regulations. Also, the C type scan will allow the subjective analysis of edema if available

Stage 1: The normal depth of the fovea vanishes, and a small optical blank area called cyst forms under the surface of the retinal layers.

Stage 2: During this stage, partial damage to the internal areas of the retina is clearly visible, with operculum attached to the margins of the hole and slightly increased thickness.

Stage 3: The hole is thickening in which operculum is attached to the retina. Retinal edema might be present, with thickening of the retina and a small tear.

Stage 4: The hole is thicker as shown in Figure 10, with retinal substance loss, edema on the retinal edges, and tear / separation of the retinal edges.

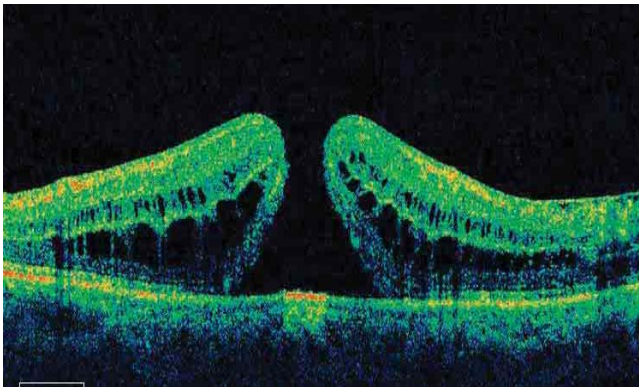

Figure 10. B- scan of stage IV – macular hole[13].
(In this cross-section of a full-thickness macular hole, the diameter of the hole is smaller toward the vitreous, and it widens as it extends toward the RPE. Small cysts occupy the inner and outer nuclear layer).

In the above (Figure 10) in the cross-section of a full-thicker macular hole, the hole diameter is less towards the vitreous, and it increased towards the RPE. Small cysts occupy the inner and outer nuclear layer.

In above (Figure 10) in the cross-section of a full-thickness macular hole, the diameter of the hole is smaller toward the vitreous, and it widens as it extends toward the RPE. Small cysts occupy the inner and outer nuclear layer.

7. Retinal Diseases in SD OCT, Visualizing Ocular Structures in 3-D

SD-OCT: The next step in OCT Technology. Spectral domain provides unprecedented views of the retina.

7.1 Results and Discussions

7.1.1 Three - Dimensional Studies

In order to obtain a 3-D analysis of a macular cube, the OCT equipment scans many times at higher resolution. In the below (Figure 11) the serial procurement of B-scans for the retinal map gives a true representation of tissue

for measurement and cross-sectional study.3-D images of the principal structures on which graphical estimation is constructed are shown on screen. This study shows a cross segment tissue of the retinal, with the image of the fund us aligned beneath it as shown in Figure 11.

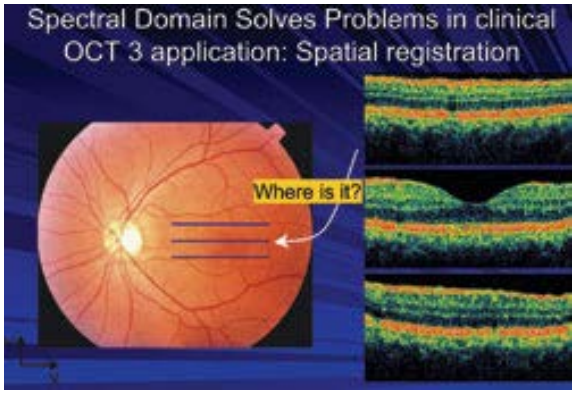

Figure 11. Spectral domain OCT can generate a fundus image, and the spatial location of each OCT sectional image is registered on the fund us image automatically[13].

To obtain 200 horizontal scans (B-scans) with 200 scan line on the Y axis (A-scans), it takes approx. 1.6 seconds. Approximate foveal thickness is 160 to 180 microns, so the hypothetical resolution of the A-scan study is under 4 microns. The 3-D images will be interpreted in various formats of analysis. The most broadly used analysis is the Macular Thickness Analysis.

7.1.2 C-Scan (En-Face) by SD-OCT

The planar C-scan analysis report operates straight on a reference B-scan moving along a plane, flat to the tissue, showing the corresponding C-scan on a different parts of the screen.

