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RF Ablation at Audio Frequencies Preferentially Targets Tumor – A Finite Element Study

D. Haemmerich[1,3], D.M. Mahvi[1], F.T. Lee Jr.[2], J.G. Webster[3]
[1]Dep. of Surgery, [2]Dept. of Radiology, [3]Dept. of Biomedical Engineering,
University of Wisconsin-Madison, WI, USA

Abstract-**Radio Frequency (RF) ablation has become of considerable interest as a minimally invasive treatment for primary and metastatic liver tumors. Major limitations are small lesion size, which make multiple applications necessary and incomplete killing of tumor cells, resulting in high recurrence rates. RF ablation is typically carried out in the frequency range of around 500 kHz. Measurements have shown a marked difference in electrical conductivity between normal liver tissue and tumor tissue. The difference is most pronounced at frequencies below 100 kHz, where tumors exhibit around two times higher conductivity compared to normal tissue. Conductivity is similar for tumor and normal liver at 500 kHz. We created Finite Element Method (FEM) models of the RITA model-30 multi-prong probe. The probe was placed in a tumor of 20 mm diameter. We simulated 12 minute, temperature-controlled RF ablation at 95 °C at frequencies of 20 kHz and 500 kHz. At 20 kHz we observed increased current density within the tumor boundaries. This resulted in an increase in lesion size by 29% at a frequency of 20 kHz compared to 500 kHz.**

Keywords - **RFA; radiofrequency ablation; RF ablation; liver ablation; liver cancer; liver tumor**

I. INTRODUCTION

Radiofrequency (RF) ablation has become of considerable interest as a minimally invasive treatment for primary and metastatic liver tumors. Surgical resection offers the best chance of long-term survival, but is rarely possible. In many patients with cirrhosis or with multiple tumors hepatic reserve is inadequate to tolerate resection and alternative means of treatment are necessary [1]. In RF ablation, RF current of 500 kHz is delivered to the tissue via electrodes inserted percutaneously or during surgery. The electromagnetic energy is converted to heat, eventually resulting in cell *necrosis*. One of the major limitations of this technique is the extent of induced *necrosis*. When tumors greater than 2 cm are treated, multiple applications are necessary to obtain complete tumor *necrosis*. Often tumor cells survive, which leads to high recurrence rates [2]. Several methods have been investigated for increasing lesion size and improving efficacy. Internally cooled probes have been used. *Interstitial* saline infusion creates larger lesions by cooling and increasing effective electrode area.

Hepatic tumors exhibit significantly different conductivity characteristics compared to normal liver tissue. Especially at low frequencies, there is a marked difference between electrical conductivity of normal and tumor tissue. Tumors exhibit around two times higher conductivity at frequencies below around 20 kHz compared to normal tissue, whereas conductivity is similar at 500 kHz [3]. We evaluated if ablation carried out at lower frequencies increases efficacy. We created FEM models of geometric configurations, where a RITA model-30 probe (RITA Medical, Irvine, CA) is surrounded by tumors of 20 mm diameter and 40 mm diameter. We used the models to compare lesions created at frequencies of 500 kHz and 20 kHz.

II. METHODOLOGY

We created FEM models of the RITA model-30, 15-gauge probe (RITA Medical Systems, Mountainview, CA; see Fig. 1). We placed the probe in a spherical tumor, surrounded by normal liver tissue. We created models with two different tumor sizes. In the first case, we created a tumor with 40 mm diameter, where the probe is completely submerged in the tumor. In the second case, the tumor was 20 mm in diameter; parts of the probe tines were extending beyond the tumor into normal liver tissue.

We used the same material properties as in [4], except for electrical conductivity of tissues where we used results from a rat tumor model [3]. Tumor had a conductivity of 0.4 S/m both at 20 kHz and at 500 kHz, normal liver tissue had a conductivity of 0.2 S/m at 20 kHz, and 0.4 S/m at 500 kHz. For each case we created two models, where we simulated RF ablation at 500 kHz and at 20 kHz; the only difference between these two models was the electrical conductivity of tumor, and normal liver tissue.

We set the initial temperature of the model and temperature at the boundary of the model to 37 ºC. Blood perfusion was modeled according to the Pennes model. The blood perfusion w_{bl} used in this model is $6.4 \cdot 10^{-3}$ 1/s. We assumed the same perfusion both in tumor and liver tissue. We simulated ablation for 12 min. The maximum temperature of hepatic tissue was kept at 95 ºC by varying the voltage applied to the electrodes. The lesion size was determined using the 50 ºC margin. We generated profiles of temperature and current intensity in a plane intersecting the center of the probe and tines.

