LASER ASSISTED CRYOSURGICAL RESECTION OF MALIGNANT TUMOR TISSUES

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ABSTRACT

A new method for resecting malignant tumors through combining laser cutting and partial freezing efficiently and safely was proposed for the first time. Conceptual experiments were performed to demonstrate the feasibility of the present tumor treatment strategy. Thermal infrared system as well as thermocouples were applied to investigate the temperature profiles of target tissues when subjected to a laser assisted cryoablation and thermotherapy. The results show that the laser assisted resection can effectively cut large frozen region tissue via a rather convenient and safe manner. This research is expected to be of significant reference for tumor treatment in future clinics.
Key words: tumor resection; laser assisted cryoablation; laser medicine; cryosurgery; bioheat transfer

1. INTRODUCTION

Resection remains a “golden standard” for some malignant tumor treatment and is recommended within patients with pretreatment midline shift whenever possible (Kreth *et al.*,1999). However, direct surgical resection is not suitable for tumors that are situated near large blood vessels, where blood loss serves as the major factor of death and morbidity (Huguet *et al.*,1992). In addition, some malignancies, such as pancreatic tumors, encasing the aorta and other major vessels, the presence of tumor involvement of vessels will, in most cases, make the patient ineligible for curative resection which may cause tumor diffusion due to blood pollution.

Cryosurgery is a clinical therapy aiming at the destruction of diseased target tissues through a controlled deep freezing and subsequent thawing (Rubinsky,1991). The cycling of thermal modalities results in cellular dehydration, protein denaturation and microcirculatory failure. Takahashi *et al.* (2006) adopted partial freezing to excise liver and homeostasis device to prevent hemorrhage. However, the excision force is significantly affected by tissue temperature and contacting resection will result in rather large mechanical stresses among surrounding normal tissue.

Owning high energy density, laser irradiation can raise local tissue temperature to gasify and resect tissue without hemorrhage. Katkhouda *et al.* (1993) discovered that the Nd-YAG laser delayed the recurrence of metastases as compared with the electrocautery resection and contributed to a longer survival, according to experiments in rats. In addition, a higher heating power used in laser applicator will not result in a higher surface temperature rise and larger temperature gradients inside the tissue than a lower heating power in the conventional constant-flux surface heating (Zhou *et al.*,2005). Therefore the surrounding healthy tissues can be effectively protected.

To enable the excision of tumor without hemorrhage and tumor diffusion, a combination of partial freezing and laser resection technique was proposed in this paper. The freezing probe developed in our lab was adopted for cooling the tissue as desired. Meanwhile, thermo-couples and infrared thermometer were applied to record and evaluate a specific cite and the whole field temperature. Then, tissue excision was conducted by laser. The experiment demonstrated the feasibility of the new method.

2. MATERIALS AND METHODS

2.1. Experimental Process

The pork tissue was used in the test, which was kept fresh at 20°C or less and cut into a block with width of 7.5cm and depth of 3.5cm (see Fig.1a), respectively. The aim of the present conceptual experiment is to resect the designated edge area through combining freezing and laser cutting.

To cool the meat, freezing probe developed with diameter of 5mm (Liu *et al.*,2004) was inserted into the tissue sample and positioned with a special shelf. Large amounts of cold were released to the target site due to evaporation of liquid nitrogen. The freezing process was kept for about 10 min. The temperature at the probe was found to decrease to -180°C and the surrounding temperature reached about -55°C.

Then, a continuous wave carbon dioxide laser (KD-III, Beijing Kedian Microwave Electronics Co.Ltd) with 10600 nm wavelength was adopted as the heating source. The power of the laser applicator was preset as 30W and then kept constant within the whole excision time. The laser applicator fixed on a plat of one dimension was moved back and forth slowly to resect the frozen pork.

