A Conformal Microwave Antenna Applicator for Circumferential Ablation

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Abstract -- **This paper presents a circumferential tissue ablation device used to form a circumferential conduction block in a pulmonary vein. The circumferential ablation element includes an expandable balloon that is adapted to conform to the pulmonary vein (PV) in the region of its ostium; a microwave transducer is provided and conformed to the balloon's skin, which can form the circumferential ablation by transmitting microwave energy. The microwave transducer includes a mechanism of impedance tuning by which the microwave ablation catheter system can match the impedance of its power supply with the transmission line to minimize reflected power and optimize energy delivery to targeted tissues.**

I. INTRODUCTION.

Catheter ablation for arrhythmia is a recent interventional discipline within electrophysiology whereby an arrythmogenic focus or critical portion of an arrhythmia circuit is identified, localized, and subsequently destroyed utilizing a percutaneous trans-catheter technique. The basic requirements for catheter ablation is to create localized injury that will effectively remove the arrhythmic focus without injuring the surrounding normal tissue. The scar or lesion that forms then blocks the accessory pathway and prevents arrhythmias. Various energy forms have been developed for this purpose, but radio-frequency (RF) energy is the most common one, with a high success rate to treat a wide range of arrhythmias, such as atrial flutter and Woff-Parkinson-White syndrome [1].

However, a high success rate has not been achieved for most cardiac patients with atrial fibrillation, a leading cause of stroke. In atrial fibrillation, the source area of the arrhythmia is too large to be corrected by the small lesion size produced with currently available RF ablation catheters.

Microwave ablation is a promising alternative to RF. In contrast to RF ablation, heating with microwaves is due to a propagating electromagnetic field that raises the energy of the dielectric molecules through which the field passes by both conduction and displacement currents. Thus, microwave ablation has the potential for a greater volume of heating than RF ablation and should result in a larger lesion.

Microwave catheter-based antennas have been used in experiments of cardiac ablation. Many studies have been published on these antennas of various geometries [2]-[5]. The principle for these antennas is similar: Microwave energy is delivered down the length of a coaxial cable terminated in an antenna capable of radiating the energy into tissue. Radiating energy will cause the water molecules in myocardial tissue to oscillate, producing tissue heating and causing cell death.

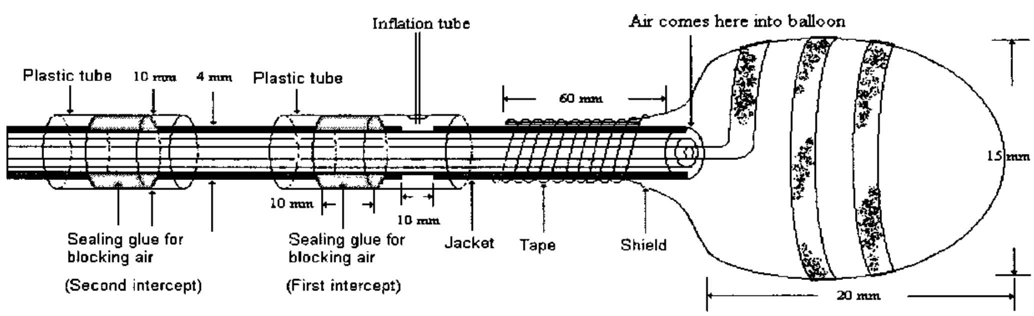

Fig. 1. A perspective view of the catheter prototype

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However, it is desirable to have a ring-type lesion, which is large enough to treat cardiac arrhythmias, such as atrial arrhythmia. These antenna designs have not resulted in satisfactory lesion patterns with only one or two time ablations.

With RF energy, the lesion that can be created is limited to a relatively small size and depth. To increase the depth and the surface area of the lesion, more RF energy can be applied or applied multiple times, or for more periods of time, to the same location. None of these is ideal. Increasing the power often results in excessive temperature at the electrode-tissue interface without the desired enlargement of lesion size, since desiccation of tissue causes an abrupt rise in impedance and limits energy transfer to the tissue. With multiple or extended applications of RF energy, time is lost performing the same operation over an extended period, and accuracy is suffered because of unintended movement of the electrode between applications. Previous designs of RF electrodes and microwave antennas have not produced the desired ring-type lesion. The following patents proposed some new considerations.

In U.S. Pat. NO. 5,575,810, Swanson et al. describes a method of ablating tissue in the heart to treat atrial fibrillation by forming a convoluted lesion pattern. The energy-emitting element is composed of a basket composite structure comprised mainly of RF electrodes. In U.S. Pat. NO. 6,111,107, Lesh describes a device and method for forming a circumferential conduction block in a pulmonary vein. A cylindrical ultrasound transducer is provided on an inner member within the balloon and forms the circumferential ablation member by emitting a radial ultrasound signal.

