Photoacoustic assisted device guidance and thermal lesion imaging for radiofrequency ablation

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ABSTRACT

Radiofrequency ablation (RFA) is a widely used treatment method for unresectable malignant tumors. In percutaneous RFA, the tumor recurrence rate is high due to incomplete ablation. Feedback from the imaging system during the RFA procedure is vital in reducing the tumor recurrence. We propose the use of photoacoustic (PA) imaging, integrated with an ultrasound (US) system to monitor the RFA procedure. The imaging system consists of a US system with a linear array and a pulsed laser illumination. We study the PA assisted RFA device guidance to an anomalous target embedded inside a chicken breast tissue. We compare both US and PA images to highlight the advantage of using the proposed method. Further, we image an ablated *ex vivo* bovine liver sample using the system. The result shows a drop in PA intensity from the ablated region compared to normal tissue. Our preliminary study shows that PA imaging is a potential modality for RFA procedures.

Keywords: Photoacoustic Imaging, Radiofrequency ablation, Ultrasound, Bovine liver, *ex vivo*, Real-time guidance

1. INTRODUCTION

In Radiofrequency ablation (RFA), an alternating current is applied through needle electrodes causing heat-induced coagulative necrosis of the malignant tissue.[1] RFA is used for the treatment of unresectable tumors in liver, lung, kidney, soft tissue and bone.[1] For deep tissue RFA procedures, imaging techniques like Magnetic Resonance Imaging (MRI), Computed Tomography (CT) and Ultrasound (US) are used for device guidance and thermal lesion monitoring.[2] However, the use of contrast agents, non-realtime imaging, large size of the instrument and high imaging cost limit the use of MRI and CT during the RFA procedure.[2,3] Widely accepted clinical practice is to use MRI or CT for treatment planning and post-ablation imaging and the US to assist the surgeon during the procedure.[3] The main issue with RFA is local recurrence due to insufficient feedback from the imaging system in device guidance and estimating ablated tissue boundary.[2,4] Hence there is a need to advance imaging technology for percutaneous RFA procedure.

In PA imaging, pulsed light generates acoustic waves from absorbers due to thermoelastic expansion. The combination of light and less scattered acoustic waves provide high optical contrast and resolution in PA imaging.[5] Metals used for clinical applications has high optical absorption compared to molecules of tissue and hence PA can be used to image surgical tools and implants.[6] Additionally, optical properties of the normal tissue differ from malignant and coagulated tissue.[7,8] These factors make PA a potential modality for both surgical tool tracking[6] and imaging thermal lesion.[8] In this work, we study percutaneous RFA device guidance through an *ex vivo* chicken breast tissue to an absorbing anomalous target under PA image assistance. We compare PA and US images of the RFA device deployed in the target tissue. Further, we study the feasibility of PA imaging in differentiating ablated and normal *ex vivo* bovine tissue.

2. METHODS

For imaging, we used an Alpinion Ecube 12R US system with a 128 element linear transducer (8.5 MHz) array. We used an Nd: YAG laser pumping an OPO as the pulsed source for PA imaging. The laser beam was then coupled to a fiber bundle with one input and seven outputs of 4 mm diameter. Six out of the seven fiber bundles

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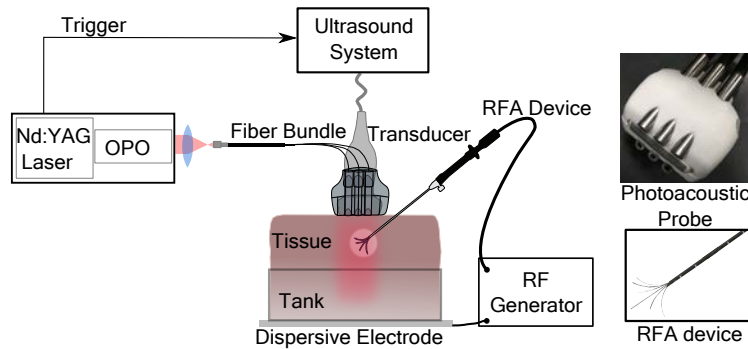
Figure 1. Illustration of the experimental setup (Left). Photographs of the PA probe and the RFA device (Right)

were attached to either sides of the US transducer along the long axis with a 3D printed housing (Fig. 1). Fibers were arranged such that beam from both sides intersect at the focus of the transducer (20 mm) and has a minimum deviation from the imaging plane. One of the output fiber bundle was used to measure the laser pulse energy. The pulse energy was kept below the maximum permissible exposure for all the experiments. Trigger output of the laser was used to synchronize the data acquisition of the US system. Once triggered, the imaging system first detects the PA signal in the receive mode and then perform a US imaging in the transmit and receive mode. Both PA and US signals were beamformed to form the images. A clinical RFA system from Angiodynamics (1500X) with an adjustable multiple electrode (9 tines) device (StarBurst XL) was used in this study. An in-house developed water tank with steel base was used to hold the tissue and the dispersive electrode from the RF generator was attached to the metal base as shown in Fig. 1.

