A hyperspectral method to analyze optical tissue characteristics *in vivo*

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Keywords
Image-guided surgery, Hyperspectral imaging, Multispectral image processing, Narrow-band imaging

Purpose
During surgery, a surgeon differentiates between healthy tissue areas, which have to be maintained and abnormal or damaged tissue, which has to be removed, replaced or reconnected. This continuous differentiation is based on his experience and knowledge only and entails great risk because injuring important structures, as nerves, can cause permanent damage to the patient's health.
In order to support the surgeon's decision by detecting optical tissue characteristics not visible for human eyes, we developed in this preliminary study a hyperspectral in vivo tissue setup and analyzed several human tissue types relating to its optical behaviors.

Methods
We built an imaging setup including a digital camera featuring a monochromatic sensor as recording device and an illumination unit. In front of the illumination unit, a filter wheel selects the specific wavelength band that arrives at the tissue. This allows a spectral scanning of the surgical area and therefore the investigated tissue. The filter wheel includes 16 filters with wavelengths starting at 400 nm up to 700 nm in steps of 20 nm. The bandwidth of every filter is about 20 nm.
Using the 16 wavelength measurements of every tissue type we are able to analyze the relating tissue properties in a 16 dimensional wavelength domain. To transform the measured data into the wavelength domain, we register corresponding tissue regions in all wavelength images to achieve a three-dimensional (two spatial and one spectral) hyperspectral cube.
The measured multispectral data is normalized to handle different illumination strength in the different spectral bands caused by the light source with the corresponding spectral filters or scattered light.
In this study, we analyze several different healthy tissue types of six patients in two different surgery types, parotidectomy and neck dissection.

Results
We investigated artery, vein, bone, muscle, fat, skin, connective tissue, parotid gland, and different nerves as nervus facialis, nervus vagus and nervus hypoglossus. To evaluate the accuracy of our hyperspectral analyzer we compared the spectral behavior of the detected artery and vein data with well-known published oxygenated and deoxygenated blood results. Equal spectral behavior is observed in the investigated visible spectrum.
For the other tissue types, we are able to provide specific spectral behaviors analog to the artery and vein data. As a result, for each tissue type, we can present a spectrum that could allow a characterization of the tissue in the wavelength domain. Figure 1 depicts the spectra of bone, muscle, fat, connective tissue, parotid gland and nerve. Each curve represents the average tissue response of the corresponding tissue, annotated by the surgeon. As it can be

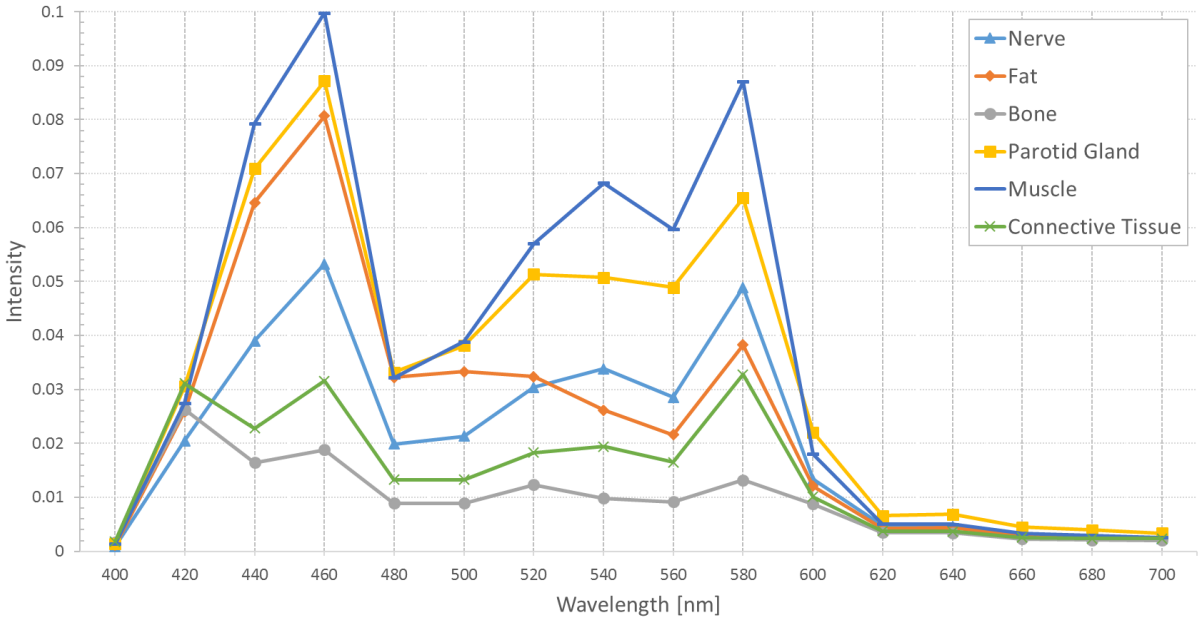

Figure 1: The measured averaged intensities of six annotated tissue types at the analyzed 16 wavelengths.

seen there, each curve has a different trend, which allows an explicit classification using interesting wavelength ranges, e.g. 420 nm to 460 nm and 530 nm to 590 nm as well as 640 nm to 680 nm.
Using this 16 dimensional spectral space allows a robust differentiation of the annotated tissue data because spectral tissue data can be separated better than in three-dimensional RGB color space. As example the RGB vectors of parotid gland and muscle

$$p_{RGB} = \begin{pmatrix} 0.0311 \\ 0.0492 \\ 0.0548 \end{pmatrix};\ m_{RGB} = \begin{pmatrix} 0.0353 \\ 0.0587 \\ 0.0599 \end{pmatrix}$$

are very similar and span a small angle of 2.29 deg. In the 16 dimensional hyperspectral case, both vectors are clearly different with crossovers and individual trends as shown in figure 1 as well as a larger angle is spanned. Therefore, a differentiation between parotid gland and muscle becomes possible using hyperspectral imaging, while both tissue types appear equal in RGB color space and a differentiation is difficult.

Conclusion
These fundamental investigations give very promising results to develop a real-time system that allows hyperspectral tissue analysis for surgery.
To do so, several questions have to be solved. The image acquisition technique has to balance between acceptable image resolution and acquisition time, because a filter-wheel setup, as used in this study, gives a high spatial resolution but the acquisition of the complete 3-dimensional spectral data set is with several seconds too time-consuming and therefore, not practical. Further, it has to be discussed how the hyperspectral data will be presented to the surgeon without concealing other important information in the surgical area but supporting treatment decisions.
In future, we will adapt the light source to extend the spectral range to near ultraviolet and near infrared. It is probable that in these regions further interesting tissue behaviors are detectable. This would make a tissue differentiation more robust.
Additionally we will investigate other interesting tissue structures.