Optical Coherence Tomography - Principle and Clinical Application

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Optical coherence tomography (OCT) is an outstanding example of applied physics in medicine. Over the last decade, OCT has become an essential tool in ophthalmology. Optical coherence tomography is a low-coherence, interferometer-based, non-invasive medical imaging modality that can provide noncontact, high-resolution, cross-sectional images of biological tissue.

Generations

Several generations of the commercial version of the OCT device have been developed. The first generation OCT 1 has transverse and axial resolutions of approximately 20µ and 10 to 15µ, respectively. The second generation OCT 2 has similar hardware with an improved user interface. Both generations acquire 100 vertical scans in a standard OCT scan in an acquisition time of approximately 1.2 seconds. The recently released third generation OCT 3 machine has improved resolution of 8 to 10µ and acquires 512 vertical scans. An experimental ultra high resolution OCT system has been developed using Ti: Al2O3 laser that provides an improved axial resolution of 2 to 3µ. This resolution makes it possible to identify otherwise unseen intermediate retinal layers, such as the retinal ganglion cell layer.[2]

Principle & Procedure -

OCT is based on the principle of **"low coherence interferometry"**. The OCT device uses a light source consisting of a near – infrared, low coherence super luminescent diode laser of 850nm wave length. This diode source connects with Michelson interferometer. In low-coherence interferometry, an interferometer is used with a broadband (white) light source. The beam of light from the source is split into two at a half mirror, which creates a measurement and a reference path. The light is then reflected, by the mirror in the reference arm and the sample in the measurement arm, and recombined to create interference before it hits a detector, usually a photodiode, measuring the field strength of the interfering beams of light. Figure 1 below illustrates this setup. Since the spectrum of the light used in low coherence interferometry is broad, interference is only be observed when the lengths of the measurement and reference arm are matched to within the small coherence length of that light, allowing for very good axial resolution.[3]

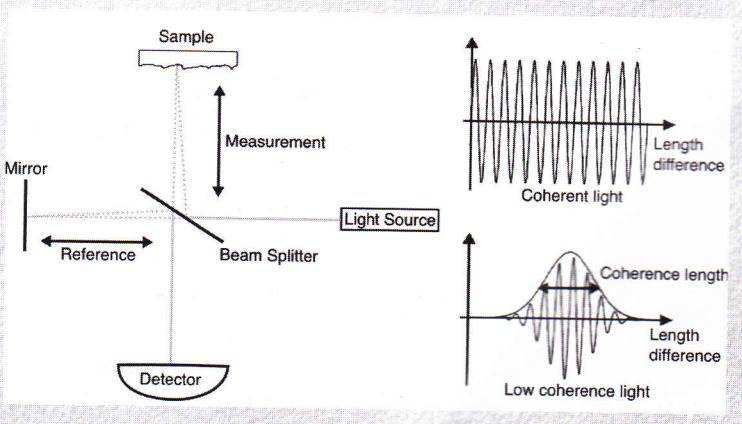

fig.1

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Infrared light from the source is divided at an optical beam splitter into reference beam and measurement beam. The measurement beam is directed onto the patient's eye and is reflected from intraocular structures at different distances. The reflected measurement beam is composed of multiple echoes which include the information about the range or distance and thickness of different intraocular structures. The reference beam is reflected from a reference mirror. The reflected reference beam returns to beam splitter where it combines with reflected measurement beam. Both beams are combined resulting in a phenomenon called **Interference**. The interference is measured by means of a photo sensitive detector. The echo time delay of the measurement and reference beam is compared and then signal is sent, which is processed electronically and used within OCT's internal computer data acquisition bank for analysis and storage.

On Z axis, 1024 points are captured over a 2 mm depth to create a tissue density profile, with resolution of 10µ. On X–Y axis, tissue density profile is repeated up to 512 times. every 5 – 60 microns to generate a cross sectional image. Several data points over 2mm of depth are integrated by the interferometer to construct a tomogram of retinal structures. Image thus produced has an axial resolution of 10µ and a transverse resolution of 20µ. The tomogram is displayed in either gray scale or false color on a high resolution computer screen.

Interpretation of Normal OCT Imaging

The physical basis of imaging depends on the contrast in optical reflectivity between different tissue microstructures. The proportion of incident light which is directly back scattered by a tissue structure defines the reflectivity of that structure. The OCT signal from a tissue layer is a combination of its reflectivity and the absorption and scattering properties of the overlying layers.The intensity of the reflected optical signal is represented on a logarithmic scale with varying degrees of brightness. The maximal optical reflection and back scattering are represented by Red – Yellow colors. Theminimal signals are represented by Blue – Black colors.

