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Feasibility assessment of magnetic resonance-thermometry on pancreas undergoing laser ablation: Sensitivity analysis of three sequences

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ABSTRACT

Laser ablation (LA) is a minimally invasive technique for the treatment of tumors as an alternative to surgical resection. The light absorbed by tissue is converted into heat, and causes irreversible cell damage when temperatures higher than 60 °C are reached. The knowledge in real time of temperature may be particularly beneficial for adjusting laser settings applied during treatment and to be notified in real time about its end-point. As a consequence, several techniques for temperature monitoring within the tissue have been investigated along the last decades. In the field of LA, particularly attractive are non-invasive methods. Among these techniques, thermometry based on the analysis of Magnetic Resonance Imaging (MR-thermometry) has gaining large acceptance in this field. MR-thermometry allows estimating the temperature variation thanks to the thermal dependence of several MRI parameters, among others the most promising are T_1 relaxation time, and proton resonance frequency shift.

The aim of this study is to assess the sensitivity of MRI thermometry using three T_1-weighted sequences (i.e., Inversion Recovery Turbo-FLASH, IRTF, Saturation Recovery Turbo-FLASH, SRTF, and FLASH) using an 1.5-T MR scanner on healthy swine pancreases undergoing LA. The reference temperature was measured by MRI-compatible fiber optic sensors (fiber Bragg grating sensors). The sensitivity of the proposed techniques was estimated and compared. The thermal sensitivity of the three sequences was $-1.47 \pm 0.08\ °C^{-1}$, $-0.95 \pm 0.05\ °C^{-1}$, and $-0.56 \pm 0.04\ °C^{-1}$ for IRTF, SRTF and FLASH, respectively. Results show that the proposed technique may be adequate for temperature monitoring during LA.

1. Introduction

Laser ablation (LA) is a minimally invasive technique for the treatment of tumors as an alternative to surgical resection. The light absorbed by tissue is converted into heat, and causes irreversible cell damage when temperatures higher than 60 °C are reached. The goal is to kill the cancer while sparing normal tissue, although a sufficient safety margin of necrosis of about 5 mm around the malignant mass is recommended [1]. The shape and size of damaged tissue depends on the distribution of temperature

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within the tissue, therefore the knowledge in real time of temperature may be particularly beneficial for adjusting laser settings applied during treatment and allows the operator to visualize the running procedure and to be notified in real time about its end-point [2].

As a consequence, several techniques for temperature monitoring within the tissue have been investigated along the last decades. These techniques are usually divided in non-invasive approaches and invasive ones [3]. In invasive method the transducer needs to be in contact with the tissue, and, at thermal equilibrium, the temperature measured by the sensor is assumed equal to the one of the tissue temperature. Among these techniques, thermocouples, thermistors and fiber optic-based sensors (e.g., fiber Bragg grating, FBG) are the most employed [4–6]. These techniques have several advantages, such as: quiet good accuracy, short response time and good spatial resolution; on the other hand they allow performing punctual measurements and need the contact with the tissue. The use of non-invasive techniques is motivated by the advantages related to the non-invasiveness and to the ability of these techniques to provide a three-dimensional distribution of tissue temperature. In non-invasive methods, measurements of temperature change are inferred from images of temperature dependent tissue properties. The three most promising methods are the following: Magnetic Resonance thermometry (MR-thermometry), which is based on the sensitivity of several MRI parameters on temperature [7,8]; Computed Tomography thermometry, which is based on the influence of temperature on images obtained by Computed Tomography scans [9,10]; and ultrasound thermometry, which is based on the dependence of several ultrasound parameters on temperature [11].

Among these three techniques MRI thermometry shows some advantages, such as high thermal sensitivity, low sensitivity to motion, good linearity and it does not employ ionizing radiations [7]; moreover, the feasibility assessment of CT thermometry and ultrasound thermometry on *in vivo* trials lacks [12].

The first investigation about the influence of temperature on MR parameters was conducted by Bloembergen et al. [13] in 1948, and only after four decades Jolesz and coauthors proposed to guide laser ablation by Magnetic Resonance Imaging [14]. Since the study of Jolesz, a big research effort has been dedicated to assess the feasibility of MR-thermometry for temperature monitoring during hyperthermal procedures, and several groups have focused their scientific activities on the improvement of MR-thermometry in terms of accuracy and of both spatial and temporal resolution and have used methods to combine two or more effects such as simultaneous measurement of the PRF shift and T_1 [15,16]. The use of MR-thermometry is particular attractive during LA, because the laser light can be transported within the Magnetic Resonance environment by a fiber optic, as a consequence specific MR-compatible devices are not required. The calibration of MRI-thermometry technique requires the use of MRI-compatible temperature sensors; the most prominent are FBG and fluoroptic sensors. As shown by many authors [17,18], fluoroptic sensors are suitable for temperature monitoring within tissues undergoing LA, although the phenomenon of self-heating due to black-pigmented encapsulation can cause measurement errors, if the sensor is placed close (4 mm) to the laser applicator. On the other hand, FBGs are not affected by measurement artifact, and are recommended for temperature measurement during *ex vivo* experiments.

The aim of this work is threefold: to assess the feasibility of three sequences (IRTF, SRTF, and FLASH) during LA of pancreas; to calculate the thermal sensitivity of MR-thermometry using the three abovementioned sequences on freshly excited pancreatic tissues undergoing LA; the comparison between the characteristics of MR-thermometry using the three sequences.

In order to perform the calibration of the MR-thermometry using these three sequences, the reference temperature has been measured by MR-compatible temperature sensors based on fiber optic technology (i.e., fiber Bragg grating, FBG, sensors). To the best of our knowledge, this study represents the first investigation of MR-thermometry on pancreatic tissue, and this is important because of the influence of the tissue histological characteristics on T_1 thermal sensitivity [7]. A further novelty of this work is related to the use of new settings for the two employed T_1-based sequences.

2. Theoretical background

Some MR parameters accessible to MR scans are sensitive to temperature [7] such as proton density, the longitudinal and transverse relaxation times (i.e., T_1 and T_2, respectively), magnetization transfer, and proton resonance frequency (PRF). As a consequence, MRI has the potential to map out temperature-dependent phenomena in three dimensions.

Proton density represents the protons concentration into the tissue in the form of water and other macromolecules (e.g., proteins and fat). For application in temperature mapping, variations in the proton density can be influenced not only by the tissue temperature but also by other parameters, as T_1. Relaxation times T_1 and T_2 are temporal parameters defining the way that the protons return back to their resting states (position and direction) after the initial radio frequency pulse signal; both these time provide information about the structure of the tissue. As is well known, T_2 is not very attractive to map tissue temperature due to several concerns, such as: low thermal sensitivity [19], the influence of motion and local magnetic field fluctuations on T_2, and because it can be masked by other factors widely reported in literature [20]. For their good sensitivity to temperature variation, T_1 and PRF are the MR parameters mostly used for thermometry; they show complementary advantages and disadvantages in terms of sensitivity to movement and sensitivity dependence on tissue. T_1 shows the main advantage of negligible sensitivity to movement, on the other hand this sensitivity experienced by PRF to movement is its main concern on *in vivo* applications [7]. This limitation is compensated by the fact that the PRF shift is not tissue-dependent and it is linearly related to temperature in ranges wider than those of T_1.