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Full Length Article

# Analysis of efficiency of different antennas for microwave ablation using simulation and experimental methods

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ABSTRACT

The objective of this study is to analyze the efficiency of different antennas proposed for microwave ablation therapy using numerical simulation and experimental approach. The simulation was done with COMSOL MULTIPHYSICS® software to design antenna prototypes and evaluate its reflection coefficient, power dissipation distribution, power dissipation density, specific absorption rate and temperature distribution in tissue. Antennas were fabricated from a 50 Ω RG405/U semi-rigid coaxial cable to match the geometric prototypes generated during simulation. *Ex vivo* bovine livers were ablated with the fabricated antennas using 50 W for 5 and 10 min. Ablation diameters, ablation lengths and aspect ratios were determined. Sleeved antenna produced lowest reflection coefficient, high power dissipation, low power dissipation density, high SAR and high temperature in the simulation. Sleeved antenna provides excellent localization, large ablative diameter, low backward heating and high aspect ratio than single slot, dual slot and monopole antennas.



## 1. Introduction

The potential applications of thermal therapies such as microwave ablation, radiofrequency ablation, high intensity focused ultrasound and cryoablation in tumor treatments have been extensively reviewed in literature [1–4]. Microwave ablation is emerging as an attractive modality for thermal therapy of large soft tissue within a short period of time, making it particularly suitable for tumors in different tissues [3,5]. Microwave ablation produces rapid temperature elevation sufficient to cause instant tissue coagulation and necrosis and it is capable of propagating through all types of biological tissues irrespective of tissues' relative permittivity and effective conductivities. Tissue destruction occurs when tissues are heated to lethal temperatures with a microwave source. Microwave energy radiates into the tissue through an interstitial antenna that functions to couple energy from MW generator to the tissue. As a result of the radiative nature of the antenna, direct heating occurs in a volume of tissue around the antenna.

The basic microwave system consists of three components: a generator, a power distribution system and antenna. Antenna is the most important component of the system that governs microwave energy distribution during tissue ablation. Antennas such as monopole [6], dipole [7,8], helical [9], triaxial [10], choked [11], sleeved [12,13] and double slot [14] have been proposed in the field of microwave thermal therapy. Microwave antennas are mostly fabricated from a thin coaxial cables of diameters between 1.5 and 2.5 mm [15]. Concerted efforts are ongoing by several researchers to produce antenna capable of producing large tumor ablation with low backward heating along the antenna shaft in the clinical application of microwave ablation in tumor management. Problems such as backward heating along antenna shaft, poor microwave energy distributions, and small ablation coverage have been reported to associate with most of these proposed antennas [16–20].

Theoretical modelling have been playing significant roles in the design and optimization of antennas by serving as a quick, convenient and inexpensive tool to evaluate the performance and efficiency of designed antennas [13–15,21,22]. Numerical techniques like the finite element method (FEM), finite integration technique (FIT), finite–difference time-domain (FDTD) and method of moments (MoM) are widely used to discretize the partial differential equations (PDEs) in time and space and solve for the temperature profile in tissue [23]. COMSOL Multiphysics software is equipped with FEM to provide all the tools needed to build and run simulation applications pertaining to antenna geometry, biological materials, meshing, physics components selection (electromagnetic and heat transfer), and a good platform for results

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evaluation [24]. In this study, we investigate the characteristics and features of proposed antennas for microwave ablation therapy to compare their efficiencies using numerical and experimental techniques.

## 2. Materials and method

The materials used for this study are COMSOL Multiphysics software version 4.4 (Stockholm, Sweden), a 2.45 GHz solid-state microwave generator (SAIREM SAS 200 W, Neyron Cedex, France), semi-rigid coaxial cable (RG405 Coax, Pasternack Enterprises Inc, Los Angeles), excised bovine liver, Teflon tape and ImageJ software (NIH) for analysis of acquired images.

### 2.1. Simulation of antennas

The antenna simulation was carried out with COMSOL multiphysics using "heat" and "radiofrequency" modules. The antennas were made from 50 Ω RG405 semi-rigid coaxial cable of 2.2 mm diameter.

The inner conductor (0.51 mm thick) was silver-plated copper clad steel with low-loss solid polytetrafluoroethylene (PTFE) as dielectric (1.16 mm thick) and copper as an outer conductor (0.52 mm thick). COMSOL Multiphysics version 4.4 software allows easy specification of the antenna geometries and to solve Maxwell's and bio-heat equations in the surrounding tissues [21]. Each antenna is 3.4 mm in diameter which include the Teflon tape to act as catheter (and a floating sleeve where necessary) to provide uniform geometrical structure. The catheter is made of polytetrafluoroethylene (PTFE) for hygienic and guidance purpose. The antennas operate at frequency of 2.45 GHz a widely frequency used in microwave ablation. The geometries and dimensions of the studied antennas are represented in Fig. 1.

