Investigation on a new local control technology with near-infrared spectroscopy for laser induced interstitial thermotherapy

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Abstract. In order to control the treatment of laser-induced interstitial thermotherapy, a new local control technique is put forward, which use a functional near infrared spectroscopy (fNIRS) system. The temperature of biological tissue is regarded as the most important indicator for treatment of LITT. So, based on the experiments of LITT being performed on a liver cancer, the temperature and reducing scattering coefficient have been obtained in real time, respectively, with probe-type thermometer and fNIRS system. The results of the two factors have the same trend with different power of laser. It is confirmed that the fNIRS can be a useful local control technology for LITT.

Introduction

Laser-induced interstitial thermotherapy (LITT) has proved to be an effective and minimally invasive surgical technique for the treatment of numerous types of vascular malformations, hemangiomas and different kinds of soft tissue tumours and metastases [1-3]. LITT involves the percutaneous introduction of an optical fiber through a rigid steel cannula. The laser fiber is located interstitially and is not visible in contrast to open surgical procedures. Control of treatment is a key issue for LITT. Previous studies have developed some ways that using open magnetic resonance imaging (MRI) or ultrasound (US) systems which offer an accurate image-guided placement of the optical fiber [1,3]. However, open MRI techniques have often been limited due to slow image acquisition sequences and high additional time-consuming and cost-intensive expense. US systems provide a good visual control of both, trajectory and placement of the cannulation needle. However, ultrasound technology cannot be used in particular anatomic areas as for example the deep oropharyngeal region.

The objects of LITT all are biological tissues. Biological tissues are composed of cells and interstitial cells with different sizes or components. There is light absorption and scattering during light transmits in the tissues. The temperature range of tissue solidification is 55-95°C. Under the temperature conditions, the composition and structure of tissue would change, which lead to changes of the optical properties, especially the light scattering properties are more significant changed [4-9].

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Therefore, the scattering coefficient could be used as the important basis during the control of treatment for LITT.

Biological tissue is relative transparency for near infrared light at wavelength range 700-1200nm. According to the phenomena, functional near infrared spectroscopy (fNIRS) technology uses near-infrared light being propagated with biological tissue. After many elastic scattering and absorption, the reflect light and scattering light could carry a large number of information about the structure and composition of biological tissues. Therefore, the organization’s internal information can be obtained by analyzing the detection of infrared light. The reduced scattering coefficient ($\mu'_s$) is an important optical coefficient of biological tissue and closely related to the temperature of the tissue.

Based on the above analysis, a new local control technology with near-infrared spectroscopy for laser induced interstitial thermotherapy has been developed in this paper. The technology uses an fNIRS system, which has the function of the temperature measurement and the reduced scattering coefficient. By comparing the changed trend of the two testing parameters under different laser power, it is confirmed that the fNIRS technology is useful for the control treatment during LITT.

**Experimental procedures**

1. **Experimental system**

Fig. 1 shows the experimental system. It is consisted of LITT system and fNIRS monitoring system. LITT system includes: laser (808nm, NL-FC-2.0-763 LASER Light); optical fiber (built-in three 200µm fibers, one is for laser input, the others are for near infrared light input and output); thermoscope (WSY-4T, diameter 300µm). fNIRS monitoring system included: USB2000 spectrometer (Ocean Optics) and halogen light source (Mikropack, HL-2000) and monitoring software. fNIRS monitoring software was developed by department of biomedical engineering of Nanjing University of Aeronautics and Astronautics based on Labview 7.1 platform, which could real-time record tissue optical properties, blood oxygen parameters and flow parameters in front of the probe [10].

![Figure 1. Illustrative diagram of experimental system.](image)

1-CNC table 2-Tested tissue 3-Optical fiber and temperature probe 4-Laser 5-Thermoscope 6-Spectrometer 7-Input of NIR

1.2. **Materials and methods**
Fresh porcine liver tissue in vitro was used for this experiment. The liver tissue has been cut into five specimens (3×3×2.5cm) under room temperature (25°C). The experiment includes five steps:
(1) The specimen was fixed on the experimental CNC table.
(2) The optical fiber and the temperature probe were penetrated the specimen vertically. The insertion depth was about 1mm.
(3) The specimen was treated with LITT, and the temperature of central zone and reduced scattering coefficient were recorded in real-time.
(4) Based on the compilation of these experimental data, the trend of temperature and reduced scattering coefficient under different laser power were analyses.
(5) At last, using MRI and Histopathological examination to validate the treatment of LITT.

The experimental parameters of LITT are listed in Table 1. The experiment with the same parameters has been repeated five times. The final experimental data was taken from the average of five tested data. In order to ensure the accuracy of tested value, the positions of optical fiber and temperature probe should be changed for the next thermotherapy on one sample after one test was end.

Table 1. Experimental parameters of LITT.

| Laser Power(W) | Action time(s) |
|----------------|----------------|
| 0.95           |                |
| 1.23           | 600            |
| 1.42           |                |

Results and discussion

The initial temperature of tissue is 25°C at the beginning of LITT. The temperature of issue increases rapidly within 100s, and gradually reaches the stable state in the next 500s. The temperature rises faster when the laser is greater. The minimal final value of tissue temperature has been achieved 52°C with laser power 0.95W. The maximal final value is 73°C with laser power 1.42W. The initial value of µ’s is 6cm⁻¹. Then µ’s continuously rise with increasing coagulation temperatures. µ’s increases fast at the beginning and than rise slightly. The upward tendency of µ’s at different laser powers was similitude, but the rising velocities were different. µ’s rises fast when the laser power was greater. The minimal final value of µ’s is about 12.6cm⁻¹ with laser power 0.95W. The maximal final value is about 17.6cm⁻¹ with 1.42W. The relationships between these two parameters with time at 1.42W are shown in Fig.2. The left y-axis and the x-axis is µ’s versus time, the right y-axis and the x-axis is temperature versus time. As shown in Fig.2, it is obviously that the changes of µ’s and temperature with time have the same trend.

According to the above analysis, the fNIRS can be used to control the treatment of LITT in real time.
At last, the treatment of LITT is validated by MRI and Histopathological examination. Fig. 3 and Fig. 4, respectively, shows the result of MRI and Histopathological examination. As shown in Fig. 3 with white arrow, the destroyed region of tissue is obvious. As shown in Fig. 4 with black arrow, the edge between the damage area and normal tissue is very clear. MRI and Histopathological examination both proved the effectiveness of the above experiments of LITT.

**Conclusion**

This work has developed a new local control technology with near-infrared spectroscopy for laser induced interstitial thermotherapy and investigated the feasibility of the technology. The main conclusions can be summarized as follows:

1. The changes of $\mu$’s and temperature with time have the same trend under different laser power.
2. It is confirmed that the fNIRS can be a useful local control technology for LITT.

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