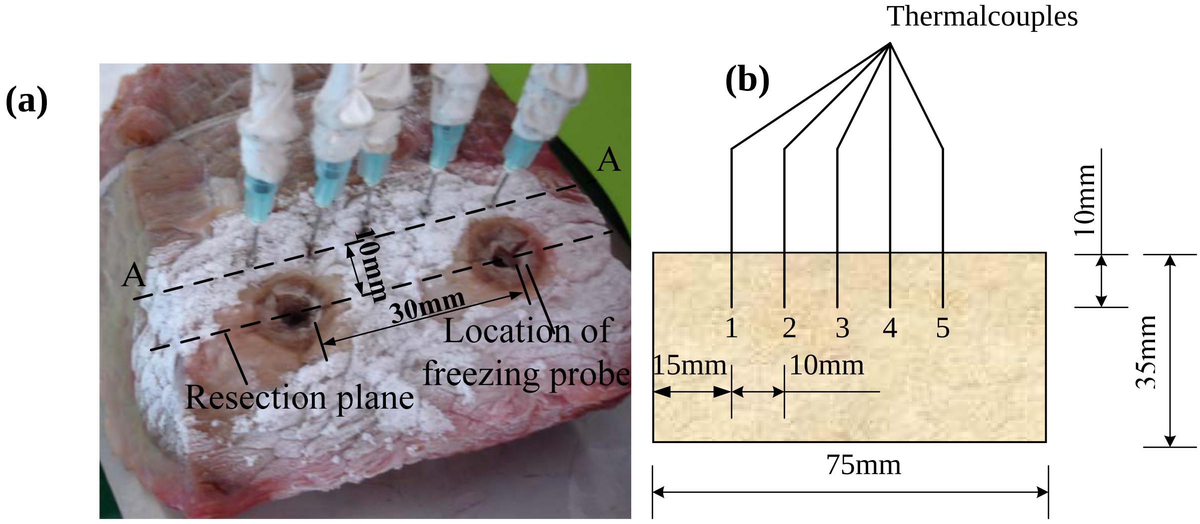

Figure 1: Schematic geometry of the experimental set up. (a) Illustration of the position of freezing probe, thermalcouples and the site to be resected by laser after experiment.
(b) Cross section plane along the black line A-A.

2.2. Temperature Measurement System

The temperature monitoring system included thermocouples and infrared imaging system. Five thermocouples (at points 1, 2, 3, 4 and 5) were inserted into the tissue and aligned in the same horizontal line as close as possible to the resection plane (see Fig.1b). Over the whole freezing and resection process, the infrared thermometer was adopted to capture the temperature images in every 5 seconds. The infrared pictures were quantitatively measured using digital image processing techniques. In addition, the thermocouples also recorded the temperature transients at different interior spots around the laser applicator.

In this way, both the interior temperature near the heat source and the whole temperature pattern of the surface can be obtained.

3. RESULTS

The experiments were conducted at the ambient temperature of 20 ºC. From the pictures taken from the infrared thermometer, one could observe the developing pattern of the temperature field and track the change of temperature due to the heat transfer effect of laser.

3.1. Thermal infrared temperature mapping

Depicted in the Fig.2 are temperature profiles for two typical states during the laser resection. In these pictures, the white color area represents those temperatures higher than the maximum displaying value of 32.3 ºC , while the black color area represents those temperatures lower than 0 ºC, in order to give out the best image contrast. It can be seen that, after frozen by the probe and before initiating laser excision, a non-pattern infrared picture for the pork surface is observed, which means a uniform icy area inside the tissue surrounding the two probes (see Fig. 2a). With the irradiation of the laser beam, the thermally affected area becomes a horizontal line along the track of laser (see Fig. 3b). However, the temperature of surrounding tissue is not elevated largely.

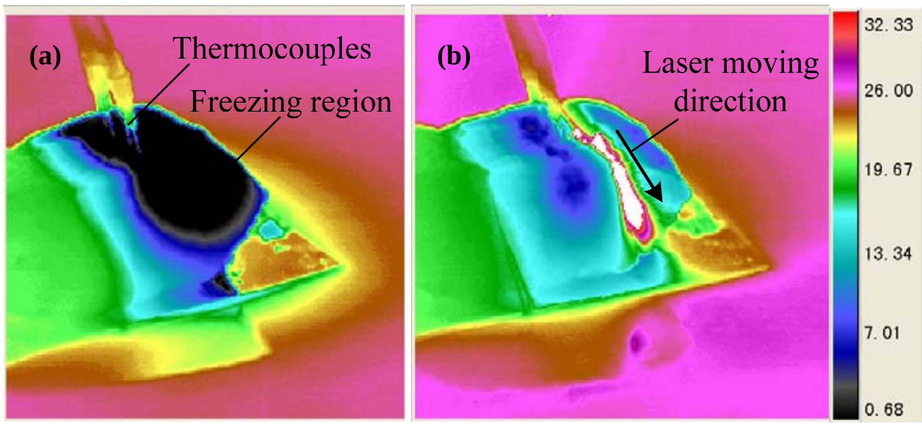

Figure 2. Thermal infrared images of the surface of pork: (a) After freezing, before starting laser (b) 10 minutes after laser heating.

