CHAPTER 7

CONCLUSIONS AND FUTURE SCOPE

7.1 Conclusions

The benefits of using heat in therapeutic medicine have been well recognized for more than hundred years. Physicians have treated various types of tumors, since the beginning of the twentieth century using heat only because it was found that heat can kill tumor cells more aggressively than normal cells. In the last twenty years, the use of RF/microwaves in medical diagnostics and therapy has increased sharply in parallel to the dramatic increase in the use of RF/microwaves in communications.

Although the treatment of cancer with RF and microwaves has various degrees of success and is well documented, but many oncological centers are yet not using these modalities. However, renewed interest in localized high-temperature for the treatment of liver, kidney, and breast cancers has led to results showing a prolongation and improvement in the quality of life.

Among various primary malignant liver tumors, hepatocellular carcinoma (HCC) is the most common and accounts for 80 – 90% of all malignant liver tumors. Various treatment options for hepatocellular carcinoma (HCC), have been discussed in detail Chapter 1. Among all options microwave ablation is most promising because of EM radiations based treatment, localized power deposition, and larger ablation lesion sizes.

Initially, for treating HCC, microwave coagulation was used in hepatic resection during open surgery for tissue coagulation and hemostasis The electrodes designed during hepatic resection were of 1 cm in diameter, though several studies have reported excellent results. But percutaneous use of microwave ablation for treating HCC is very much of concern because it does not damage the nonneoplastic hepatic parenchyma, has low-risk procedures, can be easily repeated when new lesions appear, and as occurs in most patients within 5 years.

For percutaneous use of microwave ablation, it is necessary to develop a thin electrode because, as the same electrode designed for treating during hepatic resection cannot be not used as it is too thick. Moreover the antenna has to be designed so that, this produces tissue coagulation at the tip of the electrode, but do not burn the skin.

Although clinical trials are ultimate test but computational models play a substantial role in the development and understanding of antennas used for MWA which helps the physicians to perform ablation procedures by determining the optimal placement of antenna by predicting the trajectories for particular power level and treatment durations for individual patients.

Based upon the limitations of earlier antenna designs for microwave ablation such as thermal lesion size, detrimental backwards heating, control of lesion generation and transient behavior of tissue physical properties, the present research work focuses on simulative design of three types of microwave coaxial antennas for the treatment of hepatocellular carcinoma (1) tapered cap floating sleeve antenna, (2) needle tip choke antenna and (3) multisection floating sleeve antenna. Further the objective metrics for assessing the antenna performance have been framed.

COMSOL Multiphysics, a commercial finite element method (FEM) solver has been used for modeling of antennas and to solve partial differential equations governing the electromagnetic wave propagation and hence determine heat transfer in the liver tissue. This software allows the user to specify the geometry and physical properties of the antenna to be solved. An interactive feature of COMSOL Multiphysics of coupling electromagnetic and thermal models has been used in the present research work.

The performances of different antennas for treatment of HCC have been evaluated in terms of objective metrics, antenna matching, power absorption, and SAR pattern. The reflection coefficient for impedance matching and thermal ablation zones along the cylindrical liver tissue in the direction of the antenna length are measured to check whether they fulfill the objective metrics.

The fundamental design of antennas used for MWA is based upon coaxial fed monopole or dipole antenna. This antenna is usually constructed from thin, semi rigid coaxial cable. The entire outer conductor is copper, while the inner conductor is made from silver-plated copper wire and the coaxial dielectric used is in this case is a low-loss polytetrafluoroethylene (PTFE). A small ring slot is cut through the outer conductor close to the short circuited distal tip of the antenna to allow electromagnetic wave propagation in to the tissue. This width is usually chosen to be much smaller than a wavelength which allows the source to be replaced by a narrow strip of magnetic current using equilance in analytical models.

The current distribution for slot antennas used in MWA can be determined by first recalling that the inner and outer conductors of the coaxial cable are short-circuited at the distal tip, with the radius of the inner conductor assumed to be much less than that of the outer conductor.

This current distribution can be extended to yield the radiative and power deposition patterns of the antenna. Various studies have shown that increasing the insertion depth affects the current distribution, making it highly asymmetric. This indicates that power deposition is also highly asymmetric and that SAR patterns produced by these antennas become more nonlocalized with increasing insertion depth causing backward heating.

One practical and effective solution to the backward heating problem that affects interstitial antennas is to electrically connect a thin metallic choke, usually λ_{eff} /4 in length, to the antenna's outer conductor to block axial current flow and localize power deposition near the distal tip of the antenna. As a result, properly designed choked antennas are capable of achieving highly localized SAR patterns that are less dependent on insertion depth, although such antennas are usually less minimally invasive due to their slightly in-creased diameter. Chokes have also been found to aid in impedance matching and tissue coupling during MWA.

Another design of capable of improving localization consists of a floating sleeve whose ideal length is approximately 1/2 wave-length in tissue. This design is similar to a choked antenna, but is fundamentally unique as the sleeve is not electrically connected to the antenna. Instead, a dielectric, such as Teflon, is used to hold the sleeve in place. The significant new feature of this antenna is the tapered cap on floating sleeve, used to prevent the flow of electromagnetic energy along the coaxial applicator and constrain the SAR pattern effectively. The critical parameter, the length of the tapered cap has also been optimized. Tapered cap floating sleeve antenna results are able to generate perfectly spherical ablation zone with r_{az} = 1.9 mm, AR = 0.5 mm, S_{11} = -24.8 dB at the tip without increasing the radial dimensions of the antenna. The SAR patterns were obtained at 40 mm and 80 mm insertion depth and it has been observed that the SAR distributions were unaffected by the insertion depth.

