**AN APPRAISAL ON OPTICAL COHERENCE TECHNOLOGY**

**FAISAL MUHAMMAD**

**(ST/CS/ND/20/340)**

**A SEMINAR REPRESENTED TO THE DEPARTMENT OF COMPUTER SCIENCE, SCHOOL OF SCIENCE AND TECHNOLOGY, FEDERAL POLYTECHNIC MUBI, ADAMAWA STATE, NIGERIA**

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**Abstract**

*Optical Coherence Tomography (OCT) is an emerging technology for performing high-resolution cross-sectional imaging. OCT is analogous to ultrasound imaging, except that it uses light instead of sound. OCT can provide cross-sectional images of tissue structure on the micron scale in situ and in real time. Using OCT in combination with catheters and endoscopes enables high-resolution intraluminal imaging of organ systems. OCT can function as a type of optical biopsy and is a powerful imaging technology for medical diagnostics because unlike conventional histopathology which requires removal of a tissue specimen and processing for microscopic examination, OCT can provide images of tissue in situ and in real time. OCT can be used where standard excisional biopsy is hazardous or impossible, to reduce sampling errors associated with excisional biopsy, and to guide interventional procedures. In this paper, we review OCT technology and describe its potential biomedical and clinical applications.*

**Keywords**: Biopsy, imaging, OCT, optical imaging, optical coherence tomography, tomography

**Introduction**

In the last decades, new medical imaging technologies have radically improved not only the diagnosis and clinical management of various diseases but have also provided new opportunities for understanding the pathogenesis of various diseases and for the advancement of novel therapies and interventions. The impact in medicine of three-dimensional imaging technologies such as magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), X-ray computed tomography, radioisotope imaging, ultrasound and diffuse optical tomography cannot be over-emphasized. Despite their successes and further technical developments, these techniques are limited and for many applications negatively impacted by low spatial resolution; under the best circumstances, the smallest details observable are in the range of half a millimeter. Meanwhile, optical imaging methods such as conventional and confocal microscopy, fluorescence and multi-photon imaging have spatial resolutions of micrometers or better but cannot penetrate deep under the surface of biological samples (Tearney & Smith, 2013).

Optical coherence tomography (OCT), a light interference-based optical technique, allows three-dimensional cross-sectional imaging within biological samples with a spatial resolution of 10 μm or less. OCT lies between the deep and the superficial imaging techniques conveying high spatial resolution at imaging depths of millimeters into tissue. Since its conception, in the late 1980s, OCT was developed as a technique enabling high-resolution, real-time and in-situ imaging of tissue microstructure without the need for tissue excision and processing (Tearney & Smith, 2013).

The technological advances made in the last two decades in regard to interference technologies, optical instrumentation, detectors, speed of data acquisition and processing as well as light sources have facilitated the application of OCT technology in a variety of medical fields such as developmental biology, ophthalmology, interventional cardiology, dentistry, gastrointestinal endoscopy, dermatology, laryngology, gynecology, etc. This past decade has seen OCT evolving from an optical imaging method used mostly in research laboratories into a valuable tool used in various areas of medicine and health sciences. This trend is likely to continue as medical applications that exploit the speed, resolving power and convenience of OCT imaging emerge. OCT is an optical imaging modality that is used to perform high resolution, cross-sectional imaging of internal microstructures in materials and biological systems by measuring the echo time delay and magnitude of backscattered light. The functional principle behind OCT imaging is light interference. Therefore, a light interference setup is at the core of any OCT system. Although there are many types of interference configurations, as will be described in a later section, the optical fiber-based Michelson setup will be used to demonstrate the basic concepts of light interference and its role in OCT imaging (Puliafito, 2015).

**Literature Review**

In an OCT system, the light from a low-coherence source is split into two paths by a coupler directing it along two different arms of an interferometer. One arm is designated as the reference arm, while the other is the sample arm. When the light exits the fiber end of either arm, it is shaped by various optical components (mirrors, lenses, etc.) to control specific beam parameters such as shape, depth of focus and the intensity distribution of the light. In the reference arm, the light is back-reflected by a reference mirror and it returns into the interference system, propagating along the same path it came from but in the opposite direction. The same process happens with the light in the sample arm the only difference being that the beam is backscattered by the sample. In an inhomogeneous sample, different structures within the sample will have different indices of refraction and light will be backscattered when it encounters an interface between materials of different refractive index. The returning light from both arms recombine at the coupler and generate an interference pattern, which is recorded by the detector (Fujimoto, 2016).