Bovine liver was modelled as a cylindrical geometry of 40 mm radius and 80 mm in height. The tissue was also considered to be homogeneous with its biological properties taken from literature and compared with the built-in one available in the software [25,26]. Each antenna was modelled using the dimensions shown in Fig. 1 along with its specifications indicated in the manufacturer technical sheet of the RG405 semi rigid coaxial-cable. After the antennas have been designed, microwave energy was set at the upper end of dielectric component of the antenna. An electromagnetic wave propagating in an antenna, is characterized by transverse electromagnetic fields (TEM) while in the tissue, an electromagnetic wave is characterized by transverse magnetic fields (TM). Thus, the simulation helped to predict specific absorption rate (SAR), temperature profile and tissue necrosis distributions in the liver using these antennas. Also determined were reflection coefficient, maximum SAR, maximum temperature and total power deposition. Aspect ratio was obtained using 50 °C isothermal contour line for a duration of 10 min. Image J (NIH, version 1.47) was used to determine lesion diameter and longitudinal length of designed and simulated antennas as well as the aspect ratio.

### 2.2. Experimental validation

The modelled antennas were fabricated from 50 Ω semi-rigid coaxial cable (RG405 Coax, Pasternack Enterprises Inc, Los Angeles) to replicate the geometrical prototypes described in the simulation section (Fig. 1). Slots were created for the emission of the microwave energy with the tip end soldered where necessary. Four antennas (monopole, single slot, dual slot and sleeved antennas) of different geometries were fabricated from the semi-rigid coaxial cables. The antennas were covered with Teflon tape for easy removal from the liver after ablation. Large blood vessels were also avoided during the insertion of the antenna to minimize microwave energy loss from ablating regions. Microwave energy was delivered at input powers of 20, 30, 40 and 50 W for 5 min and 10 min respectively for each of the power selected. At the end of each procedure, the ablated tissue was sliced along the antenna insertion to evaluate ablation diameter and ablation length. Each

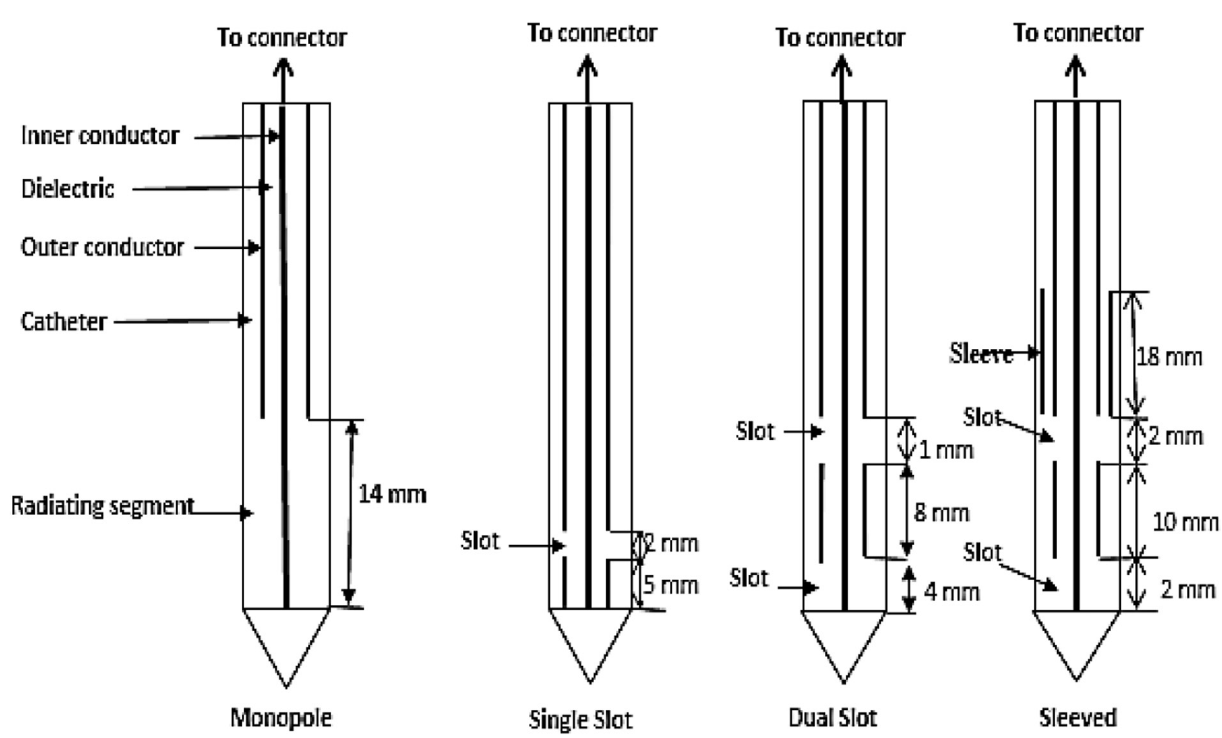


**Fig. 1.** Schematic of monopole, single slot, dual slot and sleeved antennas.

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