3.2. Transient temperature measurement

Depicted in Fig.3 are the temperature transients measured at the five interior positions surrounding the laser irradiation spot versus time, spanning from initiating the cooling to finishing laser resection. The experimental data as given in Fig.3 indicates that once frozen by the probe, the temperature of the tissue could be quickly decreased. During the laser resection process, the temperature was slowly increased and stayed at 0 ºC nearby for 20 minutes. This also indicates that the surrounding tissue has not been affected much by laser application. It can also be observed that the data of five thermocouples is uniform, representing that there is not any partial cooling or heating.

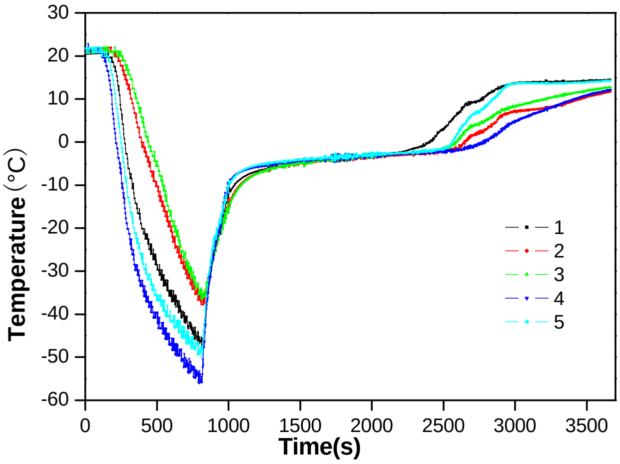

Figure 3. The temperature responses at five locations of in vitro pork tissue

3.3. Optical pictures on cutting area

Typical results for *in vitro* experiments are shown in Fig.4. It can be found that the resection plane is very neat. The area affected by laser irradiation is rather precise, i.e., the normal tissue is not destroyed as desired. However, if over heated by laser, there is carbonization in the resection plane. To prevent this to occur, a smaller output heating power of laser can be administrated or a cooling medium can be applied to cool the resection plane selectively.

Figure 4. Profile for resection plane at the end of experiment

4. DISCUSSION

It is important to minimize blood loss, improve precise killing and prevent diffusion of tumor cells during resection. A combination of cryosurgery and laser assisted resection could flexibly solve these problems. Cryosurgery can not only destroy tumor cells, but also make the tissue harden for excision. Due to its non-contact feature, the laser resection, which can be termed as “laser blade” will not bring out extrusion and twisting stress. This would make the physical damage highly focused. It is convenient to apply infrared thermometer and thermocouples to monitor the temperature field while reducing the cooling and heating damage to the healthy tissues around the tumor.

The surface temperature field taken from infrared pictures showes that the tissue has a uniform low temperature after cryosurgery (see Fig. 2a). During laser irradiation, the temperature field along the resection line increases quickly while the temperatures at the surrounding tissue increase rather slowly (see Figs. 2b). This is because water absorption coefficient of CO_2 laser is high and 70%~90% energy has been absorbed by targeted tissue within 10um. Depicted in Fig.4, the surface of transverse section appears very smooth and the remained tissue does not shrink. Clearly, for a strictly designed operation plan, the laser applicator is capable of a high quality resection under the aid of partial freezing.

5. CONCLUSIONS

The results demonstrated that laser assisted resection can effectively cut large frozen region tissue via a rather safe manner. However, the present study is still on its proof-of-concept stage. Many details such as quantitative analysis and *in vivo* experiments are seriously needed. Researches along this direction are expected to be of significant reference to initiate a highly efficient and safe tumor resection in future clinics.

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