Endoscopic ultrasound has recently been introduced as a new technology for high-resolution endoscopic imaging. Using ultrasound frequencies in the range of 10 to 30 MHz, axial resolutions in the range of 100 *µ*m can be achieved. Imaging of the esophagus or bowel requires filling the lumen with saline or using a liquid-filled balloon to couple the ultrasound into the tissue. Ultrasound can be used as an adjunct to endoscopy to diagnose and stage early esophageal and gastric neoplasms. Impressive results have been achieved using high frequency endoscopic ultrasound which demonstrate the differentiation of mucosal and submucosal structures (Tearney & Smith, 2013).

**Applications of Optical Coherence**

**Guiding Surgical Intervention**

Another large class of applications for OCT is guiding surgical intervention. The ability to see beneath the surface of tissue in real time can guide surgery near sensitive structures such as vessels or nerves as well as assist in microsurgical procedures. Optical instruments such as surgical microscopes are routinely used to magnify tissue to prevent iatrogenic injury and to guide delicate surgical techniques. OCT can be easily integrated with surgical microscopes. Hand-held OCT surgical probes and laparoscopes have also been demonstrated (Schmitt *et al.,* 2012).

One example of a surgical application for OCT is the repair of small vessels and nerves following traumatic injury. A technique capable of real-time, subsurface, three-dimensional, micron-scale imaging would permit the intraoperative monitoring of microsurgical procedures, giving immediate feedback to the surgeon which could improve outcome and enable difficult procedures. To demonstrate the use of OCT imaging for diagnostically assessing microsurgical procedures *in vitro* studies were performed using a microscope-based OCT system (Schmitt *et al.,* 2012).

Because OCT can provide image information in real time, it can be integrated directly with surgery. In a recent study, we investigated the feasibility of using high-speed OCT imaging to guide the placement and image the dynamics of surgical laser ablation . Argon laser ablation was performed in five different *ex vivo* rat organs to assess OCT imaging performance and variations between tissue types. The use of OCT to monitor ablative therapy in real-time could enable more precise control of laser delivery and reduction in iatrogenic injury. These studies were performed using a commercially available low-coherence light source (AFC Technologies, Hull, Quebec, Canada) having a center wavelength of 1310 nm and a free space axial resolution of 18 *µ*m. The signal-to-noise ratio was 115 dB using 5 mW of incident power on the specimen. For typical tissues, this sensitivity permits imaging to depths up to 3 mm. For high-speed image acquisition, the size of the region imaged was 3x3 mm and 256x256 pixels. Images were displayed on a computer monitor and simultaneously recorded to Super VHS video tape. The acquisition rate was eight frames per second or 125 ms for each image (Brezinski, 2006).

**Cellular Level OCT Imaging**

The development of high-resolution OCT is also an important area of active research. Increasing resolutions to the cellular and subcellular level are important for the diagnosis of early neoplasias as wall as other applications. As discussed previously, the axial resolution of OCT is determined by the coherence length of the light source used for imaging. Light sources for OCT imaging should have a short coherence length or broad bandwidth, but also must have a single spatial mode so that they can be used in conjunction with interferometry. In addition, because the signal to noise depends on the incident power, light sources with average powers of several milliwatts are typically necessary to achieve real-time imaging. One approach for achieving high resolution is to use short pulse femtosecond solid state lasers as light sources (Fujimoto, 2016).

