Optical Coherence Tomography in Macular Disorders

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A retinal specialist uses a wide variety of techniques to evaluate retinal pathology such as fundus photography, fluorescein and indocyanine green angiography and ultrasonography. However these techniques of imaging do not give detailed information on the cross sectional retinal anatomy nor do they provide quantitative retinal thickness measurements.

A need has existed in medicine for a technology capable of ‘optical biopsy’ imaging at or near the resolution of histopathology without performing an excisional biopsy. Advances in optics, fibre optics and laser technology has led to the development of a non contact, high resolution, optical biomedical imaging technology called “Optical Coherence Tomography.”

Thus Optical Coherence Tomography (OCT) provides a technique of imaging that is non-invasive, non-contact, provides high degree of resolution and provides cross-sectional images of the retina of 10 micron resolution comparable to a histopathological section. OCT yields information about retinal tomography that is complementary to the conventional topographic techniques.

Principle

The working of OCT is similar to ultrasound, but with two major differences.

In ultrasound, a high frequency sound wave is launched into the eye with the help of a probe and the sound wave is reflected from different boundaries between microstructures. However, the OCT uses light rather than ultrasound. The speed of the light is almost a million times faster than sound and this difference allows the measurement of structures with resolution of $\approx 10 \, \mu m$ compared to 100$\mu$ scale for ultrasound. Secondly OCT does not require contact like the ultrasound.

A broad band--width near infrared light beam (820nm) is projected on to the retina. It gets reflected from the boundaries between the microstructures and also gets scattered differently from tissues with different optical properties. It then compares the echo time delay of the light that is reflected from the various layers of the retina with the echo time delay of the same wavelength that is reflected from a reference mirror at a known distance. The interferometer then combines the reflected pulses from the retina as well as reflecting mirrors resulting in a phenomenon known as interference. This interference is then measured by a photo detector, which determines the distance traveled by various echoes by varying the distance to the reference mirror. This finally produces a range of time delays for comparison.

The interferometer integrates several data points over 2mm of depth to construct a tomogram of retinal structures. It is a real time tomogram using false color scale. Different colours represent the degree of light back scattering from different depths of retina.

The image thus produced has axial resolution of $\approx 10\mu m$ and transverse resolution of 20$\mu$. 
OCT Vs Standard Techniques of Imaging

1) A + B Scan USG

Requires physical contact with the eye and are routinely used in ophthalmic diagnosis with a typical resolution of 150 µ compared to 10 µ available with OCT.

2) Digital Fluorescein Angiography

Macular hyperfluorescence seen on DFA correlates well with increased retinal thickness measured with OCT. Though FFA provides information about the origin of macular fluid leakage and retinal vascular abnormalities, it does not give information about cross sectional retinal morphology or high magnification surface topographic images like the OCT.

3) Retinal Thickness Analyser & Heidelberg’s Retinal Tomography

HRT and RTA are the other commercially available instruments in addition to OCT to measure retinal thickness and evaluate retinal morphology. RTA may produce falsely elevated retinal thickness measurements and produces images less effectively than OCT in eyes with media opacities.

The HRT may be more effective than RTA and OCT to image the ocular retina in the presence of retinal haemorrhages and hard exudates. However, the images are acquired relatively slowly.

Ultra Resolution Optical Coherence Tomography

This enables in vivo cross sectional imaging of macular pathologies with an axial resolution of 3 µ and visualisation of sub cellular as well as intra retinal pathologies. All the major intraretinal layers can be visualized non invasively in vivo by this.

Normal macular OCT Scan

On a 10mm horizontal line scan passing through the foveal centre (A), one can clearly demarcate two major landmarks namely optic disc towards the right and fovea towards the left. The optic disc is easily identifiable by its contour- the central depression representing the optic head cup and the stalk continuing behind the anterior part of the optic nerve. The vitreous anterior to the retina is non reflective and is seen as a dark space. The interface between the non-reflective vitreous and back scattering retinal fibre layer (NFL) is highly reflective and increases in thickness towards the optic nerve. The posterior boundary of the retina is marked by a hyper reflective layer that represents the Retinal Pigment Epithelium (RPE) and choriocapillaries. The choroid and sclera are not seen well on tomograms as the signal attenuates by the time it reaches these structures. Just anterior to RPE-choriocapillaries complex is a minimally reflective layer that represents photoreceptors. Above this layer of photoreceptors are alternating layers of moderate and low reflectivity that represent different layers of neurosensory retina. The retinal blood vessels within the neurosensory retina show back scatter and also cast a shadow behind.