The second antenna considered here is miniaturized choke monopole antenna extended with a needle tip. Positioning the needle in this way improves return loss and reduces fields flowing back on the coaxial outer conductor. In turn, more energy is deposited in the tissue and less heating of the feed line occurs. The antenna generates spherical ablation zone with r_{az} = 1.9 mm, AR = 0.5 mm, S_{11} = -29.5 dB. The reflection coefficient of this antenna is much improved as compared to tapered cap floating sleeve antenna which ensures more effective thermal ablation and less backward heating in this case.

Multisection floating sleeve antenna has also been modeled and simulated, the performance has been evaluated to have comprehensiveness of the research work. The simulated results demonstrate nearly spherical ablation zone with r_{az} = 2.0 mm, AR = 0.47 mm, S_{11} = -27 dB, which are improved as compared to the basic floating sleeve antenna. However the performance is bit inferior to other two designs as discussed above. After analyzing the results it is concluded that the multisection floating sleeve antenna would be more useful in other applications such as throat cancer.

The strength of both tapered cap floating sleeve antenna and needle tip choke antenna facilitates these antennas to be inserted into the liver tissue without requiring any insertion device. Moreover one major advantage of these two antennas is that the temperature probe can be inserted along with the antenna in order to monitor temperature of the targeted liver tissue. Although the multisection floating sleeve antenna does not support the above feature of self insertion, but demonstrates equally improved characteristics with respect to floating sleeve antenna.

The liver is the largest glandular organ in the body which continuously filters blood that circulates through the body, converting nutrients and drugs absorbed from the digestive tract into ready-to-use chemicals and many more important functions. It is a vital organ that supports nearly every organ in the body in some facet. The most common type of liver cancer is hepatocellular carcinoma, because all the blood in the body must pass through the liver, and is unusually accessible to cancer cells to grow. Treatment for liver cancer depends on the stage and the condition of liver. While some liver tumors can be removed surgically, but majority of them are inoperable and must be treated by alternative means. One of such method is MWA, a surgical procedure, in which the surgeon inserts a thin antenna, which emits microwaves in order to destroy the tumor. The thermal lesion created by MWA antenna must be of spherical in shape because liver tumors are generally spherical in shape. Hence the most challenging task is to design the antenna which is able to produce spherical thermal lesion so that healthy liver tissues may not get damage during treatment.

Though traditionally coaxial dipole antennas with floating sleeve and choke antennas have been used by many researchers for MWA therapy, but it has been analysed that such antennas had limitations in terms of size and shape of lesion, SAR pattern, minimal time to create lesion and introduction difficulties in to targeted tissue. Using floating sleeve antenna at 2.45 GHz, Yang et al obtained 0.36 x 0.59 mm diameter ablation zones. The choke antenna presented by Longo et. al promised the ablation zone of 0.34 x 0.53 mm, but with poor reflection coefficient. The optimal choke antenna was able to produce 0.39 x 0.40 mm diameter ablation zone with good reflection coefficient with respect to choke antenna. Hence the tapered cap floating sleeve antenna and needle tip choke antenna developed in this research work are superior to other presented antennas in the literature in terms of ablation zones, size, reflection coefficients is the most valuable contribution made to the field of antenna. Moreover the proposed antennas have added advantage of being inserted directly into the liver tissue without the any support of insertion device.

The computational models of the antennas for MWA have been designed considering steady state dielectric properties of tissue. For best results it is beneficial to use the most complete model of devices and their interaction with tissue hence requiring large computational time. The implementation of optimizing procedure requires repeated evaluation of the objective function which makes its use impractical. For this reason models have been implemented that incorporated as many elements of the complete model as possible, while keeping computational requirements and simulation time within practical limits.

The proposed computational antenna models are useful in specific patient treatment planning to improve the delivery of microwaves through antenna at the targeted liver tissue. These computer models when combined with real time images of growth of ablation zone and thermal profiles may assist the physicians to modify the treatment parameters for better treatment planning. This will improve the efficiency of the treatment and will reduce recurrence rate of liver tumor for patients.

7.2 Future Scope

The novel antennas are designed and optimized for the physical and dielectric properties of liver tissue under steady state conditions. While clinical treatment with MWA needs to control the tissue temperature and the lesion generation accurately, in order to minimize the side effects to surrounding tissue and surrounding organs. Further, the modeling does not represent the physical structure of blood vessel in the tissue. Recent reports represent that blood flow is rarely constant throughout the course of ablation procedure and thus role of varying blood flow must be considered. Therefore modeling of heat transport is needed in order to completely explain the process of MWA within the human tissue. For optimizing the antennas more efficiently, the work presented can be extended by performing the transient analysis. Moreover the formulation of 3D modeling for approaching realistic liver tissue can also be performed. Lastly there is need to validate these computational results with an in vivo animal model to show the efficacy of these models in predicting sizes of the ablation zone.