

# Diffuse optical tomography and magnetic resonance imaging techniques biology essa...

[Science](#), [Biology](#)



## **Abstract**

This paper discusses two of the most influential medical imaging techniques that enable physicians to observe several activities in the human body.

These systems also make it possible to detect early stages of abnormalities that might grow in an organ or a tissue. The first imaging technique is diffuse optical tomography (DOT). The principle of DOT imaging is the illumination of the tissue by infrared light emitted from an array of light sources and measuring the scattered or absorbed or both with an array of detectors.

Then, a model of light propagation is developed to determine the localized optical properties of the illuminated tissue. The second method is Magnetic Resonance Imaging (MRI). In MRI imaging the body is exposed to magnetic field with field strength of 1.5 or 3.0 or 7.0 Tesla. During the exposure, the hydrogen atoms in human body will be magnetized and lined up toward the direction of the magnetic field. Radio frequency pulse is applied to synchronize the frequency of rotation and precession of the hydrogen protons. Processing the signal produced after RF pulse will determine the properties of different types of tissues in form of gray shades. The DOT and MRI are used in several applications in the medical field. The most significant applications for DOT are to screen and diagnose breast cancer, and the study of the brain, including stroke, cerebral activities hemorrhage, and brain function. The DOT is portable and cost less than MRI, while the MRI offers higher resolution than DOT. Each technique can be used individually to obtain information regarding specific tissue. They also can be used as combined modality to acquire more enhanced information about specific tissue.

## **Introduction:**

### **DOT:**

Scientists, engineers, and medical experts have been attracted to optical imaging applications in medicine and biomedical research. It has captivated their attention because of the size, portability, low cost, and ability of the technology to provide localized functional and molecular information. In the process of optical imaging, the course of light traveled through a biological tissue is subjected to a number of photophysical actions such as absorption, scattering, and emission of light. The information from the scattered or the absorbed or the remitted light can be used to obtain metabolic and biochemical information regarding specific tissue. Figure. 1 paths of photons through tissue. In DOT the tissue is illuminated by near infrared wavelength. The three substances that absorb at these wavelengths are water and both oxygenated and deoxygenated hemoglobin all have relatively weak absorption. By knowing this fact, we can spectrally localize where the light absorbed and scattered in the tissue. Figure. 2 the coefficients of oxy-hemoglobin and deoxy-hemoglobin and water absorption as a function of wavelength. Figure. 2 shows that at these frequencies we can distinguish between water and hemoglobin. For frequencies higher than shown, water absorption of light will increase significantly. Within the ranges shown in the figure we can also distinguish between oxy- hemoglobin and deoxy-hemoglobin. So, by illuminating the tissue we will receive back attenuated light with different concentrations. These differences in concentrations enable DOT to image the alterations in oxygen saturations and oxy-hemoglobin and deoxy-hemoglobin concentrations. The history of using

optical applications in medical field goes back the 20's of the past century. The technology has developed to the introduction of DOT. Cutler was the first to try image the breast lesions using continuous wave light. However, he stopped because of the unbearable heat generated on the patient skin. Another application is pulse oximeter, which a device used to measure the oxygen concentration in the blood. The ability of pulse oximeter to respond to sudden changes in oxygen concentration in blood is the reason for its wide use all over healthcare facilities. In the early years of developing oximeters, the first oximeter was connected to the ear lobe. A light source and a photocell were attached to the ear lobe. The purpose of this process was to measure the oxygen concentration via arteries and veins. The current pulse oximeter measures the attenuation of the light passing through a tissue. When the heart beats the blood volume increases in the arteries. The increase of blood will lead to higher light absorption. The oximeter will measure the higher and lower absorption. The fraction of these two values will be processed in mathematical model. The result is related to the oxygen concentration in blood. However, in the 1970's, the measurement of the cerebral activities is not applicable using pulse oximeter or other techniques such as laser. The characteristics of the detectors and photons of the pulse oximeter and laser cannot be used to detect hemodynamic changes in the brain. During 1970's, the near infrared spectroscopy was being used to measure the changes of the oxygenation in the brain. After sending the infrared signal to the brain, the scattering will be analyzed to measure the changes in the photon density. These changes are indications to the changes in the chromospheres concentrations (chromosphere is a substance

