Depth-Selective Fluorescence Spectroscopy

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Abstract—Variations in the origin of detected fluorescence signals due to illumination/collection parameters were studied through Monte Carlo modeling. In many cases, proper design of normal- or oblique-incidence geometries may enable depth-selective interrogation of turbid media.

I. INTRODUCTION

Fluorescence spectroscopy-based devices for medical diagnostics have the potential to improve public health through improved accuracy and reduced cost over current standards of care. While this technology is approaching clinical viability for applications such as neoplasia detection, it is likely that further developments may enhance diagnostic efficacy. Relatively little research has been published regarding how device-tissue interface parameters affect diagnostic efficacy. Furthermore, while a myriad of fiberoptic probe designs have been implemented in prior studies [1], the literature contains minimal data on differences in signal origin for these probes.

In this study, the effect of device-tissue interface geometry on fluorescence signal origin was investigated. A variety of parameters were studied including spot diameter, illumination-collection spot separation, and illumination and collection angles. The goal was to characterize depth-resolved distributions of sensitivity to tissue fluorophores due to the aforementioned independent variables. This data can be used to elucidate basic light-tissue interactions and identify trends useful for device optimization.

II. METHODS

Computational simulations of light propagation were performed using the unweighted-photon Monte Carlo modeling approach. Photons were launched in a spatially homogeneous manner across the circular illumination. For normal-incidence illumination photons were launched within an angular cone of ±9° from normal-incidence. Oblique-incidence cases had excitation/collection cones defined by angles relative to the normal to the tissue surface (as in Figure 1): 12.6°/31.6° and 35.6°/55.3° degrees and are referred to here by their average angles: 22° and 45°, respectively. A more detailed description of Monte Carlo modeling for light transport in tissue is available in Ref. [2].

III. RESULTS

One of the most common device-tissue interface geometries employed in biomedical fluorescence spectroscopy research involves overlapping illumination and collection spots. This is the geometry implemented by bifurcated single-fiber probes (Figure 1a). As indicated by simulation results in Figure 2, signal origin for these devices is highly dependent on spot diameter. While the smallest spot sizes produced a high degree of selectivity to tissue within 0.2 mm of the surface, increasing spot size caused the signal origin distribution to become more homogeneous.

Changes in illumination and/or collection angle for a 0.2 mm diameter overlapping spot geometry (Figure 3) produced a higher degree of selectivity to regions within 0.05 mm of the surface. By increasing either angle, similar effects were produced. High selectivity to the most superficial region was achieved using angled illumination and collection.
Device-tissue interface geometries involving non-overlapping spots provide unique characteristics that may prove useful for disease detection. The effect of illumination-collection spot (edge-to-edge) separation distance \( L \) for normal-incidence designs is shown in Figure 4. The basic trend seen in this graph is a shift from a relatively sharp subsurface peak in sensitivity for \( L = 0.025 \) mm to a more homogeneous distribution as separation distance increased. Greater variability in the \( L = 0.4 \) mm curve is due to low collection efficiency. Furthermore, as angle increases, the location of maximal sensitivity migrates towards the surface. These results are consistent with the diagrams in Figure 1, which indicate that the illumination-collection overlap region decreases in spatial extent and occurs closer to the surface as illumination and/or collection angle are increased.

The effect of changes in collection angle are presented in Figure 5 for a similar geometry as Figure 4, but with \( L = 0.1 \) mm. These data indicate increasing selectivity to subsurface regions as collection angle increases.

**REFERENCES**