OCT Imaging of Normal Retina

The OCT can scan the macula, paripapillary region including retinal nerve fiber layer and optic nerve head region. There are 10 layers of the retina and cross sectional OCT image of the retinal layers are represented like fig2.

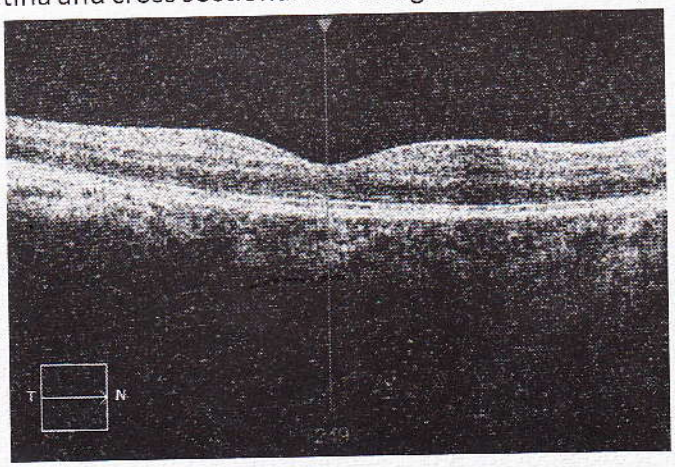


fig.2

The vitreous being non reflective is seen as a dark space. The vitreoretinal interface is demarcated by the

contrast between the non reflective vitreous and the backscattering surface of the retina. The inner margin of retina shows area of bright back scattering, a red layer that corresponding to the nerve fiber layer. A highly reflective red layer delineates the posterior boundary of the retina and corresponds to RPE and choriocapillaries. A dark layer of minimal reflectivity appears just anterior to choriocapillaries layer and represents the outer segment of retinal photoreceptors. The intermediate layers exhibit moderate back scattering. Fovea is identified by the characteristic thinning of the retinal layers.

(1)**The Optic nerve head**: It can be identified on the basis of its contour – central depression of cup and the stalk. OCT is provided with two scan protocols for detailed evaluation of optic nerve head.

Optic disc scan consists of equally placed lines scans 4 mm in length, at 30° intervals, centered on the optic disc.

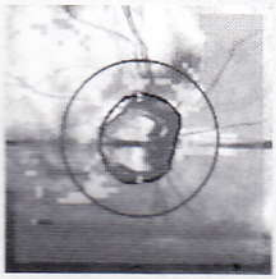


fig.3

The point at which choriocapillaris terminates at lamina cribrosa determines the disc boundaries. Extrapolation of these points to retinal surface defines a line segment which measures disc diameter. The points at which nerve fiber layer terminates determines the Cup. By this scan OCT images can measures the optic nerve head and its parameters like Rim area, Disc diameter, Rim volume disc area, Cup disc ratio and Cup volume. (Fig 4)

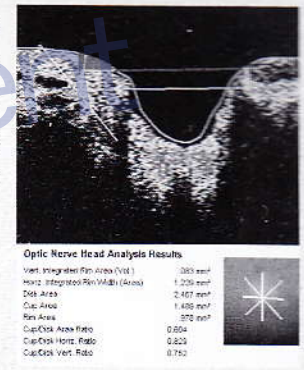


fig.4

(2) **The Retinal Nerve fiber Layer**: OCT measures the thickness of the retinal nerve fiber layer in the peripapillary region. RNFL thickness increases from macula to the optic disc. OCT 3 offers a variety of RNFL thickness measurement and analysis protocols like RNFL thickness Circle scan, Fast circle scan, Concentric 3 rings protocol, RNFL map and Proportional circle. RNFL measurement with a circular scan of 1.34 mm radius, centered on the optic nerve head has been shown to have a maximum reproducibility. Mean RNFL thickness is calculated using age adjusted RNFL thickness average analysis protocol. (Fig. 5)

