Fluorescence lifetime measurements for kidney ischemia monitoring in minimally invasive surgery

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Abstract— The paper demonstrates the results of the application of fluorescent and diffuse reflectance measurements in laparoscopic renal surgeries during the warm ischemia. The experimental setup and results of the combined use of optical modalities for cellular metabolism and tissue saturation assessment are described.

Keywords - fluorescence lifetime, diffuse reflectance spectroscopy, tissue ischemia, minimally invasive surgery, urology.

I. Introduction

An important step in the surgical treatment of kidney cancer is the temporary setting of an ischemic condition to minimize blood loss. However, there is currently a need for new methods to obtain real-time feedback on cellular signs of ischemia in order to prevent irreversible damage to nephrons after a warm ischemia procedure [1]. Thus, the aim of this work was to perform an intraoperative assessment of renal tissue conditions during warm ischemia by monitoring the autofluorescence lifetime parameters on the parenchyma of the organ.

II. Materials & Methods

For this study, we have developed and used the multimodal setup based on time-correlated single photon counting (TCSPC) approach of fluorescence lifetime measurements [2] and diffuse reflectance spectroscopy (DRS) method. Fluorescence lifetime channel includes a 375-nm picosecond UV-laser BDS-SM-375-FBC-101 (Becker & Hickl, GmbH, Germany), a scanning monochromator MonoScan2000 (Ocean Optics, USA), two HPM-100-40-CMOUNT hybrid photodetectors (Becker & Hickl, GmbH, Germany), and fluorescence optical filter MF 445-45 (Thorlabs, Inc, USA) in front of the optical inputs of the detectors. DRS channel is based on HL-2000-FHSA broadband source and Flame spectrometer (Ocean Optics, USA) to record spectra in the range of 400-900 nm and use the data to calculate tissue saturation during the measurements. To deliver the light for the intraoperative monitoring of autofluorescence lifetime parameters we used the sterilisable fibre optical probe (17.5G, or 1 mm diameter). The measurements were performed during organ-preserving renal surgeries for kidney tumours. Patients signed an informed consent form confirming their voluntary participation in the research. The patients were divided into two groups: the control one and the patients who received intravenous infusion of 15% sodium fumarate known for its antihypoxic and antioxidant effects. Fluorescence lifetime signals and diffuse reflectance spectra were recorded on the surface of the renal parenchyma before and during the warm ischemia, as well as within 20 minutes after blood supply restoration.

III. Results

The measurements in the control group demonstrated statistically significant increase of long fluorescence lifetime component τ_2 during the ischemia stage itself. On the contrary, reperfusion stage led to the significant drop of this parameter in comparison with the values before the ischemia. At the same time, tissue saturation reached was the lowest during the ischemia and the highest after the procedure. The calculated values of τ_2 and short lifetime component fraction α_1, were used to evaluate the corresponding changes in the cellular NAD(P)H/NADH ratio. α_1 used to assess NAD(P)H not bound to protein demonstrated the same dynamics. There were no statistically significant changes in fluorescence lifetime parameters in case of 15% sodium fumarate administration. This result indicate the pronounced nephroprotective effect helping to sustain cellular energy production and antioxidant protection during the whole procedure.

IV. Conclusions

The results suggest that the implemented approach allows one to assess ischemic-reperfusion changes in renal tissues *in vivo*. The characteristic changes in the endogenous fluorescence parameters of the renal tissue cells before, during and after ischemia were observed. The measurement system has also demonstrated sensitivity to the effect of antihypoxic substances. Nevertheless, further studies are necessary to develop and enhance this technology for wider use in order to optimize organ-preserving surgical operations.

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References

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