

Basic Research on Real-time Evaluating of Thermal Damage of Tissues by Visible-Near Infrared Spectra

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Abstract. The feasibility of evaluation thermal damage in real time by Visible-Near Infrared (V-NIR) spectroscopy is investigated. Thermal damage are produced in fresh porcine livers *in vitro* by laser (808nm, 5W). The V-NIR spectra (330-1100 nm) at distances of 4, 8 and 12 mm from the center of the damage are acquired respectively, and diffused light intensities at 720 nm (Rd720) are chosen as the evaluation factors. The results show that Rd720 increases quickly with tissue's temperature going up at the beginning of heating. After an effective damage is attained, temperature continues going up while Rd720 reaches a stable state if keeping heating. After the laser is turned off, temperature gradually returns to room temperature, meanwhile, Rd720 decreases slightly and remains almost a constant which is far higher than its value at the beginning. In conclusion, the intensity of diffused V-NIR light intensity can be used as an important parameter to real-time assess the thermal damage of biological tissues.

Introduction

Thermal damage is a new technology of tumor treatment that can lead to thermal necrosis (also known as thermal coagulation) after tissue is heated. Heating the tissue can be achieved in three deferent ways: focused ultrasound (FUS), radiofrequency ablation (RFA) and laser interstitial thermotherapy (LITT). LITT induces heat by absorption of interspersed laser light energy, and thermal damage is obtained by cell coagulation and necrosis generated after tissue temperature rises above a certain value which can lead to enzymes deactivation and protein denaturation. Compared with traditional surgery, LITT is a minimally invasive procedure with fewer bleeding and higher safety. Compared with radiation and chemotherapy, LITT has no toxic effect on human body [1,2]. Thus, LITT has been established for therapy of primary and secondary liver tumors and for palliative therapy of localized tumor manifestations in the kidney, lymph nodes and head and neck region.

At present, the theoretical study of thermal damage is a fruitful domain of research. However, even if the intraoperative temperature of tissue during thermal damage can be monitored by the method of open MRI or ultrasound, to our knowledge, the problem of real-time, *in vivo* damage assessment still impedes the medical application of this technology because temperatures are usually incomplete expressions for thermal damage.

The aim of the present work was to investigate the possibility of using optical quantities obtained by the visible-near infrared spectrum system to estimate thermal damage by LITT [3]. Optical quantity of tissue, such as the absorption coefficient (μ_a),

scattering coefficient (μ_s), anisotropic factor (g), etc, has been proved to be related to tissue coagulation. For simplicity, in this paper we only consider the reduced scattering coefficient $\mu'_s = \mu_s (1 - g)$ because scattering is more sensitive than absorption.

Materials and Methods

Experimental Set-up

The diffuse reflection spectrum of *in vitro* porcine liver during heating by LITT was obtained from visible to near infrared wavelength the experimental system that can be seen in Figure 1. The whole system is consisted of the laser system (includes: 808nm Semiconductor laser, the radiator Laser driver, LIMO), needle probe for laser transmission (includes a single fiber with a diameter of 0.2 mm), probe for spectrum collection (Y-type, includes two fibers, one is for visible - near infrared light output, the other is for reflection light input), thermometer (WSY-4T, 300 microns in diameter), visible - near infrared spectrometer (USB2000, Ocean Optics), halogen light source (HL-2000, Ocean Optics) and a computer. To ensure the spectra and the temperature are sampled in the same point, the y-type microprobe and the temperature probe are tied together with front alignment. Through a software (written by LabWindows), spectrum acquisition can be done with a suitable sampling frequency, set as 1Hz in this paper.

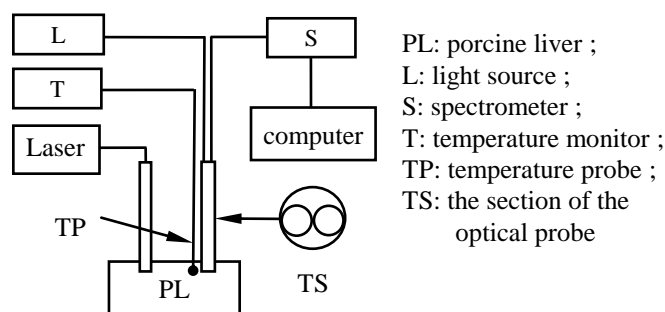


Fig. 1. System configuration

Experimental Methods

Fresh porcine liver was used *in vitro* as a sample for each experiment. After each sample was put horizontally on the experimental platform, the optical fiber was inserted vertically into the sample 15mm beneath the surface, then the spectrum probe and the temperature probe were inserted vertically the same distance beneath the surface at a distance r (mm) from the laser probe (the interoptode distance). After fixing these probes, turn on the laser switch, preheat for 15 minutes, then begin the experiment at a certain laser power. The optical parameter (the reduced scattering coefficient) were recorded in real time. The spectrum intensity at 720 nm (Rd720) was chosen as the evaluation factor. Each experiment was carried out on a new sample.

In the present work, we have chosen the set of configurations that laser power was 5W, the distance r (mm) was 4 mm, 8 mm and 12 mm respectively. Given the individual deference of the samples, experiment was reproduced 5 times for the same configuration. All the experiments were divided into three groups. Final data for each group were calculated by average algorithm.

