Ultra-Wideband Microwave Ablation Therapy (UMAT)

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Abstract — We propose an alternative microwave ablation therapy, Ultra-wideband Microwave Ablation Therapy (UMAT), that can potentially be used for the treatment of various cancers including liver, kidney, breast, lung, and bone. The technology relies on extremely small size ultra-wideband antennas that can deliver power to the tissue with more than 90% power transmission efficiency from beginning to the end of the ablation procedure. The resulting ablation technology is far superior to the existing microwave ablation therapies in terms of power usage, ablation time and zones. In order to validate the system, we provide ex vivo animal experiments.

Index Terms — Microwave ablation, ultrawideband antennas, cancer treatment

I. INTRODUCTION

Historically, radio frequency (RF) ablation has been the workhorse of all ablation procedures for many years. It has mainly been used for the treatment of heart arrhythmias, and liver tumors. The RF ablation generators operate at very low frequencies (mainly 480 kHz) and the power levels can be as high as 200W. The procedure requires a ground pad located in the vicinity of the RF probe to create a close circuit between the probe and the ground. There are several issues associated with this procedure. As the tissue heats up, the tissue conductivity significantly drops and creates an open circuit limiting the ablation zone diameter. Therefore, the ablation zones are small (mm range) and ablation times are long (more than 10 minutes). In addition, the ground pads can cause skin burns. Because of the small ablation zones, RF is often inadequate to treat many tumors using single probes [1]–[3]. Recently, Microwave (MW) ablation emerged as a new technology with potential to eliminate the problems associated with RF ablation [4]–[9]. In contrast to RF ablation, MW ablation uses higher frequencies (915 MHz and 2.4 GHz) and works on an electromagnetic energy propagation principle. When the microwave power is turned on, an antenna on the MW probe radiates electromagnetic energy into the tissue creating the ablation zone [10]–[17]. As a result, MW ablation can be used for many organs such as lung and bones with higher impedance values where RF ablation would fail [12]. In addition, MW ablation does not rely on ground pads thereby eliminates the potential unwanted skin burns. Also, it has been shown that MW ablation can create much larger ablation zones compared to RF ablation [18]–[21].

Despite many advantages, there are still major problems associated with the current MW ablation systems. These problems are mainly due to the narrowband nature of the

antennas used in these systems. In order to eliminate these problems, we propose to utilize ultra-wideband antennas for more efficient and unique MW ablation therapy.

In this study, we have developed very small size ultra-wideband antennas that can be utilized for microwave ablation of liver, lung, kidney, breast, and bone. We provide theory behind the antenna design, present return loss results. Finally, we validate the proposed technology using ex vivo pig liver experiments.

II. CURRENT MICROWAVE ABLATION SYSTEMS

As mentioned above, the current microwave ablation systems suffer due to narrowband nature of the antenna used in probes. We will present an illustrative example to show how narrow band antennas can degrade the power transmission efficiency. Consider the dipole antenna in fig.1 (designed for ablation at 2.4 GHz). It has been embedded into a medium emulating the electrical properties (dielectric constant - ϵ_r and conductivity - σ) of the liver tissue. It is a known fact that temperature changes affect the electrical properties of the tissue. This effect can be seen in [22]. As seen from the table, ϵ_r (from 44.98 to 26.76) and σ (from 1.79 to 1.26) significantly drops as the tissue temperature increases from 15 °C to 98.9 °C. These changes deteriorate the matching of the antenna impedance to the surrounding tissue impedance resulting significant drop in power transmission efficiency. The red curve in fig.1 is the reflection curve at the start of the ablation procedure. The arrow on the red curve shows the minimum reflection point at 2.4 GHz with 2.5% reflection and 97.5% power transmission into the liver. However, as the temperature increases, the red curve approaches to the blue curve shifting

Figure 1. Dipole antenna matched to surrounding liver tissue electrical properties at 15 °C providing 97.5% power transmission as opposed to 20% power transmission when temperature is at 98.9 °C. The dip on the red curve in the plot shows the frequency of operation at 2.4 GHz before the ablation procedure begins.

the minimum reflection point further away from 2.4 GHz. At

the end of the ablation procedure (at 98.9 °C), the arrow on the blue curve indicates that only 20% of the power is transmitted efficiently into the tissue while 80% is reflected back to the probe. This inefficient power transmission into the tissue results in unwanted ablation regions, higher input power requirements, and longer ablation times.