responsible for the coloring of the tissue). Later on, technologies were developed able to enable the use of photon migrations characteristics to perform actual imaging of the tissue. Instrumentation: Most optical systems can be categorized into three methods: Time-domain (TD) system, in which the system sends very short light pulses to a specific tissue. As the light passing through the tissue, it will be subjected to attenuation and broadening in time. Specific detectors are used to measure the changes. Frequency-domain (FD) system the light source is modulated to produce sine wave between 100-1000 MHz. A macroscopic wave of photon density will develop (Photon-density wave). Steady-state domain (SSD), in which the tissue is illuminated by several light sources constantly with the same energy. The intensities of the light will be measured at the detectors. Time-domain system: In the time domain system, the light transmitted into the tissue is a short laser pulse. The pulse will be registered as a function of time. The output pulse has lower intensity than the input pulse and it looks wider than the input pulse. In figure. 3 the mean pathlength of the traveling photons is indicated at time when the response pulse reaches its maximum. Greater scattering coefficient will lead to increase in the mean pathlength and longer time for the maximum to be reached. Figure. 3 Time-resolved impulse response for a tissue The decreasing of the curve reflects information about the absorption coefficient of the tissue. When the absorption of the photons increases the steeper the curve slope will become. The time-correlated single-photon counting is the most used technique in time-domain DOT. The system consists of: Laser diodes as light sources. They produce pulses with 10-50 picosecond pulse duration and 1-50 MHz repetition time.

Optical fibers to carry the light and collect the photons emitted from the tissue and carry them to microchannel plate photomultiplier (MCP-PMT). Constant fraction discriminator (CFD). Time-to-amplitude converter (TAC). Pulse-height analyzer (PHA) to count the output from (TAC) as discrete units and accumulate them until they reach 100, 000-1000, 000 counts. Computer to store the time-response curves. Figure. 4 Time-domain DOT components

Frequency-domain system: Frequency-domain light sources generate amplitude-modulated sinusoidal waves. The original signal is usually modulated with frequency in the range of 100- 1000 MHz. The measured parameters of the transmitted wave are relative to the parameters of the wave before it enters the body. The parameters to be analyzed are the phase shift ( $\Phi$ ) and the demodulation.  $\text{Demodulation} = (\text{AC}_{\text{output}}/\text{DC}_{\text{output}})/(\text{AC}_{\text{input}}/\text{DC}_{\text{input}})$ .  $\text{AC}_{\text{input}}$ ,  $\text{DC}_{\text{input}}$  are the amplitudes and the offset intensity for the incident light.  $\text{AC}_{\text{output}}$ ,  $\text{DC}_{\text{output}}$  are the amplitudes and the offset intensity for the light after it passes through the medium. Figure. 5 frequency-domain parameters of incident light and the light transmitted through a tissue

After measuring the parameters for all frequencies, a Fourier transform will be performed on the data. In terms of the hardware parts, making measurement using frequency-domain is simpler and more effective. The frequency-domain system consists of four major components: (figure. 6) Laser diodes as light sources, and AC source + DC current for the intensity modulation process. Optical fibers to carry the light from the laser diode to the tissue and to collect the remitted after passing the medium. Detection of light is achieved by consist of Photomultiplier tubes (PMTs) and silicon photodiodes or avalanche photodiodes. Cross-correlation process to measure

the phase shift and demodulation. In this process the large frequencies range of the modulation signal will be reduced into range of 1 KHZ. By using accurate digital parts, Measuring the phase shift and demodulation is easy to achieve at this low frequencies range. Figure. 6 experimental design of the frequency domain system

Steady-state-domain systems (continuous wave):

Steady-state-domain systems were not used commonly earlier. However, recently they are widely used in medical settings. The system generates continuous light wave transmitted into the tissue. Then, measure intensities of the remitted light. Figure. 7 light transmitted through a tissue in Steady-state-domain systems

Dr. Christoph H. Schmitz developed dynamic near-infrared optical tomography (DYNOT). The system contains two laser diodes that generate wavelength between 700-850 nm. The light generated by the two beams is connected to 32 fiber bundles-by the means of demultiplexer that carry the light to different locations on the tissue. Each source fiber bundle is joined with a detection fiber bundle. The detection bundles are connected to the detection unit module. Tests show that (DYNOT) has data-acquisition rate (3968 measurements/second) faster than all near infrared optical instruments that uses several light sources. Figure. 8 basic set up of steady-state-domain system

Comparison between all DOT systems: The level increases from Steady-state to frequency to time domain systems regarding the complexity of hardware and the amount of information. The time-domain system is the most accurate when it comes to separating the scattering and absorption of light transmitting through a tissue. The data-acquisitioning rate is much faster in steady-state domain than frequency and time domain.

