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Wavelength selection using diffuse reflectance spectra and machine learning algorithms for tissue differentiation in orthopedic surgery

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Abstract: DRS-based measurements of tissue types encountered in orthopedic surgery are utilized to establish a wavelength selection methodology using machine learning techniques, which enables rapid development of clinically translatable optical systems.

1. Background

Orthopedic and neurological surgeries involving bone manipulations often pose risks to breaching and over-drilling of critical neurovascular and skeletal structures, leading to severe injuries or potentially death. Choices of image guidance modalities such as computed tomography (CT), magnetic resonance imaging (MRI) and endoscopy to be used during these types of surgeries are usually surgeon dependent; however, it is often cost-ineffective and thus navigation through the procedure is mostly relied on the surgeon's experience as well as the safety measures implemented in the orthopedic drill. Diffuse reflectance spectroscopy (DRS), which has been known to distinguish different biological tissues based on their wavelength dependent absorption and scattering properties, is a non-invasive monitoring technique that can be integrated within the orthopedic devices for real-time haptic feedbacks when approaching critical structures. To date, there are limited studies published on DRS wavelength selection algorithms for tissue differentiation in orthopedic surgeries [1-2]. The potential of optical spectroscopy and imaging have not been fully explored to complement and enhance the standard surgical procedures for adjunctive guidance, specifically to reduce surgery-associated complications, prevent damage of critical structures, and increase surgical accuracy and precision. The aim of this study is therefore to develop a methodology to effectively select DRS spectral bands to classify tissue types in surgical procedures including craniotomy, laminectomy, intramedullary (IM) nailing and total hip arthroplasty. The objectives are to 1) determine the optimal wavelengths that can differentiate tissue types with maximal contrast using machine learning algorithms such as support-vector machine and partial least squares, and 2) develop the most suitable selection algorithm for orthopaedic applications.

2. Methods

DRS measurements of *ex vivo* tissue samples including fat, muscle, marrow, cortical and trabecular bone were collected (n = 1000 for each tissue type) and analysed using machine learning algorithms to generate weighting score matrices for feature selection. Feature selection (FS) is the process of detecting the relevant and non-redundant features, and discarding irrelevant and redundant ones to confront the problem of high dimensionality. Some common methods include filter methods (e.g. ReliefF, mRMR), which assess the relevance based on the intrinsic properties of training data; wrapper methods (e.g. sequential feature selection, genetic algorithm), which consider feature subsets by the performance quality of a modelling algorithm to optimize the given classifier; and embedded methods (e.g. SVM-RFE, Decision trees). Feature ranking scores were calculated. Feature extraction methods such as principle component analysis (PCA) were also evaluated. All DRS measurements were calibrated against a standard reflectance phantom. Normalization techniques such as standard normal variate (SNV), area under curve (AUC) and first derivative were applied. Classifiers including discriminative analysis (DA), support vector machines (SVM), k-nearest neighbors (KNN) and decision trees were established to determine and compare classification accuracy. The key wavelengths should be theoretically located within 350-500 nm since several important biomarkers (e.g. collagen) exhibit absorption and emission within the wavelength range. All data analyses were performed in MATLAB (The MathWorks, Inc., MA, USA). Future studies include optical properties (absorption and reduced scattering coefficients) extraction from DRS measurements based on Monte Carlo inverse model, which will be compared with optical properties measured by a time-of-flight system. Auto-fluorescence and DRS of the aforementioned tissue types as

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well as bone cements would be simultaneously acquired for further differentiation analysis, which will demonstrate the major features between tissue and bone cements and provide insights for many orthopaedic revision procedures. Additional measurements include DRS measurements of bone cements and stepwise DRS measurements of drilling into sheep femur bones.

3. Results

Preliminary results of DRS spectral slope, which demonstrates a characteristic profile for determining subtle changes, showed the presence of the highest peak at 585 nm in cortical bone and bone marrow tissue types (Fig. 1a). Single FS ranker techniques created a binary feature ranking between cortical bone and bone marrow tissue type. In particular, ReliefF generated 434 nm as the first ranked feature while mRMR generated 970 nm as the first choice. However, by only applying single FS techniques, the linear correlation is very high at 0.9998 indicating significant data redundancy. Ensemble learning should therefore be used to further process the results. Moreover, PCA analysis was performed on fat, muscle and cortical bone tissue types, which demonstrated clear class separability. The first principal component showed the highest weighting score at 445 nm. Classifier using quadratic discriminant analysis resulted in a classification accuracy of 99%.

a) b)

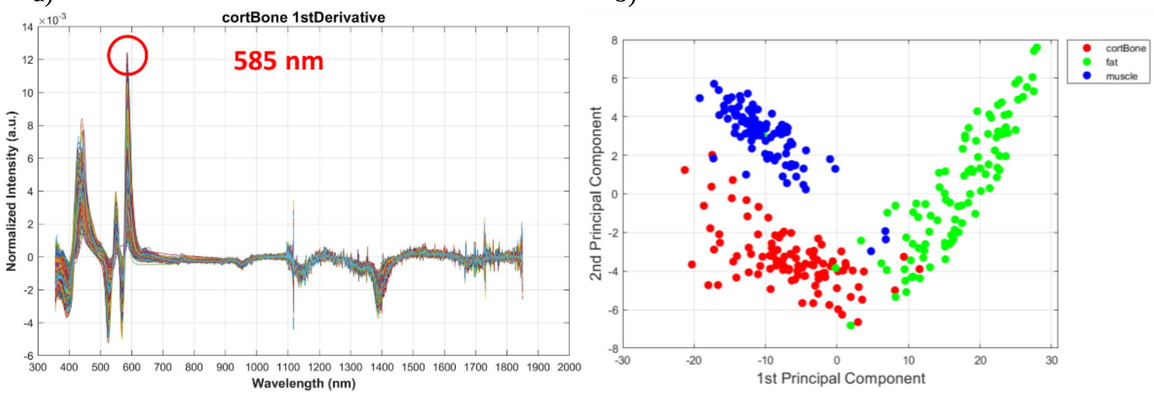

Fig. 1. a) DRS slope profile of cortical bone measurements showing the highest normalized intensity peak at 585 nm, which is comparable to the slope profile of bone marrow. b) PCA analysis between fat, muscle and cortical bone tissue types demonstrating class separability.

4. Significance

The impact of this study would be to confirm and consolidate wavelength selection for optical devices development as well as to provide an algorithm platform for rapid developments of future clinically translatable systems. Furthermore, optical methods of tissue determination could lead to lower exposures to radiation from current image guided system, protecting both operators and patients, and possibly leading to wider dissemination of the techniques.

5. References

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