In Advanced Visualisation Analysis, the C- scans or coronal scans can be examined. These pictures demonstrate clinically essential perspectives, permitting us to plot the axial images (B-scans) over areas that are not regularly analysed. Spectral domain OCT equipment shall ascertain and then recreate C-scans from the obtained macular cube.

7.1.3 Macular Degeneration (DRUSEN)

7.1.3.1 Age-Related Macular Degeneration

Age-related macular degeneration (AMD or ARMD) is initially sighting of certain drusen, during the eye exam through OCT. The development of yellow deposits in the initial stage of AMD called Macular Drusen. These deposits develop between the RPE and the choroid layer. The development of AMD is characterised by the inability of the macula to get rid of waste products or to get oxygen rich nutrients from the underlying tissues. Macular degeneration then sets in. It is a painless loss of central vision due to the degeneration or dying of cells in the retina, called the macula. AMD is either atrophic or exudative, i.e., twoforms of ARMD are

- Dry macular degeneration (Atrophic AMD) - most common and less harmful with neo-vascular layers. Light yellow deposits. These drusens are small and round with very sharp borders.
- Wet macular degeneration (Exudative AMD) - more severe and sudden vision loss. They are larger with less defined borders.
- Exudative AMD is characterised by the Intra-Retinal Angiomatous Proliferation (RAP) and Polypoidal Angiomatosis Choroidopathy. OCT plays a vital role in determining the best treatment options for these abnormalities.

7.1.3.2 Atrophic Macular Degeneration

The atrophic macular degeneration is the most common type of AMD. The chorio-capillaries and the choroid are with marked scleroses of the principal blood vessels shown in Figure 12. Using OCT, we can identify dynamic atrophy of the RPE *(identified in Figure 12)* and the retinal layers, particularly the external membrane.

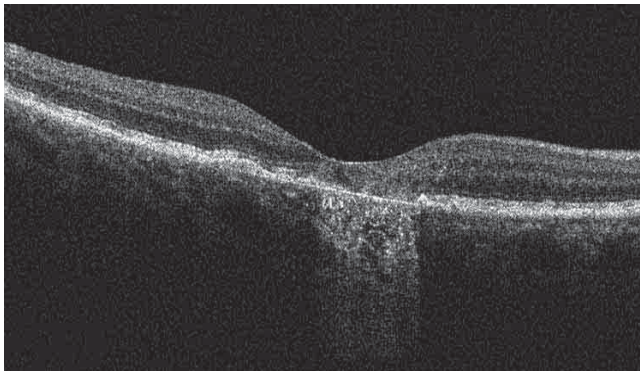

Figure 12. B-scan of atrophic macular degeneration – drusen[22].
(The retina is significantly thinned at the posterior pole, with corresponding changes in retinal contour).

7.1.3.3 Pseudo-vitelliform Macular Degeneration

Pseudo-vitelliform in adults is a dominant autosomal hereditary condition that in initial stage progresses gradually from the vitelli-form stage to the pseudo-hypopion stage and finally to the atrophic stage.

Figure 7 display the pseudo-hypopion stage, with a non-transparent yellow-orange sub-retinal deposit and a central retinal detachment. The overlying retina is diminished

Figure 13 shows the RPE Detachments in AMD Patient.

In this image the retinal cube has been sectioned to show the RPE detachment.

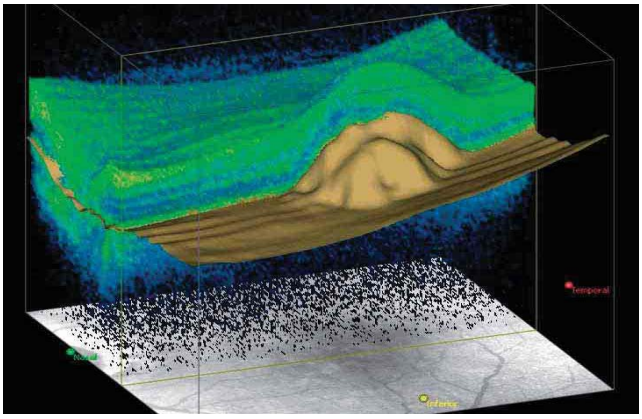

Figure 13. RPE detachments in AMD patient[13].
(The retinal cube has been sectioned to show the RPE detachment).