The seemingly wide cell membranes in the OCT images are actually composed of membranes and extracellular matrix. The OCT image shows cells with varying size and nuclear-to-cytoplasmic ratios as well as cells undergoing mitosis. In developmental biology, the ability to image cellular and subcellular structure can be used to study mitotic activity and cell migration which occur during development. The extension of these results to human cells has important implications, but is challenging because differentiated human cells are smaller than developing cells. Additional improvements in resolution and technology are necessary to achieve this objective. In ophthalmology, improving resolution should allow more precise morphometry measurements of retinal features such as retinal thickness and retinal nerve fiber layer thickness, which are relevant for the detection and screening for macular edema and glaucoma. High-resolution imaging should also improve OCT diagnosis of early neoplastic changes. Standard OCT image resolutions are sufficient to image architectural morphology on the 10 to 15 *µ*m scale and can identify many types of early neoplastic changes. However, the ability to image with cellular level resolution should not only enhance the spectrum of pathology that can be imaged, but also improve sensitivity and specificity. Current light sources for ultrahigh-resolution OCT imaging are based on short pulse lasers and are not clinically viable because of their complexity and expense. However, with the development of new technologies, especially in the telecommunications industry, compact and lower cost light sources should become available in the near future (Tearney & Smith, 2013).

**Biomedical Imaging Using Optical Coherence Tomography**

Several features of OCT suggest that it will be an important technology for biomedical imaging (Izatt & Hsing-Wen, 2017).

1. OCT can image with axial resolutions of 1 to 15 µm, one to two orders of magnitude higher than conventional ultrasound. This resolution approaches that of histopathology, allowing architectural morphology and some cellular features to be resolved. Unlike ultrasound, imaging can be performed directly through air without requiring direct contact with the tissue or a transducing medium.
2. Imaging can be performed in situ, without the need to excise a specimen. This enables imaging of structures in which biopsy would be hazardous or impossible. It also allows better coverage, reducing the sampling errors associated with excisional biopsy.
3. Imaging can be performed in real time, without the need to process a specimen as in conventional biopsy and histopathology. This allows pathology to be monitored on screen and stored on high-resolution video tape. Real-time imaging can enable real-time diagnosis, and coupling this information with surgery, it can enable surgical guidance.
4. OCT is fiber optically based and can be interfaced to a wide range of instruments including catheters, endoscopes, laparoscopes, and surgical probes. This enables imaging of organ systems inside the body.
5. Finally, OCT is compact and portable, an important consideration for a clinically viable device.

**Ophthalmic Imaging**

OCT was initially applied for imaging of the eye. To date, OCT has had the largest clinical impact in ophthalmology. This image is 250 transverse pixels wide and imaging was performed using a wavelength of 800 nm with a 10-µm resolution. The OCT image provides a cross-sectional view of the retina with unprecedented high resolution and allows detailed structures to be differentiated. Although the retina is almost transparent and has extremely low optical backscattering, the high sensitivity of OCT imaging allows extremely weak backscattering features such as the vitreal-retinal junction to be visualized. The retinal pigment epithelium and choroid, which is highly vascular, are visible as highly scattering structures in the OCT image. The retinal nerve fiber layer is visible as a scattering layer originating from the optic disk and becoming thinner approaching the fovea. The total retinal thickness as well as the retinal nerve fiber layer thickness can be measured. Because these images have a resolution of 10 µm, there can be residual motion of the patient's eye on the 1 to 2 second time scale necessary for the measurement. However, because OCT measures absolute position, image-processing algorithms can be used to measure the axial motion of the eye and correct for motion artifacts (Izatt & Hsing-Wen, 2017).

OCT image of the human retina papillary-macular axis in vivo illustrating the ability to discriminate structural morphology. The optic disk as well as several of the retinal layers are observed. The highly backscattering retinal nerve fiber layer (NFL) and choriocapillaris appear red in the false color image. Clinical studies have been performed to investigate the feasibility of using OCT for the diagnosis and monitoring of retinal diseases such as glaucoma, macular edema, macular hole, central serous chorioretinopathy, age related macular degeneration, epiretinal membranes, optic disc pits, and choroidal tumors. In addition, the ability of OCT to perform real-time imaging has also been used to study dynamic responses of the retina including retinal laser injury. Images can be analyzed quantitatively and processed using intelligent algorithms to extract features such as retinal or retinal nerve fiber layer thickness. Mapping and display techniques have been developed to represent the tomographic data in alternate forms, such as thickness maps, to aid interpretation. OCT is especially promising for the diagnosis and monitoring of diseases such as glaucoma or macular edema associated with diabetic retinopathy because it can provide quantitative information retinal pathology which is a measure of disease progression. OCT has the potential to detect and diagnose early stages of disease before physical symptoms and irreversible loss of vision occur (Izatt & Hsing-Wen, 2017).

