Assessment of Burn Depths on Organs by Microwave

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Abstract

Monitoring the burn depth in heart during ablation of atrial fibrillation is a real challenge for the next years. The influence of the burning effect on the dielectric properties is not very developed and represents a growing interest in terms of characterization in medicine. Here, the microwave characterization of biological tissues in a liquid medium is performed through an open-ended coaxial probe placed directly against each sample. The evolution of the relative variation of the reflection coefficient is correlated with the depth of burned tissues. Measurements are performed on bovine muscles and pork hearts. Results are similar for both tissues.

Keywords: burn depth assessment; dielectric properties; microwave measurement; open-ended coaxial probe.

1. Motivation

In medicine, practitioners need to burn organs parts for therapeutic purposes. For example, cardiac arrhythmia substrates may be cured by intra-cardiac procedures, which consist in burning specific endocardial sites [1]. Furthermore, the depth of the obtained cardiac lesions is a very important parameter to assure the effective suppression of arrhythmia recurrences. At this point in time, it can’t be assessed accurately during the procedures [2]. Indeed, electrophysiologists have no information about the burn in progress into the body.

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In this work, we propose a method based on the microwave characterization of materials. So far, all studies, focused on the burn characterization, were done in the air or with an evolution of the temperature measurement [3]. Here, the experiments are realized in a liquid medium at constant temperature.

2. Principle and experimental device

The experimental setup used for the microwave characterization of biological tissues as a function of the burn depth is depicted in fig. 1. A thermostatic bath is used to maintain the temperature of a physiological solution (distilled water with 0.9 %wt of NaCl) at 37°C. The sample is immersed into this solution during measurements.

Through an irrigated catheter, a radiofrequency generator sends energy to produce one burn for each sample. The frequency used to burn is set to 500 kHz, the power output fixed to 30 Watts and the irrigation flow is fixed to 30 mL/min to limit the burn temperature at 48°C. This device is commonly used by practitioners to achieve the burns directly in the heart of patients. The increase of the burn depth is obtained by augmenting the time of ablation. The pressure applied through the probe on the sample is set by a “z axis controller”. This pressure is unchanged for all measurements to avoid a variation of the signals. Data acquisition is performed using a vector network analyzer.

The measurement is based on the microwave characterization of materials. It consists in the analysis of the complex reflection coefficient \( \Gamma \), which is defined as the ratio between the reflected wave and the incident wave, which propagates in the coaxial probe in contact with the material. The vector network analyzer gives directly the couple real \( \Gamma' \) and imaginary part \( \Gamma'' \) of the reflection coefficient.

After all measurements, a transversal cut is made on the sample and the depth of the burn tissue is measured with the help of a photography (fig. 2).

Based on a previous work [4], the study of the relative variation of the reflection coefficient \( \Gamma \) gives access to the depth of burned tissue. Due to a maximum of variation, the industrial frequency 2.45 GHz is used for the study. Using a coaxial probe [5], measurements are done at constant controlled contact pressure and temperature (37°C).
\[
\frac{\Delta \Gamma(f)}{\Gamma(f)} = \frac{\Gamma_{\text{burn}} - \Gamma_{\text{reference}}}{\Gamma_{\text{reference}}} (f)
\]  

(1)

3. Results

Firstly, the evolution of the complex relative variation occurred by the burn depth is performed using a biological model composed of muscle fibers (beef meat). Indeed, the dielectric properties of beef meat and pork heart are similar at the frequency of interest [6]. Moreover, beef meat is easy to obtain in a practical way and doesn’t need any preparation. For each burn depth between 2 and 6 mm with one millimeter step, five samples are measured to establish the reproducibility of the measurement. The averages and uncertainties of each burn depth are calculated and kept into a calibration curve (fig. 3). This calibration curve represents the evolution of the imaginary part of the relative variation of the reflection coefficient as a function of the real part.

Secondly, several measurements are performed on heart tissues with unknown burn depths. The obtained measurements for the heart tissues are reported on the calibration graphic (grey points in fig. 3).

On this figure, a linearity of the evolution of both part of complex relative variation is observed with the burn depths. Thus, it is possible to compare the heart burned depth obtained from the calibration curve with the real burn depth obtained after a transversal cut of each burned point (fig. 4).

![Fig. 3: Calibration curve of the measurements of burn depths on beef meat](image)

\[y = -2.6165x\]
\[R^2 = 0.9811\]

![Fig. 4: Correlation curve of the burn depths on pork hearts obtained from measured signal.](image)

\[y = x\]
\[R^2 = 0.953\]
On this figure, a linear regression is done for several points. It gives the equation of a bisector with a correlation coefficient of 0.95. From this result, the information is that the calibration curve obtained from the beef meat samples conducts to a good assessment of the burn depths of biological tissues. The second information is that the evolution of the relative variation of the reflection coefficient is similar for both tissues.

4. Conclusion

The results presented in this work highlight the ability to determine the depth of burned tissues with a non-invasive technique by microwave characterization. The use of the microwave frequency conducts to the evolution of the reflection coefficient according to the burn depth. This evolution is due to a variation of the concentration of water molecule into the tissue. The limiting factor of this study comes from the size of the open-ended coaxial probe. In order to consider any in-vivo measurements, a reduction of the probe size is in progress.

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