Fig 1. Normal macular scan

Image Interpretation

There are two ways of interpreting the OCT scan - Objective and Subjective.

Objective

Pathologies can be hyperreflective or hyporeflective. Hyperreflective lesions include hard exudates, blood and scars. Hyporeflective lesions include retinal oedema and hypopigmented lesions of RPE.

Subjective

Subjective can be qualitative and quantitative. Qualitative includes retinal thickness/ volume analysis as well as change analysis.
This technique has been increasingly used to evaluate and manage a number of retinal diseases such as
1) Diabetic Macular Oedema
2) Macular holes and cysts.
3) Age related macular degeneration
4) Identify Vitreomacular traction and epiretinal membranes.
5) CSR
6) Identify and quantify macular oedema and atrophy.
7) Measure retinal thickness change in response to therapy.

**Diabetic Macular Oedema**

The conventional 2-dimensional imaging techniques including fundus photographs and fluorescein angiography give a topographic view of the retina that helps delineate treatable lesions but are unable to depict the changes occurring within the retinal layers. In addition to allowing appraisal of intraretinal changes, OCT helps to diagnose macular traction, taut posterior hyaloid membrane, foveal serous detachment and lamellar macular holes which are often missed by clinical examination alone.

**Role of OCT in Diabetic Macular Oedema**

1) Defining the disease pattern: Flattening of the foveal pit may be earliest sign. Five distinct patterns seen are
i) Sponge like retinal thickness- Seen as macular thickening with reduced optical back scatter. Hard exudates are seen as hyporeflective lesions with shadowing effect (Fig. 2).

ii) Cystoid macular oedema: Seen as hyporeflective spaces of varying size mainly in outer retina Fig 3.

iii) Subfoveal serous retinal detachment (Fig. 4).

iv) Foveal tractional retinal detachment.

v) Taut posterior hyaloid membrane.

2) Monitoring response to an intervention. OCT gives an ultra structural detail of changes in the retinal layer and quantifies retinal thickness thus making it easier to monitor response to therapy.

3) Defining indications for Parsplana Vitrectomy. Foveal tractional detachment and taut posterior hyaloid membrane are definite indications for surgery while cystoid macular oedema or serous detachment due to mechanical traction are relative indications.

**Macular Holes**

OCT is a very useful tool in the diagnosis and management of macular holes.

1) It helps in differentiating various retinal lesions that cannot be clinically distinguished. eg: lamellar or full thickness macular holes, macular cysts, foveal detachment of retinal pigment epithelium or neurosensory retina and epiretinal membrane with pseudo-hole. Full thickness macular holes show a breach in all layers of retina while lamellar macular
hole shows only partial loss of tissue Fig. 5(A & B) with steep foveal contour. RPE detachment (Fig. 7) and macular cysts (Fig. 6) are characterized by the presence of a well defined, round, localized area of hyporeflectivity in the outer retinal layers subretinally. Macular pseudoholes are characterized by contour of foveal pit, thickened edges, steep foveal contour, presence of retinal tissue at the base.

2) OCT helps in staging of macular holes that helps in evaluating surgical intervention.

OCT has led to a new classification of macular holes.

Stage 1 A: Partial thickness pseudocyst with perifoveal vitreous detachment (Fig. 8).
Stage 1 B: Full thickness pseudocyst with roof (Fig. 9).
Stage 2 A: Full thickness tear or pseudo macular hole: Partial opening of roof, focal vitreous attachment to flap.
Stage 2 B: Full thickness operculated macular hole; Traction to retina released. <400µ
Stage 3: Full thickness operculated macular hole >400µ Traction to retina released.
Stage 4: Full thickness macular hole; PVD complete.

3) OCT gives quantitative information regarding the diameter of macular hole that helps in prognosticating response to surgical intervention.

4) OCT helps in surgical decision making in macular holes surgery
   a) Stage 2 A holes require only limited surgical intervention in the form of limited pars plana vitrectomy and fluid air exchange
b) Stage 2 B or larger holes alone will require pars plana vitrectomy with ILM peeling.

