OPTICAL TOMOGRAPHIC EVALUATION OF RETINAL NERVE FIBER LAYER IN GLAUCOMATOUS EYES

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Optical Coherence Tomography (OCT) - Prinicples

Optical Coherence Tomography (OCT) is a new medical diagnostic imaging technology which can perform micron resolution cross-sectional or tomographic imaging in biological tissues **[1-4]**. The operation of OCT is analogous to ultrasound B-mode imaging or radar except that light is used rather than acoustic or radio waves.

Techniques such as X-ray, computed tomography (CT) and magnetic resonance imaging have been applied for diagnostic imaging in ophthalmology **[5-7]**. However, these approaches have not been widely used in routine diagnostic applications in ophthalmology because of their limited resolution and preclusive cost and complexity.

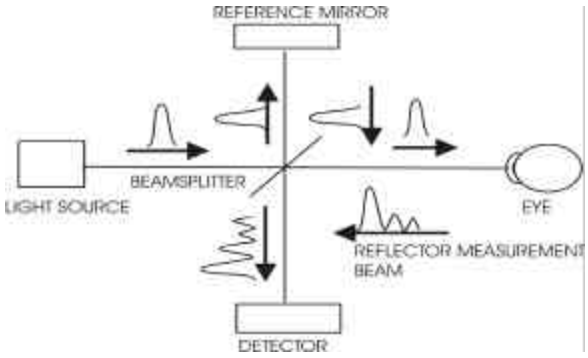
The operation of OCT is based on an optical measurement technique known as **low-coherence interferometry.**

Low-Coherence Interferometry:

Optical coherence Tomography uses low-coherence or white light interferometry to perform high-resolution range measurements and imaging. In order to perform high-resolution structure measurements with tens of micron resolution (corresponding to echo delay times of tens of femtoseconds), it is necessary to use an optical instrument which compares or correlates one optic beam or light wave with another. This measurement may be performed by an optical device known as an interferometer.

Diagram shows a schematic of an optical interferometer. An optical beam from a laser or light source which emits either short optical pulses or short coherence length light is directed on to a partially reflective mirror (optical beam splitter). The partially reflecting mirror splits the light into two beams, one beam is reflected and the other is transmitted. One light beam is directed onto the patient's eye and is reflected from intraocular structures at different distances. The reflected light beam from the patient's eye consists of multiple echoes, which give information about the range or distance and thickness of different intraocular structures. The second beam is reflected from a reference mirror at a known spatial position. This retro-reflected reference optical beam travels back to the partial mirror (beam splitter) where it combines with the optical beam reflected from the patient's eye. When the two light pulses coincide they produce a phenomenon known as **interference**, which is measured by a photodetector.

The key feature of the interferometer is that it can measure the time delays of optical echoes by comparing the reflected light beam with a reference beam. While the explanation presented here assumes that the list is composed of short optical pulses, the measurement may also be performed using non-pulsed, or continuous light with a short coherence length **[8-11]**. For this reason the measurement technique has been termed "Low Coherence interferometry".



The light source for the interferometer is a super luminescent diode, which is coupled directly into an optical fiber. This light source is similar to laser diodes used in optical compact disc players, except in OCT, that the diode source is designed to emit short coherence length light.

OCT in Glaucoma

Measurement of retinal nerve fiber layer (NFL) thickness with OCT are potentially useful in the early diagnosis of glaucoma and the early detection of glaucomatous progression.[12,13] Additionally, significant retinal nerve fiber layer loss may precede both the development of visual field defects and identifiable cupping **[14]**.

Several types of scanning patterns are useful in evaluating the optic nerve head and NFL. Radial OCT tomograms acquired directly through the optic disc

provide cross-sectional information on cupping and neuroretinal rim area. Three-dimensional information on disc parameters may be obtained from multiple radial tomograms acquired at different angular orientations, or from a series of parallel tomograms offset at various distances from the center of the disc.

A single circular scan around optic nerve head allows the variations in NFL thickness in different regions around the disc to be assessed and compared. A circular tomogram evaluates the cross sectional structure of the NFL in a cylindrical section surrounding the optic disc, and may be displayed "unwrapped" as a flat image on the page.

In more advanced cases of glaucoma, areas of NFL thinning around the disc, as measured by OCT, correlate with visual field defects and losses in the neuroretinal rim **[13]**. In the earlier stages of glaucoma, NFL thinning may occur out of proportion to visual field loss or cupping. Direct measurement of NFL thinning with OCT may enable earlier detection of glaucomatous changes.

Widely varying results have been reported**[15]**. The following information has been published so far:

1. There are individual and age-related difference in the thickness of the retinal nerve fiber layer, and glaucoma cannot be evaluated on the basis of local thickness alone **[16,17]**.
2. In healthy eyes, the superior or inferior arcuate bundle is thick above and below the optic disc, whereas in glaucomatous eyes it is thin and flattened **[18,19]**.
3. Glaucomatous damage is least likely to be manifested on the nasal side of the retina **[20]**.
4. It is generally accepted that anatomical changes such as those due to myopia are more likely on the temporal side of the retina, and are unlikely to be manifested on the nasal side **[21]**.
5. The nerve fiber thickness decreases with increasing distance from the disc margin **[22]**.

