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Diffuse Optical Imaging: Safe and Functional Medical Imaging Technique

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Abstract:

Optical imaging method provides safe and encouraging tool in many medical applications. In this editorial, principle operation, instrumentation, medical applications and advantages of diffuse optical imaging technique are presented and discussed.

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Introduction

Diffuse Optical Imaging technique or shortly "DOI" provides a spatial distribution of tissue optical properties and related physiological parameters, the tissue is probed with light and the transmitted light distribution on the tissue surface is measured. The measured data then become an input to a model-based iterative image reconstruction scheme [1].

It is called diffuse because the light propagates diffusely through any turbid medium such as biological tissues due to the effect of multiple and denes scattering property [2].The technique utilizes light in the red and near infrared spectral range to measure tissue physiology non-invasively due to its high penetration depth in biological tissues at that region [3].

To apply the diffusion model, light is detected at predetermined distances from the sources (source-detector pairs). Light can be detected in either reflection or transmission geometry through a section of thick tissue [4,5]. The measured tissue optical parameters which are absorption coefficient, scattering coefficient and anisotropy are highly related to important physiological changes in tissues like hemoglobin and melanin concentrations and tissue water content as well.

Instrumentations for DOI

According to the type of light source used in imaging, diffuse optical imaging device can be divided into three categories; steady state or continues wave (CW), time-domain, and frequency domain FD imaging. Frequency domain technique can be classified to frequency domain photon migration FDPM or spatial frequency domain imaging SFDI [6]. Each technique has its benefit, the CW technique is considered inexpensive, fast and commercially accessible, it can be useful for measuring relative changes in tissue chromophores, however, this method can't directly separate absorption from scattering measurements without utilizing a suitable mathematical model.

In time- domain (or time-resolved) techniques pulses of light are delivered to the sample and time gated and/or single photon counting detectors are used to measure the attenuation of the source pulse after propagation through the tissue, an analysis of the detected signal (temporal point spread function, t-PSF) can distinguish between tissue absorption and scattering [7]. In time domain imaging, the source is a sharp temporally focused beam and after penetrating the tissue it would broaden in time, this broadening is on the order of a few ns and depending on the source detector separation as well as tissue absorption and scattering properties.

The frequency domain is analogue to the time domain; it is the Fourier transform of the time domain. In the frequency domain method the source wave are described by three main parameters; the average intensity (DC- component), an amplitude (AC-component) and frequency [8]. The frequency domain method can also be used to predict tissue optical properties as the detected signals are related to the tissue absorption and scattering properties.

Frequency domain techniques are more complex but give more information about the medium; it has two types: frequency domain photon migration (FDPM) and spatial Frequency domain imaging (SFDI). In FDPM, the light source is intensity modulated at hundreds of MHz the intensity-modulated laser light creates photon density waves (PDWs) that propagate through the sample. A photo-detector samples the light some distance away from the source. Relative changes in amplitude and phase of the oscillating signal and the source light are measured which together provide an accurate estimation of the sample's optical properties [8].

In SFDI, patterns of light are projected onto the sample at different spatial frequencies and phases. The resulting reflectance is measured with extended, non-contact camera to measure the s-MTF. The detected signal is fit to a model of light propagation in turbid media such as Mont Carlo method [9]. SFDI technique provides non-contact wide-field imaging of tissue absorption and scattering properties. Figure 1. presents a simple single source-detector pair configuration of DOI.

Image Reconstruction for DOI

In DOI technique, to recover tissue optical parameters from the measurements of light propagation within tissue, model-based image reconstruction techniques are utilized including forward and inverse

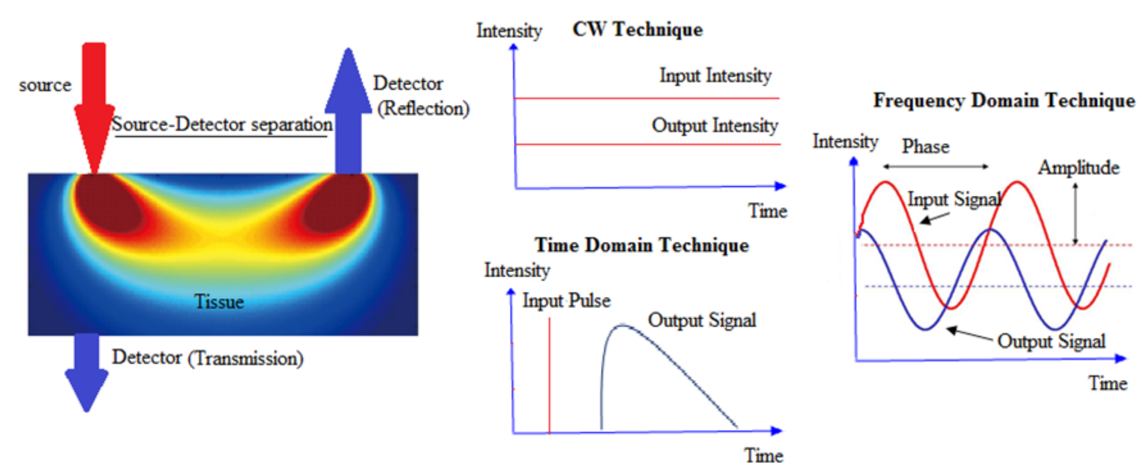

Figure 1. Single source-detector pair configuration of DOI in CW, TD, and FD methods.

models [6].The collected data from source-detector pairs are employed to reconstruct images that represent optical absorption and scattering of the examined tissue, one wavelength at a time [10]. This process is difficult and considered non-linear and ill-posed problem due to the diffuse and multiple scattering propagation of light in biological tissues.

Many alternative algorithms are employed to reconstruct images in DOI such as Newton-based, Broyden-based and adjoint Broyden-based iterative image reconstruction methods [11]. Beecause the inverse problem is ill-posed, the regularization method has a great importance to improve resolution of the reconstructed images. Linear regularization, sparse regularization, Levenberg–Marquardt regularization and Tikhonov regularization are commonly implemented in DOI image reconstruction [12,13].

Medical Applications of DOI

Diffuse optical imaging technique has been widely utilized in many medical researches and applications. It was employed to determine the light dose during photodynamic therapy treatment [14,15]. Moreover, DOI is used in breast cancer imaging and the technique is commonly called optical mammography, it is considered as a promising alternative for the existing imaging modalities for breast cancer screening including X-ray mammography and magnetic resonance imaging [16]. FDPM imaging has the ability to probe the entire tissue volume of the human breast and give precise information about tissue chromophores and metabolism [3].

In the medical applications related to skin imaging, SFDI can be effectively applicable due to its shallow penetration depth, high lateral resolution and wild field imaging characteristics [17]

SFDI technique is also applied in neurological imaging and brain function monitoring during brain injury, stroke [18], cortical spreading depression [9], and Alzheimer's disease [20]. In general, the various DOI techniques are most effective when dealing with heterogeneous tissues such as tumors, wounds and injuries in which the optical absorption and scattering properties differ from the healthy or normal tissue.

Conclusion

Diffuse optical imaging technique can be used to characterize biological tissues especially breast and brain tissues and predict some important information about tissue metabolism and many physiological changes in tissues, therefore, it can be employed in early detection of many abnormalities in tissue regarding blood contents or tissue oxygenation. It is a functional method that can significantly improve the medical diagnoses process of breast cancer and monitoring function activation of brain and muscles as well, it is also play and important role in wound healing and therapeutic drug monitoring.

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