7.1.4 SD-OCT for the Study of Glaucoma

Spectral domain OCT provides important data to guide clinical decision-making

For diagnosis of glaucoma the depth information about the layers of retina is obtained from the OCT image. OCT is an advanced imaging technique used to detect the presence of glaucoma. The confirmation of glaucoma and the accurate measurement of Cup Disc Ratio (CDR) can also be done in OCT images[14].

OCT gives us accurate images for the management of glaucoma, by providing essential subjective and objective information. It enables us to investigate the optical disc morphology and morphometry and the peri-papillary nerve strands. Also with the first-generation OCT, the measurement of the RNFL thickness empowers in vivo visual representation of retinal areas. Various studies have demonstrated a similarity between OCT computations and histologicalcomputations[15,16].

7.1.4.1 Cirrus HD-OCT- Important Diagnostic Tool

The CirrusHD-OCT empowers us to acquire and display various data identified with damage to glaucoma in a transparent manner. The glaucoma study is complex and the data from a single instrument, though it may be exact, is not adequate for diagnosing more difficult cases. We must perform our diagnoses based on all of our clinical investigations.

The OCT Nerve fiber or RNFL analysis is a latest method of glaucoma testing in which the thickness of the NFL is calculated. In the (Figure 14) shows the image of patient with glaucoma in which the indication of thinner areas shows that the damage is caused by glaucoma.

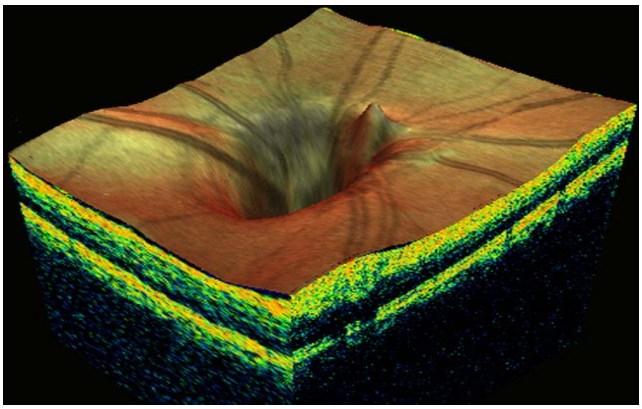

Figure 14. Image of patient with glaucoma[13].

OCT develops images by utilizing particular beams of light. The OCT machine can make an outline map of the optic nerve, optic cup and calculate the RNFL/NFL thickness. Over a period this machine can identify the loss of optic nerve fibers.

7.1.5 Diabetic Retinopathy

7.1.5.1 The Role of OCT in Managing the Diabetic Retinopathy

OCT allows us to:

- Examine the causes for reduced visual acuity
- Find the retinal status and monitor changes
- Identify the presence of retinal oedema
- Quantify edema and calculate its volume along with retinal thickness
- Restrict treatment areas with the help of retinal topography and C-scan

- Track the efficacy of treatment.
- Determine if Vitreo-retinal surgery is required.

7.1.5.2 Macular Edema in Non-proliferative Diapetic Retinopathy

Macular edema is the main cause of reduced vision in non-proliferative DR. The SD-OCT investigation shows retinal areas with histological accuracy, thus by enabling further investigation of DR. The edema begins with central edema, advances to diffuse edema, and then can become cystic. Serous detachment is a part of the development of diabetic edema.

7.1.5.2.1 Focal Edema

Focal edema can be detected either by FA or with OCT, which displays a thickened retina. The OCT map of retinal is essential in cases of focal edema, since it allows better localization to coordinate treatment. It additionally affirms treatment adequacy.

7.1.5.2.2 Diffuse Edema

Through OCT, the retina with diffuse edema is thickened and shows irregular, small cavities. The areas of low reflectivity are increased and particularly evident in the external retinal layers, where diabetic edema is most frequently found as shown in the (Figure 15). The external plexiform layer shows the most edema in the given image below.

OCT has become essential tool for detecting and investigating various stages of DR. In specific cases, OCT replaces the FA, permitting enhanced diagnosis and evaluation of lesions.