None of the above-cited references discloses a microwave antenna catheter for forming circumferential ablation with impedance tuning function by way of the second slave balloon or third slave balloon. The slave balloons play a role of a flexible reflector to reduce the reflected power or limit the microwave energy radiated only in the radial direction, and therefore increase the ablation efficiency. The higher efficiency comes with lower power supply down to 30 W to create ablated tissue temperature up to 95 C in 60 seconds with only one time ablation.

II. FABRICATION

A. *Catheter - One Master Balloon.*

FIG. 1 shows a perspective view of a prototype of the microwave antenna catheter used in *in vitro* tests for producing circumferential lesions. The antenna applicator is developed using a coaxial cable RG58. This kind of cable is chosen because of its flexibility, size, and commercial availability. There are two kinds of RG58. One has an outer diameter of 0.195 in and an inner conductor of AWG 18mm^2. The other has an outer diameter of 0.158 in and an inner solid conductor of AWR of 20mm^2. Both types have been used. *In vitro* tests show that the coax with the thicker inner conductor works better. The total catheter length is chosen to be 100 cm. Since the coverage of the braided shield (of an outer conductor) of the coax is less than 100%, the remaining space among the braids of the shield can be used for inflating the balloon. At a distance far enough from the balloon, a 10 mm section of the jacket is stripped and the copper is exposed. The same procedure is repeated at a distance of 20 mm from the first gap to form the second intercept. Both gaps are then sealed by liquid glue that is allowed to penetrate into the braid and contact the Teflon. The active part of the antenna is composed of the copper sheet tailored in the shape of a spiral with 1.5 mm width and 1 mm spacing between turns embedded in the balloon skin. The spiral is taped and is covered with a thin layer of glue as an insulator and is fed to the inner conductor of the transmission line. The total catheter length is approximately 2.5 turns. The balloon is secured at the neck port and additional parts of the balloon neck are wound around the transmission line.

B. *Catheter - One Master Balloon and Two Slave Balloons.*

Adding two flexible reflectors inside the balloon can increase the radiation efficiency of the antenna. One is on the distal end of the balloon and the other is on the proximal end. Both reflectors are connected to the external conductor of the transmission line and made similar to parts of the conductive disk. The conductive surfaces of the reflectors should face the center of the balloon.

The antenna performance can be improved further as follows. Although the master balloon shown in the FIG. 1 has a role of impedance tuning, its size may not be practical for resonance. After adding the second balloon, the adjusted range for balloon size is much larger. In addition, inside the pulmonary vein lumen, the master balloon should be secured tightly and contacting the surrounding tissue during ablation. If only one balloon is used, sufficient contact may not be ensured. If the antenna is not at resonance, it can be tuned by changing the balloon size. Besides the second balloon, a third balloon can be added, that is, one master and 2 other slave balloons. Each balloon has its individual inflation port. The total radiation system, coupled to the transmission line, thus, has more dynamic adjusting range.

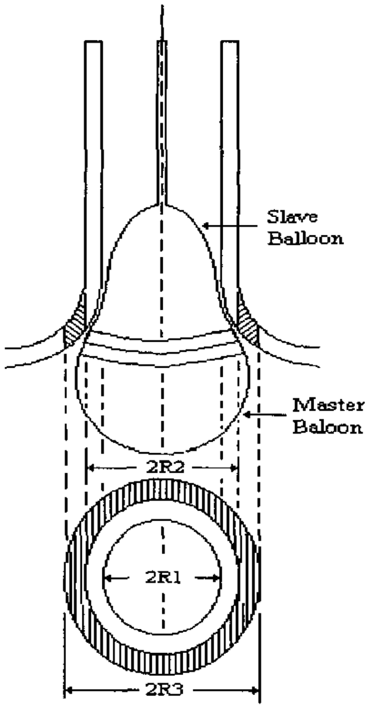

Fig. 2. A view of the proposed lesion geometry and a transverse cross-sectional view of a circumferential lesion.

III. PERFORMANCE

FIG. 2. shows proposed lesion geometry after circumferential ablation. The master balloon circumferentially engages the PV ostium region. The conductive band ablates the surrounding circumferential path of the tissue in the PV wall and forms a circumferential lesion that circumscribes the PV lumen and transects the electrical conduction of the PV to block conduction in the direction along its longitudinal axis. There are 3 different diameters shown in the figure. The difference in R3-R2 represents the width of circular lesion band, typically 1-2 mm. The difference in R2-R1 should be kept about 2-3mm. (However, if it is less, the blood may be heated while heating the targeted tissue.) R1 represents the diameter of PV lumen.

The antenna performance is evaluated by S11, a reflection coefficient of the antenna tested by a vector network analyzer. First, insert the antenna into the phantom, and inflate the balloon by way of a tube using a syringe. Typically, 10 ml of air is needed to have the balloon inflated to about 1-1.5 cm in diameter. This value typically falls into the 1.6-1.75 GHz range at resonance. It is also necessary to take the antenna off the phantom and change the length of the spiral (usually by shortening it). It will result in the resonant point shifting back toward 915 MHz. This procedure is normally repeated several times.