5) Perioperative OCT evaluation shows the following 4 foveal patterns on OCT as described by Desai VN, Hee HR, Wong C, Puliafito C (1999).

1) Open :- Full thickness macular hole indicating failed surgery.
2) Closed:- Re approximation of hole edges with relatively normal foveal contour and normal foveal thickness.
3) Thin:- Closed macular hole with foveal thickness =100µ.
4) Foveolar Detachment : Reapproximated edges but separated from RPE
6) OCT Pattern of closure determines the visual prognosis. Two Patterns are described by Vishali Gupta, Amod Gupta, Mangat R Dogra.

Type-1 Closure : Closure without neurosensory deficit.
Type 2 Closure : Closure with neurosensory deficit.
Smaller sized holes have better prognosis as they tend to show type 1 closure.


U Type - Normal foveolar contour
V type : Steep Foveal Contour
W type :- Foveal Defect of neurosensory retina
Visual return = U> V>W
The larger holes are associated with poor visual outcome and closure without restoration of neurosensory retina. Hole Form Factor of less than 0.5 is reported to be associated with poor surgical closure rates.

Age Related Macular Degeneration

OCT is complimentary to clinical examination, fluorescein angiography and indocyanine green angiography in disease categorization.

Drusens: Drusens are seen as areas of focal elevation of RPE with no optical shadowing underneath. (Fig. 14)

Geographic Atrophy: Seen as increased optical reflectivity from the choroid due to increased penetration of the light through the overlying atrophic retina.
Neovascular ARMD

1. Classic CNVM: there is disruption/thickening of the RPE-Chorio-capillaries band with the thickened edges demarcating the boundaries of CNVM.

2. Occult CNVM – Here boundaries are poorly defined. They also have accompanying subretinal fluid/retinal oedema that helps differentiate them from pigmentary atrophy.

3. Serous PED: Elevation of RPE with an optically clear space underneath and optical shadowing.

4. Fibrovascular of PED – Elevation of RPE with a clear demarcation between RPE and underlying structures that appear as yellow/green. Optical shadowing is absent.

5. Hemorrhagic PED: Same as serous PED but with back scattering from RPE which attenuates towards the outer retina with absent choroidal reflections.

6. Disciform Scar: Seen as area of increased reflectivity from underlying choroids that is consistent with atrophy of overlying RPE. There is no associated subretinal fluid (Fig. 15).

Epiretinal Membranes

OCT helps in confirming the diagnosis of epiretinal membranes. It demonstrates the extent of the membrane, vitreoretinal interface, status of posterior hyaloid membrane associated changes like cystoid macular oedema, vitreofoveal traction, macular hole etc. This helps in prognosticating the outcome of surgery in these eyes. OCT also helps in followup of eyes following Pars Plana Vitrectomy, thus obviating the need for repeat fluorescein angiography (Fig. 14).
Central Serous Retinopathy
Like fluorescein angiography, OCT shows certain characteristic features including
1) Serous Retinal Detachment: Characterised by elevation of neurosensory retina due to fluid accumulation between RPE and neurosensory retina. (Fig. 18).
2) PED: PED is seen in almost all cases of CSR and has been found to correspond to the point of leak on fluorescein angiography (Fig. 19).

Small PEDS which may be missed on clinical examination can be demonstrated by OCT. The complication of central serous retinopathy can be diagnosed such as CNVM, subretinal fibrin, RPE rip or atrophy. It is helpful in diagnosis of a typical cases and differentiating them from ARMD, metastatic deposits etc.

Retinal Vascular Occlusions
OCT documents either macular oedema or atrophy. The area of ischaemic pale retina appears hyperreflective during acute phase and regains its original reflectivity over a period of time. OCT thus helps in documenting improvement by quantifying retinal thickness.

Retinal Vasculitis
OCT is helpful in diagnosing macular oedema, cystoid macular oedema, epiretinal membranes, pseudo macular holes and tractional retinal detachment. It is also helpful in monitoring response to treatment objectively.

Retinal Trauma
Closed globe injuries can damage the retina and underlying choroids and include commotio retinae, choroidal ruptures with choroidal neovascular membrane, macular cyst, macular hole, retinal detachment, subretinal hemorrhage etc. OCT helps in diagnosing and monitoring the development of new changes and monitoring response to therapy.