In the first experiment, RFA needle guidance was performed on an *ex vivo* chicken breast tissue. We used three layers of chicken breast tissue with an absorbing target placed around the focus of the transducer as the sample. The target was prepared by immersing a portion of the chicken tissue in India ink and dried in air for 30 mins. To enhance the PA signal from tine electrodes, a black marker ink was used to coat its surface. RFA device was then inserted to the target under PA image assistance and tines were deployed. PA and US images were acquired and saved during the procedure. In the second experiment, an *ex vivo* bovine tissue was ablated at a temperature of 105^0 C for 5 mins. The sample was placed at the focus of the transducer using a transparent polyethylene film and a solution of Phosphate-buffered saline ($1\times$) and Intralipid was used between the transducer and the sample. The solution was used for acoustic coupling and to diffuse the light for uniform illumination. PA and US B-scan images were acquired at steps of 1 mm and scanned over a length of 25 mm to image the ablated region. Reconstructed 2D US and PA images were stacked to form a volumetric image of the tissue.

3. RESULTS AND DISCUSSION

Figure. 2 shows the RFA device tracking under PA and US imaging. The *ex vivo* tissue with the target anomaly is shown in Fig. 2 (a). A hypoechoic region corresponding to the anomalous target tissue as well as the different layers of the chicken breast tissue is visible in Fig. 2 (b). In Fig. 2 (c) high PA signal can be observed from the absorbing target tissue. US and PA images captured after RFA device placement is presented in Fig. 2 (d) and (e) respectively. PA image in Fig. 2 (e) offers a better visibility of RFA trocar, tines, and the absorbing target compared to the US image in Fig. 2 (d).

The *ex vivo* bovine tissue used for ablated tissue imaging is shown in Fig. 3 (a). The ablated region is visible in whitish color at the center of the sample. The green rectangle marks the imaged region. The Maximum Intensity Projection (MIP) of 3D US image in Fig. 3 (b) shows the tissue boundary and the hole made by the trocar at the center. The MIP PA image in Fig. 3 (c) shows a low intensity compared to native tissue. This is due to the increased scattering and reduced absorption of the tissue with heating. The charring occurred around the trocar can also be observed as a high PA signal at the center in Fig. 3 (c).
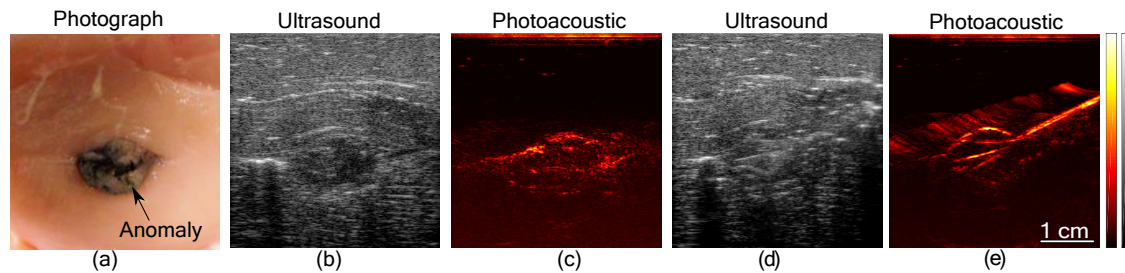
Figure 2. RFA device guidance: (a) *Ex vivo* chicken breast with anomalous absorbing target. (b) US and (c) PA image of the tissue. (d) US and (e) PA image after device placement.
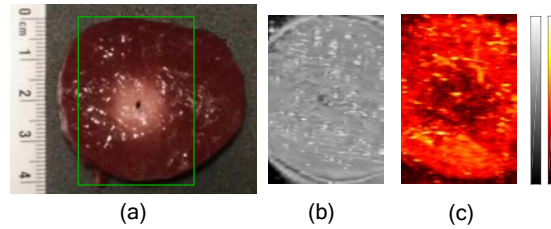

Figure 3. Ablation imaging: (a) *Ex vivo* bovine tissue with ablated center. The imaged region is marked in green. Maximum Intensity Projection (MIP) of 3D (b) US and (c) PA image of the ablated tissue.

4. CONCLUSION

Through our results, we have shown that: (i) PA imaging can be a potential modality for percutaneous device guidance and (ii) the change in optical properties with heating can be utilized in PA imaging to visualize ablated tissue boundary. Further works can be directed towards deep tissue ablation imaging using interstitial illumination and other aspects of RFA procedure such as blood vessel mapping.

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