Thus, the steady state domain will be ideal to measure the changes of the

physiological state of an organ or the hemodynamics variations resulting from sudden stimulus. Several studies showed that the measured signal from the steady-state system -if it was used alone- does not distinguish between the absorbed and the scattered light transmitted through a tissue. The observer cannot tell between the changes in the signal are if it was caused by the absorption or the scattering coefficient of the tissue. Limitations of all three systems: The DOT systems are not able to measure the absolute optical characteristics of traveling light. It is only able to measure the changes of the optical characteristics with respect to a specific material or a physiological activity. It is difficult to measure the absolute values because it is difficult to determine the absolute attenuation of the light passing through a tissue. Some application of DOT: Breast imaging: DOT is used in breast imaging to detect cancerous tumors. These tumors will affect some of the vital parameters such as, oxygen concentration, blood flow, metabolism and blood volume. These biological information are affected and modified by cancerous growth in the breast. DOT provides the ability to image the changes in these parameters. Tumors usually have more blood vessels than the surrounding tissue. Thus, when the light is passing through the breast, there will be a difference in the amount of absorption. This difference is due to the change in oxy- and deoxy hemoglobin in blood. Another advantage of DOT, that it is capable to distinguish different areas among the tumor itself. Determining which area has more cancerous activity among the tumor (which area has higher malignancy rate). Brain function: There several imaging techniques used to image the brain activity such positron Emission Tomography (PET), functional MRI (fMRI), EEG and other instruments.



Although most of these techniques offer higher resolution than DOT, the advantage of DOT is its ability to simultaneously measure the concentration of both oxy- and deoxy hemoglobin. Imaging the brain function with DOT can describe the relationship between the neuronal activities and the hemodynamic response to these activities. Stroke: Strokes that occur due to blocking in blood vessel which lead to decrease in the blood flow to the brain (ischemic strokes) can be treated by specific medications. If the stroke is caused by internal bleeding (hemorrhagic strokes), the medication could put the patient be at a risk of sudden death. DOT can be used to detect early stages of stroke and can distinguish between the different kinds of stroke. Advantages of DOT: Nonionizing, noninvasive, inexpensive and portable in most cases. It can measure absorbed and/or scattered light. It can distinguish between oxy- and deoxy hemoglobin concentrations. Low resolution is limitation of the DOT compared to other imaging techniques.

### **Magnetic Resonance Imaging (MRI):**

MRI is medical imaging procedure that uses electromagnetic waves to image a chosen tissue or an area of the body. The MRI imaging relies on the physical properties of the Hydrogen protons. The protons are electrically charged and spin around their own axes. The proton is represented by vector which has magnitude and direction. At resting state protons are have random magnetization direction. Thus, they cancel each other and that magnetization is zero. When an external magnetic field is applied, the protons will align in the direction of the magnetic field. The protons will be orientated in the same direction. A small energy pulse (RF) of specific

frequency (Larmor frequency) is applied to the oriented protons. The pulse will tilt the net magnetization vector to a direction perpendicular to the original direction. When protons absorb the energy, they will start precessing "wobbling". This rotation will generate the NMR signal. Figure. 9 Rotation and precession of proton

The basic advantage of MRI is the ability to produce exceptional contrast resolution. When using high magnetic strength, MRI imaging able to detect microscopic contrast differences in soft tissue, even more so than with CT images. The other significant advantage is the ability to create images from all possible planes. Hardware: Magnets: These magnets are called the main magnets. They generate the main external magnetic field which induces the net magnetization. There are three types of magnets used in MRI imaging: A permanent magnet, which has been magnetized. They are magnetized all the time. The strength of these magnets is relatively very low and ranges between 0.064T ~ 0.3Tesla. they have an open design, which can be more comfortable for the patient. Figure. 9 permanent magnet

Resistive magnets: They are relatively very large electro magnets. Power source is used to generate current, which is carried through loop of wiring surrounds the magnet. The electric current will generate the magnetic field. The current will generate a lot of heat. Thus cooling system is needed. The strength of the magnet is up to 0.3 Tesla. They require a lot of power to operate. They system is turned off when it's not being used to save energy. Figure. 10 Resistive magnet

