Carbon fiber needle for MRI-guided radiofrequency ablation

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Introduction: Radiofrequency (RF) ablation is one of the thermal ablation methods which widely accepted in clinical therapies for tumors, due to its advantages of minimal invasiveness and low complication rate [1]. During the RF ablation, the current is directly delivered to tumor through an electrode (also known as ablation needle) for tissue heating. To ensure the efficacy of treatment and for clinical safety concern, it is crucial to take real-time control of the tissue temperature. Nowadays, magnetic resonance imaging (MRI) is the most promising imaging modality that can noninvasively offer both target localization and temperature monitoring information. Therefore, MRI-guided radiofrequency ablation is a strong candidate for cancer treatment. At present, the commercialized ablation needles are mainly made of metallic material such as titanium alloys that obviously leads to substantial susceptibility artifacts during MR scanning [2]. In this study, we present a promising ablation needle made of carbon fiber composites, compared with the conventional metal electrodes, they avoid the artifacts issue from basics. Meanwhile, it also performed quite well in heat generating. The results showed its potential in further clinical application.

Materials and Methods: A carbon fiber needle and a titanium alloy needle with the same identical dimension (diameter of 2mm and length of 200mm) were used in our study. In order to evaluate the image artifacts of carbon fiber/titanium alloy needle, the two needles were inserted into the cylindrical gel phantom 30mm depth from the surface. T1-weighted image was acquired by a 1.5T MR scanner (SIEMENS 1.5T Symphony). The interventional SE pulse sequences (TR/TE=500ms, slice thickness=2mm) was employed. As the carbon fiber needle was used as an RF ablation electrode, the numerical analysis was accomplished with finite element method (FEM) to illustrate the performance. During the ablation, the electric field in tissue was determined by the given voltage applied to the electrode. Then the temperature of the tissue caused by local power density can be calculated via Pennes' Bioheat equation [3]. In simulation, the cylindrical simplified model of 50mm diameter and 120mm height was built to imitate the liver tissue. The tip of carbon fiber needle was placed to the center of liver model. There only 10mm of the needle tip contact with tissue, the rest of the needle was coated with Teflon mimicking the commercial ablation needles. Respectively, the source (22V electric potential) and ground (0V electric potential) voltage was applied to the electrode and the outer model layer. Initial tissue temperature was set as 37°C, which was also applied to the model boundary. We also calculated the temperate of titanium alloys needle with the same environment parameters for comparison. All simulations were based on COMSOL Metltiphysics solver. Besides, for determining the heating efficacy of carbon needle, we did *ex vivo* ablation experiment on pork. The frequency of current ablation was 400kHz, output power was 20W produced by RF power amplifier, 300s of duration time.

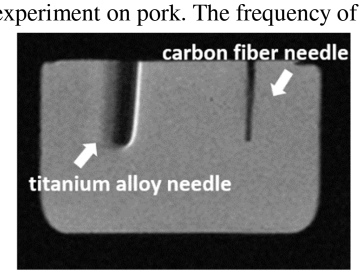

Figure 1. artifacts under MRI between carbon fiber and titanium alloy needle. Carbon fiber is on the right and titanium alloy is on the left.

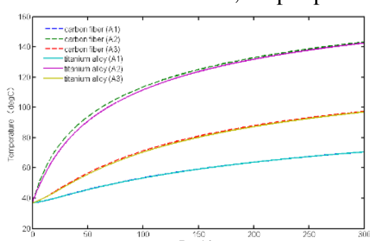

Figure 2. Curves of temperature and time of the carbon fiber and titanium alloy needle at site A1, A2 and A3.

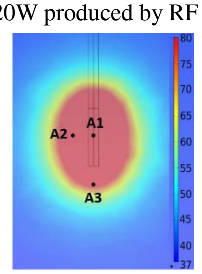

Figure 3. Simulation of heat distribution in tissue by carbon fiber needle.

Figure 4. Longitudinal section of the swine tissue after heating

Results and Discussion: Figure1 shows the artifacts in T1-weighted image. There is no significant diameter increasing of carbon fiber needle, but the diameter of the titanium alloys needle was increased to approximately 8mm. The artifact also causes the magnetic signal inhomogeneity around the titanium alloys needle, while the carbon fiber needle shows well signal homogeneity. The comparison indicates, considering the artifacts under MRI, carbon fiber needle is a better choice than titanium alloys needle. Figure 2 shows the numerical result of thermal ablation to carbon and titanium needles. Curves were temperature read at site A1, A2 and A3 changing with time. A1 was the middle of the needles, A2 was 5mm apart by side from the middle point and A3 was 5mm far from the tip along the axis. From the curves, we can find the two needles share the similar heat characteristics. Figure 3 shows the simulation of temperature spatial distribution when tissue heating by carbon fiber needle. It illustrated the high-temperature region was concentrate around the electrode. Figure 4 is the result of heating pork with carbon fiber needle. The coagulation necrosis region was consistent with the simulation result. Above all, the carbon fiber needle shows no disadvantage comparing to the commercial titanium alloys needle in heating capability with minor artifact.

Conclusion: In conclusion, compared with the titanium alloy needle, the carbon fiber needle has barely artifacts under MR monitoring, and capable of generating enough heat to complete an ablation application. So it is a promising instrument to perform MRI-guided radiofrequency ablation.

References: [1] V. Albino *EUR J SURG ONCOL.* 2013;39; [2] HY. Liu *J APPL PHYS.* 2008;83(11). [3] Pennes HH. *J APPL PHYSIOL.* 1948;1(2):93–122.