Results

The curve of relative change for scattering light intensity, i.e. normalized Rd720, at distance (r) of 4 mm, 8mm and 12mm is shown in Fig. 2. Every data is the average value of the five experiments of the same group. The relative error of averaging for each data point is between 5% ~ 10% because of good repeatability. As one can see from the figure, the smaller the distance is, the faster the Rd720 rises. The time need for Rd720 to reach its maximum value was 500s, 700s and 1000s for the distance of 4mm, 8mm, and 12mm respectively.

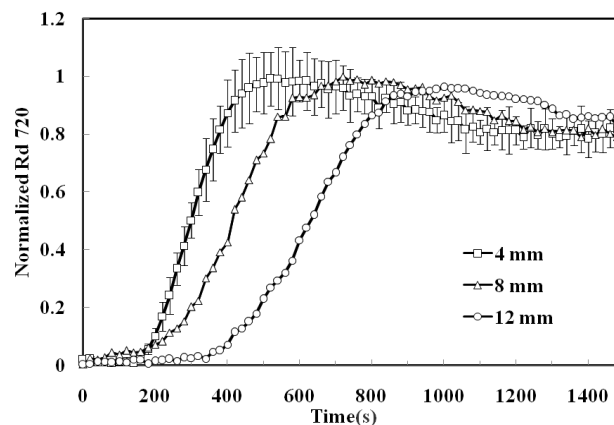


Fig. 2. Relative change of normalized Rd720 versus time at different distances

Fig. 3 depicts the trend of the normalized Rd720 and temperature changes over time at the distance of 4mm during LITT (550s for heating). The left ordinate axis of the figure represents the normalized Rd720. The right ordinate axis of the figure represents the temperature. The abscissa axis represents time. The trends of the two curves were similar during laser heating, however, the temperature gradually decreased while the normalized Rd720 slightly dropped to a stable stage after the heating was end.

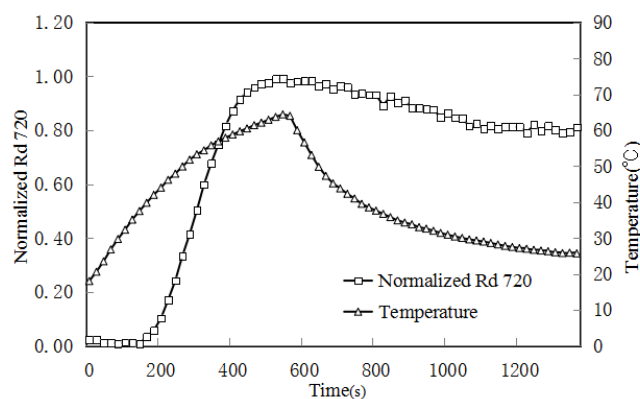


Fig. 3. Profile of normalized Rd720 and temperature versus time at distance of 4 mm

Discussion

The validity of the thermal damage for tumors has been proved in animal studies and clinical applications [4,5], however, the monitoring of thermal damage has not been effectively solved in real time. Light scattering of biological tissue has a certain relationship to the thermal damage degree. Based on the real-time monitoring on the scattering intensity of biological tissue during heating process, one can *in vivo* evaluate the effect of thermal damage in real-time [6-9].

The scattering light intensity (here is the normalized Rd720) changes versus time and the related influencing factors are mainly analyzed in this study from the real-time temperature and light intensity recording using spectrometer and other devices to perform LITT experiments on *in vitro* porcine liver. The results showed that, during the heating, the temperature kept rising while the scattered intensity of light reached a stable stage when it increased to a certain value. When the laser power is certain, the farther away from the heating center, the lower the damage rate. The damage degree of the biological tissue is negatively correlated with the distance to the damaged center. When effective damage of tissue was achieved, the heating was end by turning off the laser power switch, then the temperature was gradually return to the initial value, meanwhile, the intensity of the scattered light was not return to its initial value but remained stable after a weak drop, which showed that Rd720 was mainly decided by the damaged degree of tissue, and was much more sensitive than temperature for evaluation of thermal damage.

We conclude that, if one wants to make timely and effective assessment during thermal damage of tissue, it is probably necessary to monitor scattering intensity of the heated tissue in real-time.

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References

- [1] Dou JianPing ,Yu Jie, Cheng ZhiGang, et al. Ultrasound in Medicine & Biology. 42 (2016) 1825-1833.
- [2] Ioana Smith, Michel Kahaleh. Gastrointestinal Endoscopy Clinics of North America. 25(2015) 793-804.
- [3] Dai L J, Qian Z Y, Li K Z, et al. J.BioMed.Opt. 13 (2008) 044003.
- [4] Wang Qiang, Liu Ruibao, Zhang Licheng. Clinical Medicine of China(In Chinese) . 26 (2010) 439-441.
- [5] Li Xiaofeng, Qian Guojun. Contemporary Medicine (In Chinese). 17 (2011) 114-118.
- [6] Qian Zhiyu, Li Weitao. Life Science Instruments (In Chinese). 11 (2013) 45-52.
- [7] Tanis E, Spliethoff J W, Evers D J, et al. European Journal Of Surgical Oncology. 42 (2016) 251-259.
- [8] Wang Jinyang, Qian zhiyu, Qian Aiping, et al. Chinese journal of quantum electronics (In Chinese). 28 (2011) 91-95.
- [9] DAI Lijuan, HUA Guoran, QIAN Aiping, et al. Applied Mechanics and Materials. 121-126 (2012) 3998-4002.