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Accuracy of Hyperspectral Near-Infrared Spectroscopy in Measuring Tissue Water Content

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Introduction: Edema, an abnormal increase in tissue water fraction (WF), affects over one million Canadians chronically. Cerebral edema (CE) is especially concerning, as it is a predictor of mortality in stroke and traumatic brain injury. While magnetic resonance imaging and computed tomography can assess WF, they are costly, not readily available, and inappropriate for continuous monitoring. Hyperspectral near-infrared spectroscopy (h-NIRS) offers a frugal alternative, using light attenuation across many wavelengths to quantify tissue components like water. This study evaluates the accuracy of h-NIRS for WF estimation using simulations and tissue-mimicking phantoms.
Methods: Simulations were run in NIRFAST v9.1 with source-detector separations of 10–40 mm. Two sets of simulation were conducted: one incorporating only tissue-like scattering and water, and another also included oxy- and deoxy-hemoglobin (tissue oxygen saturation of 65%). In both cases, WF ranged from 50% to 90%. Two corresponding sets of tissue-mimicking phantom experiments were conducted using gelatin, distilled water and a constant concentration of Intralipid-20% as the scattering agent. The first set included only scattering and water, with WF from 50–90% in 10% steps. The second added India Ink (1 mL of a solution diluted to 0.05–0.25% in 0.05% increments) to simulate absorption, testing WF at 50%, 70%, and 90%. A 20-W halogen lamp and QE-Pro spectrometer were used for measurements. Measurements were acquired using a 20-W halogen lamp and QE-Pro spectrometer. Light was delivered and collected via optical fiber bundles placed on the phantom surface at the same source-detector separations used in the simulations. WF was estimated using a spatially resolved approach. Accuracy was assessed via root-mean-square error (Arms) and variability via coefficients of variation (CoV).
Results: Simulations and phantoms experiments showed high accuracy, with Arms< 2.5%. Slight increases in error were observed with the inclusion of hemoglobin/India Ink. CoV remained below 6% across phantom tests, indicating strong reproducibility.
Discussion: The h-NIRS technique demonstrated excellent accuracy and repeatability under all tested conditions. Limitations include the use of homogeneous phantoms and India Ink rather than blood. Future work will incorporate whole animal blood to better simulate tissue absorption.

Keyword-1

Near-infrared spectroscopy

Keyword-2

Hyperspectral

Keyword-3

Tissue Water Content

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