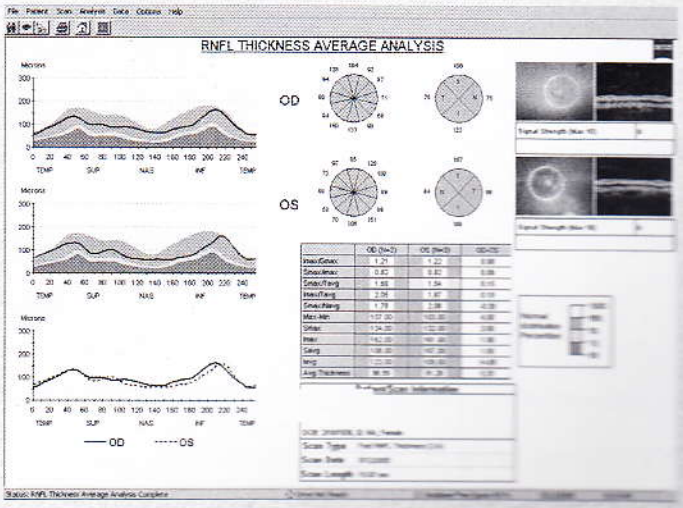


fig.5

(3) Macula : The normal fovea is identified by its characteristic depression of the inner retinal border secondary to the lateral displacement of tissue anterior to Henle's layer. The macular scan is composed from six linear scans in a spoke pattern configuration equally spaced 30º apart. In the color coded macular thickness map blue color represents thinner retina and yellow green, thicker retina. OCT has become part of routine imaging modality with suspected or known macular pathology. (Fig. 6)

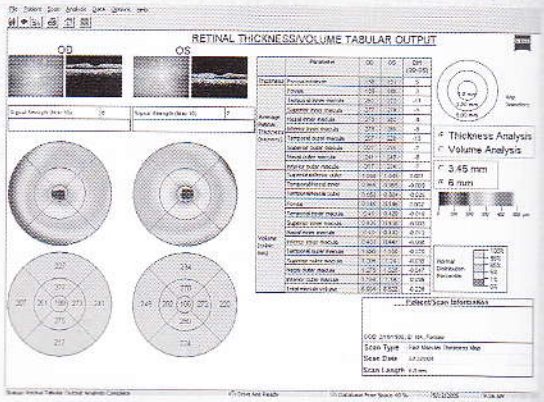


fig.6

Interpretation of Abnormal OCT Imaging

Reflectivity pattern of the scanned images is used to interpret abnormal finding as follows:

Hyperreflectivity: It can be caused by inflammatory infiltrate into any layer of retina, fibrosis like disciform or other scar, hard exudates, and hemorrhages. Thin hemorrhages appear as thin, high reflective bands with little effect on underlying tissue. Thick hemorrhages completely attenuate reflections from underlying structures.

Hyporeflectivity: It can be caused by retinal edema, serous fluid, hypopigmentation of RPE.

Nature of Fluid: It is based on the basis of reflectivity. Serous fluid is either optically clear or hyporeflective, blood has both enhanced reflectivity and increased attenuation of incident light. Exudate typically has intermediate appearance between blood and serous fluid.

Applications

Application of OCT can be summarized as:

(a) Follow up of the clinical course, understanding the pathogenesis of the disease.

(b) For assessing the response to medical, surgical, laser therapy.

(c) For documentation and explaining the prognosis of a particular disease.

OCT in Glaucoma: OCT provides high resolution measurements and cross sectional imaging of the retina, optic disc and RNFL. Recent studies indicate that RNFL thinning to be the first sign of early glaucoma. The main uses are

To evaluate the RNFL for early (pre perimetric) glaucoma detection

To detect, study and follow the macular changes in hypotony induced maculopathy after glaucoma surgery

To evaluate cystoid macular edema after combined cataract and glaucoma surgery.

OCT in Macular diseases: OCT provides reproducible, high resolution, cross-sectional imaging of the retina allows diagnosis, monitoring, and quantitative assessment of macular pathology.