Chorioretinal Inflamations
OCT is able to define the extent, depth and thickness of the inflammatory lesion and the layer involved. The associated secondary changes like cystoid macular oedema, choroidal neovascular membrane, epiretinal membrane, subretinal fluid and sub retinal fibrosis can be demonstrated.

Other Uses
OCT can diagnose macular involvement in various retinal diseases such as heredodystrophic disorders, juxtafoveal telengectasia, intraocular metastasis, and for macular involvement following retinal detachment surgery.

Reproducibility
OCT measures retinal thickness with a high degree of accuracy and reproducibility for a given patient from one examination to the next and also when the examination is performed by different examiners.

Disadvantages
Although OCT is an extremely valuable technique, there are limitations and pitfalls to its use.
1. OCT images are degraded in the presence of media opacity like dense cataract.
2. The scan quality depends on the skill of the operator.
3. OCT may not be possible with uncooperative patients.
4. Foveal thickness measurement may be inaccurate if scan is not centred on the fovea.

NEWER DEVELOPMENTS IN OCULAR IMAGING

OCT/SLO Combination Imaging Systems
This system generates OCT images using multiple T-scans instead of A-scans as in the conventional OCT systems. The result is superior image quality with the added advantage of simultaneous C-Scan SLO confocal imaging. There is a simultaneous confocal pixel to pixel correlation between the SLO image and OCT image. It is possible to register where the pathology is located and how it is oriented on the fundus. This overcomes one of the major drawbacks of conventional OCT. The fast C-Scan OCT stack features provides both 3D topographic volumes and surface topographic maps.
These can be compared using subtraction to detect retinal thickness changes over time and assess response to treatment.

**Spectral OCT**

Offers ultra fast acquisition rates of OCT images with improved resolution (4-6 microns) and a higher signal to noise ratio (SNR). This system also provides a simultaneous confocal scanning ophthalmoscope (SLO) image of the fundus and generates full 3D Topographic and tomographic images. Software allows users to automatically compare two topographic maps, subtract them from each other and evaluate changes over time. A new 3D advanced software allows users to automatically remove different layers of the vitreoretinal and inner retinal structure to improve the observation and assessment of the pathology.

**3D OCT With Non-mydriatic Retinal Camera**

3D OCT images are got upto 50 times faster than existing time domain technology to reduce patient eye movement and to increase patient comfort. It provides a three dimensional virtual microscopic view of the specific targeted area, with accurate retinal registration for the most reliable and reproducible measuring results.

**References**


**ON A LIGHTER VEIN**

**Of Pupils… and Teachers**

Dr. Raghu Varma

Our temper and temperament; diagnosis and dealings; in fact the whole philosophy of life would have been inculcated into us by or experiences - in and out of classrooms. And much of it can be attributed to our peers and teachers. All of us have had remarkable and not so remarkable teachers and friends. Some of them simply refuse to fade into oblivion.

During my undergraduate days I had a classmate who was a body builder-turned-medical student. He was, in fact, the ‘Mr.Kerala’ of the previous year and had got in to the medical college via the sports quota. In spite of his remarkably formidable physique, he was very queasy about the sight of blood and sickness, and dead bodies in particular. And needless to say, he had to make several attempts before he could pass Anatomy. But we remained close to each other in spite of him being four batches behind me in clinics; and we used to have ‘combined study sessions’. He was a firm believer in what he called ‘spontaneous cure’. “There is no point in treating any disease”, he would say. “Because if the patient is going to get well, he will; and if he is going to die, he will”. His dictum in his own peculiar English was “what what things will happen; that that things will happenae happen”, enunciated with an elongation of the happen-ae part (italics are mine). When I see the unexpected results of some of the surgeries and other procedures we do I really feel like agreeing with him. He reminds me of another huge senior of mine, who was in fact my first roommate too. On our first night together I discovered why he didn’t have a roommate. He use to SNORE. And I, who never had a roommate before was left sleepless. Being about half his weight and size, I was reluctant to wake him up and tell him to snore a little less loudly. Suddenly he turned over in his sleep and fell totally and eerily silent. I bolted upright and after a few suspenseful seconds went over and put my hand under his nose. What a relief! He was breathing. Friends, in the OT, when the pulse-oxymeter falters, it gives one a little flutter like the one I had that night!

Many are such happenings and happenstances that crowd into ones memory at unexpected moments in one’s OP and OT.