Spatial Frequency Domain Imaging for Chromophore Measurement

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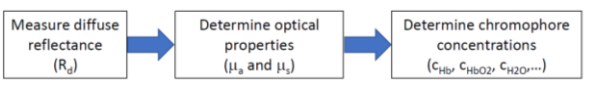
INTRODUCTION

Spatial Frequency Domain Imaging (SFDI) is a wide-field, non-invasive imaging technique for optical diagnostics. SFDI measures wavelength absorption and scattering using the projection of modulated spatial frequencies, or sinusoidally-striped illumination patterns. We can determine a sample's diffuse reflectance and optical properties at multiple wavelengths, using this data to solve a system of equations for the sample's chromophore concentrations. This is a method of determining the location and content of chromophores such as oxygenated and de-oxygenated blood, fat, and lipid within a living sample.

METHODS

When tissue is illuminated with light, the light that is reflected contains specular reflection, light that reflects off the top surface of the tissue, and diffuse reflection, light that enters the tissue before being re-emitted. Diffuse reflection (Rd) is made up of light that has interacted with the bulk tissue and may carry useful information about the different components present within the tissue. The intensity of diffusely reflected light depends on the absorption and scattering properties of the tissue (μ_a and μ_s), which vary by wavelength. If the tissue is strongly absorbing or weakly scattering, the diffuse reflectance intensity will be low (and vice versa).

Different tissue types (skin, liver, breast, brain, etc.) have different absorption and scattering spectra, depending on the concentrations of different chromophores (blood cHb, cHbO2, water cH20, fat cfat, etc.) present in the tissue. These chromophore concentrations can be determined following the flowchart below.



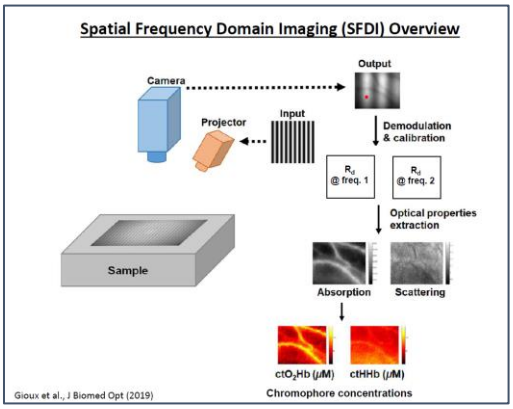


Figure 1 : SFDI Overview. Gioux et al JBO 2019.

Because we can't determine 2 unknowns, μ_a and μ_s , from one Rd measurement, we measure Rd at multiple spatial frequencies. "Spatial frequency" refers to the stripe pattern of projected light. We collect raw images of tissue at two spatial frequencies, DC (0 mm^{-1}) and AC (0.1 mm^{-1}). DC is constant illumination while AC is striped.

We then demodulate the raw images at each spatial frequency, combining multiple AC images of differing phases. Using Rd values and pixel illumination from a calibration object, the demodulated images are then converted to diffuse reflectance, Rd^{DC} and Rd^{AC} . We can then use these two values and a look up table to find μ_a and μ_s.

To determine cHb, cHbO2, cH2O, we assume that the measured absorption, $\mu_{a,tissue}$, is a combination of concentration-dependent contributions from the different tissue chromophores. Absorption is concentration times extinction coefficient.

$$\mu_{a,\,tissue} = \mu_{a,\,Hb} + \mu_{a,\,HbO2} + \mu_{a,\,water} + \mu_{a,\,fat} + \ldots$$
$$\mu_{a,\,tissue} = c_{Hb}\varepsilon_{Hb} + c_{HbO2}\varepsilon_{HbO2} + c_{water}\varepsilon_{water} + c_{fat}\varepsilon_{fat} + \ldots$$

If we measure $\mu_{a,\,tissue}$ at multiple wavelengths, we can generate and solve a system of linear equations for the unknown chromophore concentrations.