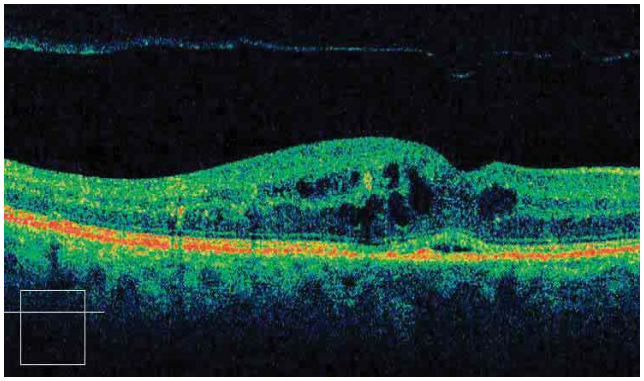

Figure 15. B-scan of non-proliferative diabetic retinopathy[22].

7.1.5.2.3 Cystoid Macular Edema

Constant retinal edema will result in the destruction of the Muller cells, leading to the formation of cystoid cavities in the retina. These cavities begin in the Outer plexiform layer and successively permeate the granular layers and the inner plexiform layer. Advanced cystoid edema penetrates the retina, causing the atrophy of the remaining tissue.

7.1.6 Retinal Epitheliopathy

7.1.6.1 Central Serous Chorio-Retinopathy (CSCR)

Central Serous Chorio Retinopathy (CSCR) occurs most regularly in men between middle ages (25 to 45); it is frequently recurrent and bi-lateral. Generally, FA shows a point of diffusion that starts and increases progressively. In serous RPE separations, multiple points of diffusion may be visible where the RPE is isolates from Bruch's membrane as shown in Figure 16, forming empty spaces that filled with fluorescein dye. In acute CSCR, OCT may display a little break in the RPE at the dispersion or diffusion point inside the serous RPE detachment. From this opening, we might once in a while seethe reflective material that appears to leak from the choroid towards the inside of the detachment. In cases of acute CSCR, all layers and retinal stripes appear normal in the non-detached retina.

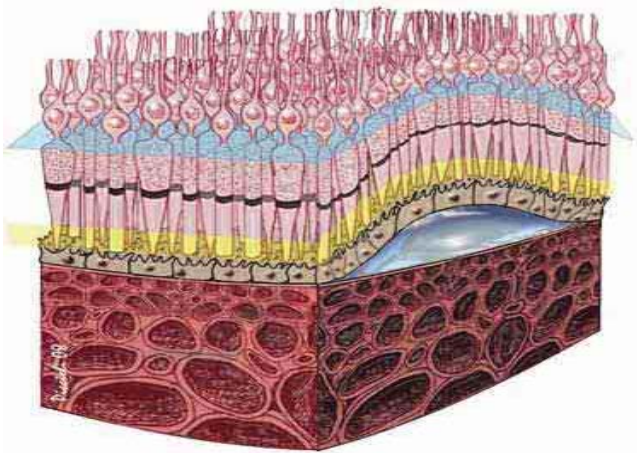

Figure 16. Serous RPE detachment in CSCR[22].

In the Figure 16, the RPE has separated from Bruch's membrane, disconnecting the retina without modifying

the RPE. The separation is optically clear, and there is no diffusion of the sub-retinal fluid.

8. OCT an Accurate Diagnostic Tool in Variety Areas

OCT- In Terms of All the Processes Involved

8.1 OCT Imaging Engine

8.1.1 In Sanning

Doppler/ Polarization/Spectroscopy
Parallel detection
Frequency Scanning
Spectral radar

8.1.2 In Image Processing

Motion reduction
OCT image/video overlays
Segmentation, Registration, Fusion, Image Enhancement
Rendering Algorithms

8.1.3 In Beam Delivery and Image Probes

Ophthalmoscope
Microscope
Handheld probe
Laparoscope
Forward Endoscope / Catheter, Transverse Endoscope/ Catheter

8.1.4 Computer Control

Synchronization
Real time display
Data management
OCT in other fields
OCT for Clinical Applications other than Ophthalmology.

8.2 Other Medical Fields

8.2.1 OCT Biopsy and Functional OCT

Excision biopsy imposes problems like the risk of cancer cell spreading, infection and haemorrhage. Optical biopsy promises to assess tissue and cell function and morphology. OCT offers properties like high resolution, high penetration depth, and a potential for functional imaging considered as prerequisites for optical biopsy. Standard OCT can clarify the relevant architectural tissue morphology as said by author. Many diseases, including cancer in its early stages, require higher resolution for accurate diagnosis. Ultra-high resolution OCT, therefore, is an important step towards such optical biopsy. Below, we mention a few examples of high-resolution and functional OCT.