**Imaging in Nontransparent Tissues**

With recent research advances, OCT imaging of optically scattering, nontransparent tissues have become possible, thus enabling a wide variety of biomedical applications. One of the most important advances for imaging in optically scattering tissues was the use of longer wavelengths where optical scattering is reduced. By performing OCT imaging at 1300-nm wavelengths, image penetration depth of 2 to 3 mm can be achieved in most tissues. This imaging depth is comparable to the depth over which many biopsies are performed. In addition, many diagnostically important changes of tissue morphology occur at the epithelial surfaces of organ lumens (Tearney & Smith, 2013).

One class of applications where OCT could be especially powerful is where conventional excisional biopsy is hazardous or impossible. For example, in ophthalmology, biopsy of the retina is impossible and OCT can provide high-resolution images of pathology that cannot be obtained using any other technique. Another scenario where biopsy is not possible is imaging of atherosclerotic plaque morphology in the coronary arteries. Research has demonstrated that most myocardial infarctions result from the rupture of small to moderately sized cholesterol-laden coronary artery plaques followed by thrombosis and vessel occlusion. The plaques at highest risk for rupture are those which have a structurally weak fibrous cap. These plaque morphologies are difficult to detect by conventional radiologic techniques and their microstructural features cannot be determined. Identifying high-risk unstable plaques and patients at risk for myocardial infarction is important because of the high percentage of occlusions which result in sudden death. OCT could be powerful for diagnostic intravascular imaging in both risk stratification and guidance of interventional procedures such as atherectomy (Fujimoto, 2016).

**Optical Biopsy and Detecting Early Neoplastic Changes**

Identification of early neoplastic changes is important clinically because once metastatic, treatment is difficult. The diagnostic indicators of early neoplastic changes include accelerated rate of growth, mass growth, local invasion, lack of differentiation, anaplasia and metastasis. The evaluation of structural and cellular features of these types is necessary for the correct identification and grading of neoplasias. Changes in architectural morphology and glandular organization are relatively easy to identify because they fall within the resolution limits of most standard resolution OCT systems. As OCT technology improves, the ability to image cellular level features should improve, and the range of applicability of OCT imaging should increase (Fujimoto, 2016).

**Catheter and Endoscopic OCT Imaging**

To perform OCT imaging in vivo, it is necessary to develop image delivery systems for internal body imaging. Because OCT imaging technology is fiber-optic based, it can be easily integrated with many medical diagnostic instruments to enable internal body imaging. OCT laparascopes and hand-held surgical probes have recently been demonstrated. Using fiber optics, a small-diameter transverse scanning catheter/endoscope has been developed. The catheter/endoscope consists of a single-mode optical fiber encased in a hollow rotating torque cable. At the distal end of the catheter, the fiber is coupled to a graded index GRIN lens and a microprism to direct the OCT beam radially, perpendicular to the axis of the catheter. The rotating cable and distal optics are encased in a transparent housing. The OCT beam is scanned by rotating the cable to permit cross-sectional transluminal imaging, in a radar-like pattern, in vessels or hollow organs (Tearney & Smith, 2013).

**Conclusion**

OCT can perform a type of optical biopsy, the micron-scale imaging of tissue morphology in situ and in real time. Image information is available immediately without the need for excision and histologic processing of a specimen. The development of high-resolution and high-speed OCT technology as well as OCT compatible catheter/endoscopes and other delivery systems represent enabling steps for many future OCT imaging clinical applications. More research remains to be done and numerous clinical studies must be performed to determine in which clinical situations OCT can play a role. However, the unique capabilities of OCT imaging suggest that it has the potential to have a significant impact on the diagnosis and clinical management of many diseases.

**Recommendations**

1. The paper recommends that the various applications of optical coherence technology it is more recommended that it be used over the ultra-sonic.
2. It also recommends that this technology be provided in most health facilities to provide good medical checkup.

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