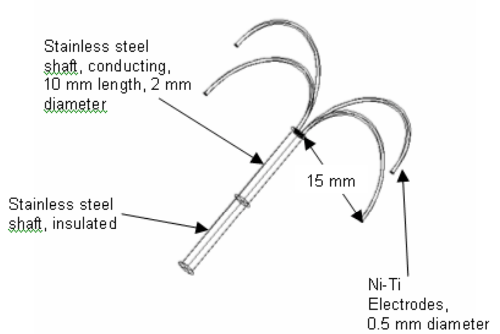

Fig. 1. RITA Model-30 4-prong ablation catheter.

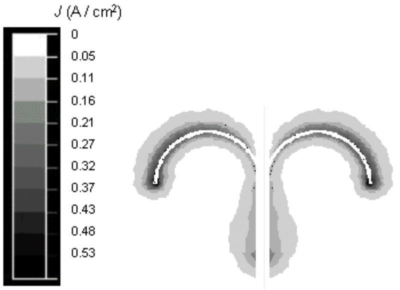

Fig. 2. Current density for 20 mm diameter tumor, 500 kHz ablation.

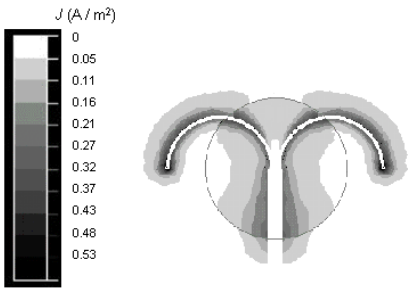

Fig. 3. Current density for 20 mm diameter tumor, 500 kHz ablation.

III. RESULTS

We did not observe any differences in lesion for a 40 mm diameter tumor. Following we present results for a 20 mm diameter tumor. Figures 2 and 3 show current density for 500 kHz and 20 kHz ablation, respectively. Figures 4 and 5 show temperature distribution at the end of th ablation for 500 kHz and 20 kHz, respectively. Figure 6 shows the additional lesion created at 20 kHz (black area).

IV. DISCUSSION

The energy deposition during RF ablation is mainly determined by the electrical conductivity of tissue close to the probe. Since tumor has similar conductivity at 20 kHz and 500 kHz, we did not observe any difference in lesion shape between 20 kHz and 600 kHz when the tumor had 40 mm diameter and was completely encompassing the probe. We did observe a significant difference for a tumor of 20 mm diameter, where part of the probe tines are protruding into normal liver. As Figure 3 shows, current density is highly increased within the tumor due to the higher conductivity of tumor compared to normal liver tissue at 20 kHz. This increase resulted in increased lesion size at a frequency of 20 kHz (Figure 5) compared to 500 kHz (Figure 4). The additional lesion is mainly located within the tumor boundaries, since that is where the current density is increased (see Figure 6). The lesion volume was 29% larger at 20 kHz compared to 500 kHz.

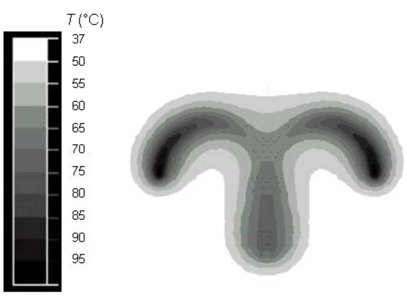

Fig. 4. Temperature distribution for 20 mm diameter tumor, 500 kHz ablation.

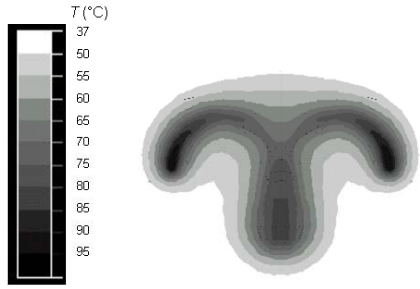

Fig. 5. Temperature distribution for 20 mm diameter tumor, 20 kHz

Fig. 6. Additional lesion produced for case 2, at frequency of 20 kHz compared to 500 kHz. The circle represents the tumor boundary.

V. CONCLUSION

RF ablation at lower frequencies may result in larger lesions, preferentially within the tumor boundaries. However, it should be noted that low frequencies below around 20 kHz can stimulate excitable tissue (e.g. heart), and should be avoided.

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