8.2.2 High-resolution OCT in Gastroenterology and Dermatology.

Imaging of the GastroIntestinal (GI) tract is a first example for the need of increased resolution in OCT. Gastroenterological OCT has been initiated by a study performed by the author Izatt who showed that OCT and OCM can delineate sites like internal histological-level tissue microstructure in bulk GI tissue samples. A second example where high resolution is a key issue for OCT application is dermatology. Skin is a highly complex tissue with many inhomogeneities.

OCT penetration depth covers the *stratum corneum*, the living epidermis containing mainly keratinocytes, and the *dermis* consisting mainly of a network of collagen and elastin fibres and fibroblasts.

8.2.3 Endoscopic OCT in Intra-Arterial Imaging

Depth resolution in OCT is provided by the coherence gate and, therefore, independent of the width of the probing beam. Hence, OCT is predestinated as an endoscopic modality for high-resolution intraluminal imaging of organ systems.

Endoscopic and catheter-based procedures are enabling technologies for low-invasive treatments in medicine and, therefore, are growing rapidly. The first endoscopic OCT system has been introduced by the author Tearney for optical biopsy imaging of internal organ systems.

8.2.4 PS-OCT in Dentistry

A field where polarization-dependent backscattering might play an increasingly important role is dental OCT. Human teeth consist primarily of enamel, dentin and pulp. The bulk of the tooth is made up of semitransparent dentin, with micrometre-sized dentinal tubules, radiating from the pulp cavity towards the periphery.

8.3 Non- Medical OCT

8.3.1 OCT for Artwork Diagnostics

Applications of OCT in various art object such as oil paintings on canvas-Imaging of glaze and varnish layers, porcelain, faience, and parchment are available. Also applications to surface profilometry of painting on canvas are there.

This Article referred in *Optical Coherence Tomography for Artwork Diagnostics- Hindawi Publishing Corporation, Laser Chemistry*[17].

8.3.2 Low-Coherence Interferometry

Already it has been used in optical production technology and other technical fields. For example, LCI or interference with white light has been used for many years in industrial metrology, e.g. as position sensor for thickness measurement of thin films and for other measurands that can be converted to a displacement.

8.3.3 Hertzion Crack

A related application of OCT has been described by the author Bashkansky in the year 2001. These authors detect the subsurface extent of the Hertzian crack on the surface of a silicon nitride ball to compare it with predictions of crack propagation theories based on principal stresses and on maximum strain energy release.

9. OCT- Pros and Cons

The advantages of OCT over the non-optical imaging modalities are its

- high depth and transversal resolution,
- contact-free and non-invasive operation, and the possibility to create,
- Function dependent image contrast. Related contrasting techniques are based on Doppler Frequency shift, polarization and wavelength-dependent backscattering.
- Ophthalmology is still the dominating field of biomedical OCT. The most important reason for that is the high transmittance of ocular media.

The main disadvantage of OCT compared to alternative imaging modalities in medicine is its limited penetration depth in scattering media.

- Scanning with the OCT suffers from a lack of registration and questionable repeatability.
- Lack of large-scale clinical trials
- Penetration: 2-3mm, Ideal: 4mm
- Catheter/endoscope based image:19 μm
- Non-catheter: 4 μm.

10. Conclusion

OCT was initially applied for imaging in ophthalmology. Advances in OCT technology have made it possible to use OCT in a wide variety of applications. Medical applications are still dominating all other areas. Besides the closely related surface topography techniques, only a few non-medical OCT applications have been investigated so far. This work has given an overview of the development of OCT, the current state of research and commercial areas, and the advance technique in clinical imaging.

The development of advanced OCT source, beam delivery and detection technology in SD-OCT, Ultra-high OCT are very useful in wide area of clinical applications in the field of ophthalmology, cardiology, and oncology, among many others for diagnosing accurately. The future of OCT will continue to benefit from and be strengthened by the upcoming research work and progress of moving technology thereby helping the doctors to potentially detect the diseases for early diagnosis and monitoring conditions in pre-op and post-op stage.

11. Future Work

My idea and future work towards this study is to determine and analyze one particular eye disease such as Macular Degeneration or some other disease and it is diagnosed by OCT to obtain OCT-images which categorise possible symptoms of the disease in that image. For this we need various methodologies available in image processing techniques. Methodologies like image pre-processing, segmentation and classification based on specific algorithm are used to diagnose the particular disease could be identified in the given image or not.

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