(a) **Macular Hole:** Diagnosis and staging of macular holes by biomicroscopy can be difficult for even the most experienced examiners owing to simulating conditions, such as a lamellar hole, vitreomacular tractional syndromes, and cystoid macular edema with central cyst. It is also useful in monitoring the course of disease, whether spontaneous resolution or progression to a full thickness macular hole, and the response to surgical intervention. (fig.7)

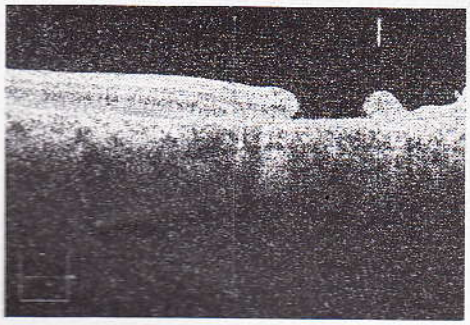
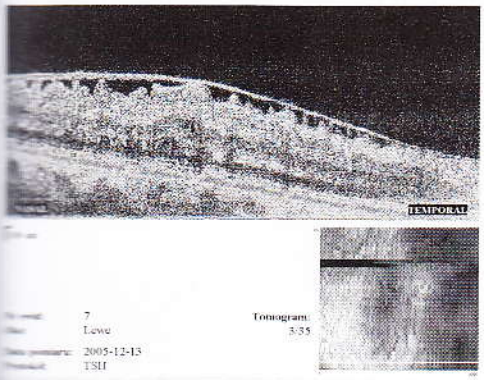


fig.7

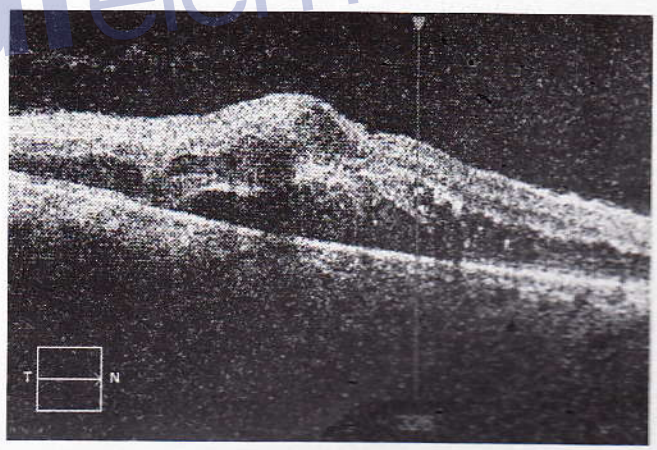


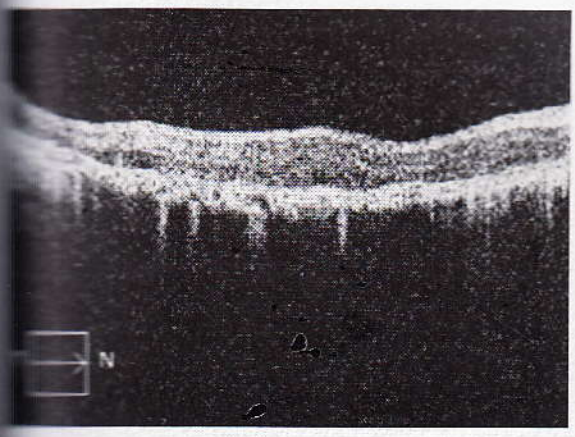
(b) Epiretinal membrane: OCT images confirm the diagnosis of faint, diaphanous membranes and provide a cross sectional assessment of factors contributing to vision loss. It provides information about membrane thickness, cystic changes and its adherence to retinal surface.

fig.8

(d) **Cystoid macular edema:** Although cystoid changes are visible by slit lamp biomicroscopy and fluorescein angiography, only OCT can quantitatively assess retinal thickness and demonstrate any associated RPE structural anomalies beneath the edematous retina, which can be obscured by leakage on angiography. Measurements of retinal thickness by OCT correlate more strongly with visual acuity than the presence of leakage on angiography.

fig.9





(e) Diabetic retinopathy: Clinically Significant Macular Edema is the leading cause of treatable vision loss in patients with diabetic retinopathy. OCT may be more sensitive than biomicroscopy in detecting macular edema. OCT almost gives the in vivo histopathology of the retinal layers that helps in a better understanding of the pathogenesis of the disease process.It is a useful tool in monitoring response to an intervention in CSME.

fig.10

(g) Central Serous Chorioretinopathy: It is effective in quantifying the amount of serous fluid accumulation in CSR. It is also used to monitor the course of CSR. It exhibit well defined reflection at fluid RPE interface , whereas elevation of RPE reflection above an optically clear space occurs when the pigment epithelium is detached.

fig. 11

Limitations

Presence of conditions like asteroid hyalosis, cloudy media, high astigmatism, decentred lens implant and dense cataracts can compromise quality of the tomograms.

Limited transverse sampling

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