FIG. 3 shows a plot of the reflection coefficient versus the frequency of the proposed microwave antenna catheter. Since the desired antenna resonance is 915 MHz, the reflection coefficient S11 should be minimum at or near this frequency to ensure maximum energy couples into the targeted tissue and not reflected back into the coax.

FIG.4 shows the S-parameter versus the expanded balloon sizes at frequency of 915 MHz. Initially the balloon is empty without any gas and then inflated by air. We can see the balloon antenna is resonant at 915 MHz for different inflation volume from 8-12 ml. The 4 curves represent 4 different applications of air. Since the inflation is controlled manually, the S11 curves have different shapes, but the minimum values below -20 dB always exist. Based on these experimental results, the proposed antenna system is proven practical.

Based on these requirements, *in vitro* tests were conducted in the New England Medical Center Hospitals. The typical results can be seen in FIG. 5. The cross-sectional view can be seen in FIG. 6, showing heating throughout the tissue wall. Note that instead of using a pig heart, a PV model consisting of muscle tissue with a drilled hole is used. Detailed *in vitro* test description can be referred to the paper [6].

V. CONCLUSION

This paper presents a surgical device that uses the microwave energy to ablate a selected circumferential region of tissue that is located along a pulmonary vein wall. The microwave antenna applicator includes impedance-tuning arrangement using the second or the third balloon as a reflector or tuner to minimize reflected power and maximize catheter to tissue coupling.

ACKNOWLEDGEMENT

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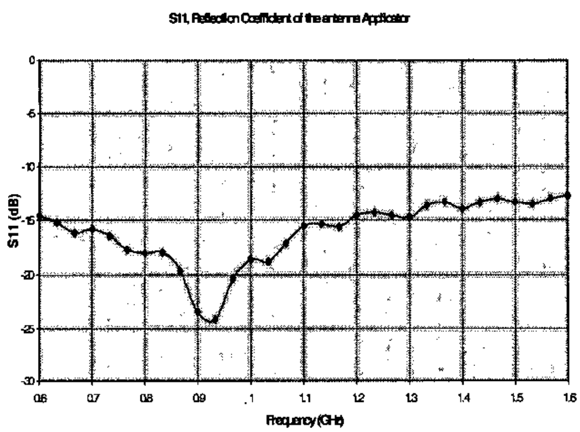

Fig. 3. The reflection coefficient versus the frequency of the proposed microwave antenna catheter surrounded by phantom.

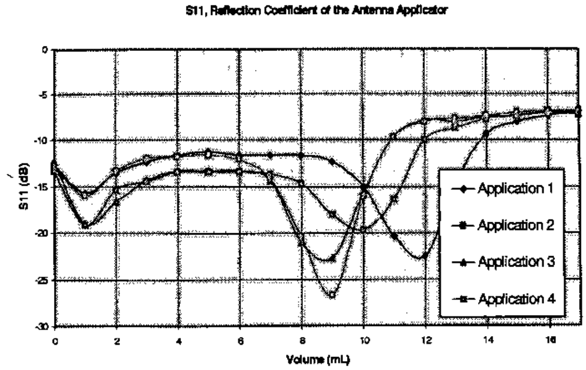

Fig. 4. The reflection coefficient versus the inflatable balloon size at 915 GHz.

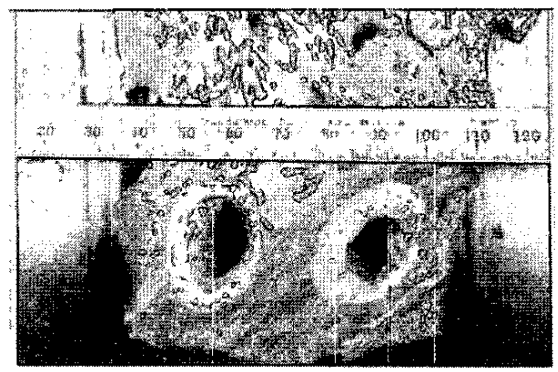

Fig. 5. A typical lesion from *in vitro* test, top view.

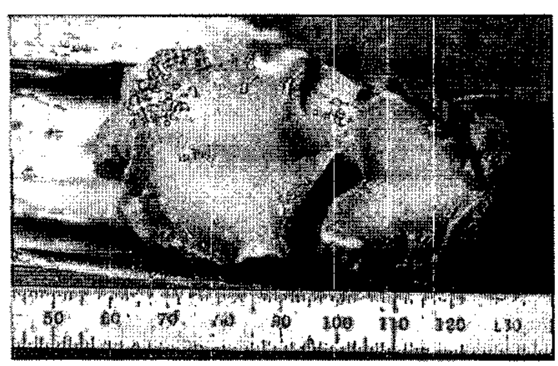

FIG. 6. A typical lesion from *in vitro* test, cross-sectional view.