Computer Image processing technique:

Computer image processing technique may be applied to the circular OCT tomograms in order to automatically identify the reflective boundaries at the vitreoretinal interface, the retinal pigment epithelium, and the NFL. NFL or retinal thickness may be computed automatically from these boundaries and can be displayed as an averaged over quadrant (superior, inferior, temporal, nasal), or over clock hour, or individually for each A-scan comprising the OCT image. These quantitative measurements may then be compared with standard normal values or values obtained from previous examinations to assess glaucomatous progression **[13]**. The direct measurement of NFL thickness provided by OCT combined with automated image analysis allows a completely objective assessment of glaucoma onset and progression.

Optical Tomography Versus Ultrasound:

Since ultrasound imaging depends on the reflection of sound waves from intraocular structures, it requires direct contact of the ultrasound measuring device with the eye or immersion of the eye in a liquid which facilitates the transmission of sound waves into the globe. Further higher frequency ultrasound is strongly attenuated in biological tissues. Imaging can be performed to depths of only 4 to 5mm, limiting the application of high resolution ultrasound to the anterior eye.

In contrast, optical measurement and imaging techniques rely on the use of light rather than sound waves. For this reason, optical diagnostics can be performed without physical contact to the eye, thereby minimizing patient discomfort during examination. In addition, the use of light rather than sound waves provides a significantly higher spatial resolution than possible with ultrasound. Current OCT imaging technologies yield images, which have approximately ten times higher than standard ultrasound B-mode imaging. The inherently high resolution of OCT permits the imaging of fine structures within the retina as well as anterior eye, thus facilitating the diagnosis of a wide range of clinically relevant pathologies.

Future of OCT:

OCT is yet another diagnostic tool which helps to narrow down the grey areas in glaucoma management. Because of its ability to pick early nerve fibre loss, it will be useful in detecting glaucomatous nerve damage even before the visual fields can detect it. It will also be a useful tool for a close serial follow up in advanced glaucomas with limited fields where waiting for a visual field analyzer to pick up small amounts of deterioration in a field may be too much of a loss to a patient with an already compromised field.

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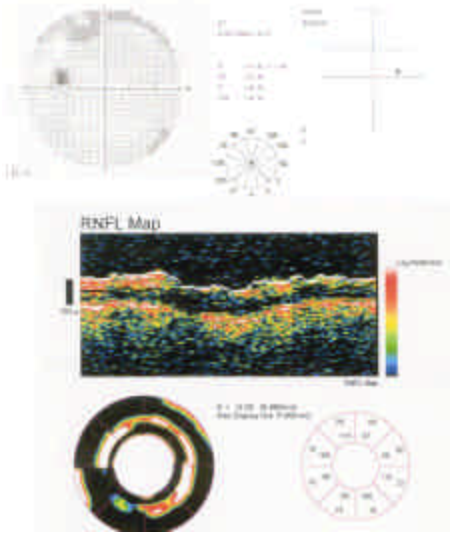

Figure 1

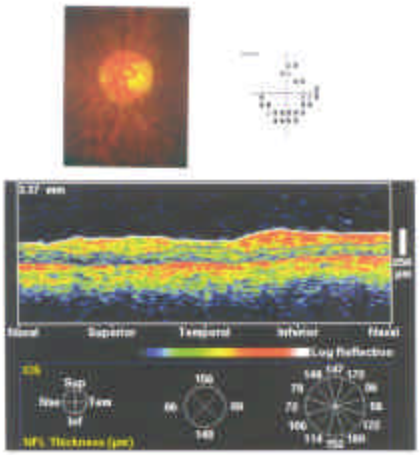

Figure 2

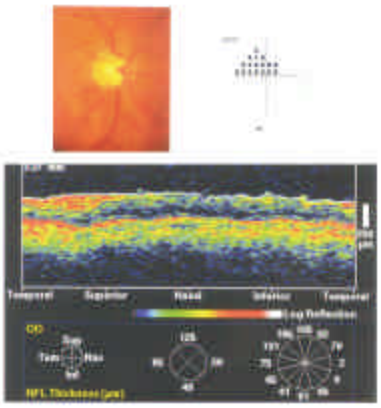

Figure 3

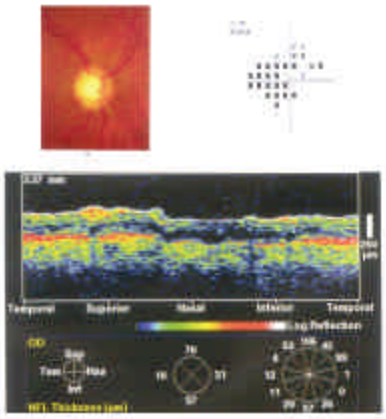

Figure 4

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The art of medicine consists of amusing the patient while nature cures the disease (Voltaire).