Superconducting magnet : They are the most common used magnets. Electrical current will generate the magnetic field. The current is carried in a loop of wiring. The wiring is surrounded with cooling system such as liquid helium. The use of

liquid helium is to reduce the temperature to 4 kelvin (-269 C). At this temperature the wire will not have any resistances. Thus, the magnetic field will not be lost. These magnets can have strength up 12 Tesla. The most common used clinically are the 1.5 Tesla magnets. The superconducting magnets are surrounded by vacuum vessels to maintain the temperature and to prevent the liquid helium from evaporating. Figure. 11 the vacuum vessels surrounding the superconducting magnet

Figure. 12 superconducting magnet

Comparison between the three types of magnets:

Magnet type	Advantages	Disadvantages
Permanent	consume low power, the cost to run is low, No cooling system required	low field strength (<0.3T), very heavy
Resistive	The total cost is low, Light weight, Can be turned off	consume a lot of power, Limited field strength
Superconductive	High magnetic field strength, Homogeneous field, Consume low power, High resolution	Faster scanning

The total cost is high, require expensive cryogen, Noise, Complex system

RF Coils: They are used to send radio frequency wave that causes the magnetization of the protons to tilt. They also receive the NMR signal emitted from the protons. The MRI systems usually have different RF coils to make it possible to obtain images from any part of the body. Several types of coils can be used depending on the area being scanned. There are volume coils, surface coils, quadrature coils. Figure 13 quadrature RF coil

Gradient coils: Let's assume the magnetic field is homogeneous all over the body. After applying external magnetic field, all protons will be precessing at resonance frequency. If we send an RF signal, we will receive NMR signal

from the whole body. Gradient coils will cause small variations in the magnetic field in certain area of the body, so we can only receive signal from this area. Advantages and disadvantages of MRI: Advantages Very high contrast resolution Show the details and specifications of the tissue Able to take images from any plane Non ionizing Ability to provide information about the flow of the blood inside the vessels Disadvantages Very expensive It produces a lot of noise Can make people feel uncomfortable due to the close design and the noises. Patients with pace makers or any internally implanted device that contain metallic material cannot be examined. Affected by movement, so imaging area that contains possible motion at any time is difficult. For example, coughing and swallowing can produce unclear imaging of the mouth. Relatively long imaging time.

### **Combination of DOT and MRI to image cancerous tumors "small animals":**

Combined DOT/ MRI system can provide integrated information and detailed specifications about cancerous tumors. Both MRI and DOT are non-ionizing imaging technique that can provide information regarding the structure and the function of specific tissue or physiological state. DOT is used to acquire information regarding the chromosphere (substance responsible for the color) concentration distribution on the area of study. For example, the concentration maps of oxyhemoglobine, deoxy hemoglobin, water, fat. High resolution imaging of the functional and structural of the water, fat, and the blood vessels volume can be obtained by MRI. In optical imaging some reconstruction models require precise information about the boundary of the imaging volume. MRI system is capable of obtaining this information, and

also provides information about the motion of the tissue of study. The information about the structure of the tissue can be used as "prior" information to improve the reconstruction of the image in DOT. The information regarding water, fat and blood vessels volume obtained by MRI can be used to enhance the quality and accuracy of the reconstruction of oxyhemoglobine, deoxy hemoglobin. Thus, improving the detection of cancerous activity related to the changes of arrangement and parameters of the vascular surrounding. MRI and DOT have the ability to increase our knowledge regarding the complicated biological behaviors associated with cancerous tumors. By combing the DOT and MRI, we can observe the changes among the tumor in response treatment. So, we can measure the effectiveness of the cancer therapy.

### **Summary:**

DOT and MRI are two of the most used imaging techniques. Both techniques don't put the patient at the risk of ionizing radiations. DOT uses near infrared light which enables the user to differentiate between oxy-hemoglobin, deoxy-hemoglobin concentration. Its relatively low cost and portability have increased the clinical use of DOT in the last decades. The exceptional resolution of MRI has made it favorable to image the very tiny details of soft tissues. Its ability to take images from any imaginable plane helped monitoring most activities of an organ or a tissue. Combining the two modalities enhances each system and reduces the limitations of each system and improves the quality of the reconstructed images.