III. ULTRA-WIDEBAND MICROWAVE ABLATION PROBE DESIGN

A slot between two different media behaves like a leaky wave antenna. For a small width of the slot w_s , (compared to the media on either side of the slot) between two different dielectric media the asymptotic value of the complex propagation constant is given by

$$k_w = \beta + \frac{k_d^2}{2\beta \left[1 - \frac{4}{\pi} \ln(\gamma_e k_d \frac{w_s}{8}) \right]}$$

where γ_e is the Euler's constant, $k_d = \sqrt{k_2^2 - k_1^2}$,

$\beta = \sqrt{(k_2^2 + k_1^2)/2}$, and $k_i = k_o \sqrt{\epsilon_{ri}}$ with $i=1,2$ and k_o is

the free space propagation constant. The rays are launched in the dielectric with lower dielectric constant with an angle γ with respect to the slot axis given

$$\gamma = \cos^{-1} \sqrt{\frac{\epsilon_{r1} + \epsilon_{r2}}{2\epsilon_{r2}}}$$

The above equation indicates that the direction of the main beam is essentially independent of frequency and we have utilized this phenomenon to design extremely small antennas that can be used for in-body applications. For this, we have exploited the high dielectric constant of human tissues and low permittivity and low loss material like FR4 epoxy on which the antenna is printed. The geometry of the antenna used for ablation is shown in fig.3. It consists of slot which is coiled in a small area (5.5 mm x 5.5 mm) printed on FR4 substrate and microstrip line printed on the back side which provides the excitation. The antenna is provided with a tapered tip FR4 substrate for ease of insertion into the tissue. The slot, when excited with a suitable microstrip excitation, generates leaky waves over a very large bandwidth. Because the resulting antenna is ultra-wideband in nature, the power transmission efficiency is between 95% and 99.9% for all frequencies from 300 MHz to 10 GHz (fig.4).

In this study, our focus will be 915 MHz, 2.4 GHz and 5.8 GHz. In fig. 3, we show preliminary results from *ex-vivo* pig liver experiments. These measurements prove that UMAT eliminates the unwanted ablation regions (fig.3, 2nd row 2nd

picture) and allows adjustable ablation zones (fig.3, 2nd row, pictures 3&4) by changing the input frequency. In addition, the power levels and ablation times are significantly lower than previously reported in the literature. The results in figure 3 were generated using 20W input power with only 4 minutes of ablation. Also note that in figure 3, we present the first ever MW ablation at 5.8 GHz which is more circular and smaller than the zone at 2.4 GHz. We envision that higher frequencies (5.8 GHz or higher) can be used for small tumors that require smaller zones while lower frequencies (2.4 GHz, 915 MHz or lower) can be used for larger tumors.

Figure 3. Top pictures show the new ultra-wideband probes. Currently, the antennas are printed on plane substrate for the sake of simplicity, however, in the final prototype, we will modify the antennas to conform on a 14 to 17 gauge probes. The bottom pictures are the measurement setup and the ablation results for 5.8 GHz and 2.4 GHz. Note that the ablation zone at 5.8 GHz is smaller and more circular.

Figure 4. Antenna reflection from 300 MHz - 10GHz.

IV. CONCLUSION

In order to increase power transmission efficiency, new ultra-wideband probes have been fabricated that function between 300 MHz and 10 GHz. Tested at 915 MHz, 2.4 GHz, and 5.8 GHz, the ultra-wide band MW ablation probes

maintain power transmission efficiency between 95% and 99.9% while producing optimal ablation zones.

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