Machine Learning based Monitoring, Optimal Localization and Treatment of Hepatocellular Carcinoma Using Microwave antenna sensor for post covid-19 patient

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I. INTRODUCTION

In MWA, interventional procedures include exposure to very high temperatures, which results in tissue necrosis. The treatment employs an antenna probe that is image-guided to the tumour's target area and eliminates it with high-frequency dielectric heating. This therapy is safe when used to treat malignancies of the kidney, liver, bone, lung, and other soft tissue. Additionally, owing to its cost-effectiveness, it has become a commonly used approach in immunology and oncology research.

Thermal ablation (MWA) is a minimally invasive treatment that may be done under local anaesthesia and may result in same-day discharge. As a result, it is commonly used in the treatment of hepatocellular carcinoma (HCC). Each year, around 7,60,000 new HCC cases are reported globally, with India accounting for more than 50000 instances; hence, HCC accounts for one in every six cancer patients. Additionally, according to research performed by ILBS, New Delhi (2020) on the demographic distribution of HCC patients, Andrapradesh accounts for 8% of the entire cases which is a significant proportion. Age, gender, and alcohol use are all prominent risk factors for HCC, and as life expectancy increases globally, the direct association between older patients and HCC is becoming an increasing source of worry. Certain kinds of hepatitis may also result in HCC, and Uttar Pradesh alone accounts for 25000 cases of viral hepatitis each year according to the study conducted in 2019, which can progress to HCC if left untreated.

According to some reports, surgical resection is the primary line of therapy for HCC, with thermal ablation reserved for those who are not surgical candidates. However, as stated in a recent paper, the death rate associated with surgical resection has risen in older patients relative to younger patients, and numerous surgical resections may impair a patient's quality of life and are a very invasive and costly procedure.

Additionally, significant technological and clinical breakthroughs have been documented in the years since the microwave ablation treatment was introduced. This development comprises a matching antenna applicator, the employment of a state-of-the-art antenna structure, the optimization of the antenna applicator site, the reduction of the elongated ablation pattern, and a larger and quicker ablation zone to compensate for the thermo-regulatory impact. The goal of this study is to develop a better detection mechanism for HCC via the use of numerous machine learning algorithms, as well as to thermally ablate tissue using the same applicator that will be utilized to construct training sets for machine learning components.

II. OBJECTIVES

Since the recent past, significant progress has been made in the design of various ablation antennas, including dipole with sleeve, triaxial, monopole, slot, and SIW-based antennas, etc, (as shown in Fig. 1) but little progress has been made in the measurement of the dielectric properties of biological tissue using the treatment applicator. However, open-end coaxial probes have been examined for non-invasive tissue permittivity testing; however, due to the non-invasive nature of the technology, it cannot be used to assess the dielectric properties of internal organs such as the liver, kidney, or lungs. As a result, the applicator antenna injected into the tissue may be utilized to monitor permittivity changes and also to offer ideal applicator localization for maximal ablation in this procedure.

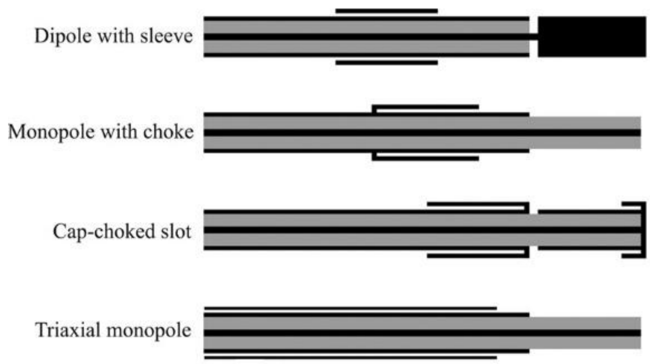


Fig.1 Conventional Microwave Ablation applicators

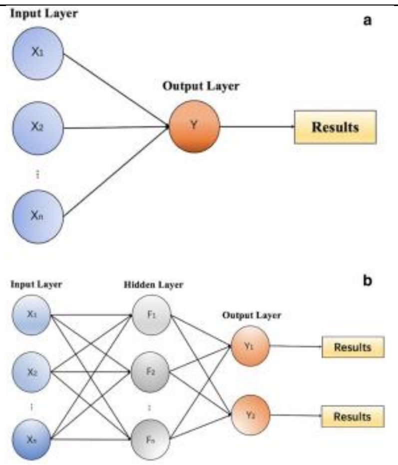
Because a complex permittivity difference of 17-35% is detected between healthy and tumorous tissue, this approach also aids in the targeted identification and monitoring of the rate of ablation, which may result in improved therapeutic results. The primary distinction between the open-ended sensing probe and the suggested antenna sensing technology is that the antenna sensing area is much bigger. The energy density emitted by the applicator is highest in the normal direction and decreases monotonically in the radial direction, allowing for improved transversal monitoring and ablation. Therefore, the primary objective of this work is to use a novel interstitial applicator antenna for monitoring and treatment of the tumour in HCC in a simulated environment. The monitoring of the thermal ablation zone will be done by the same antenna (used in ablation) without using any external intervention. Further, by accurate monitoring, the successful ablation of the targeted tissue can be facilitated which can improve clinical outcomes.

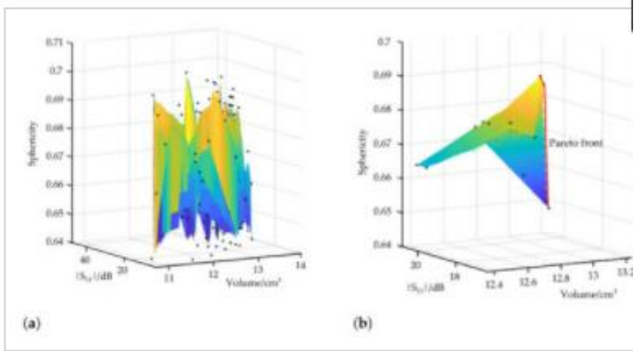
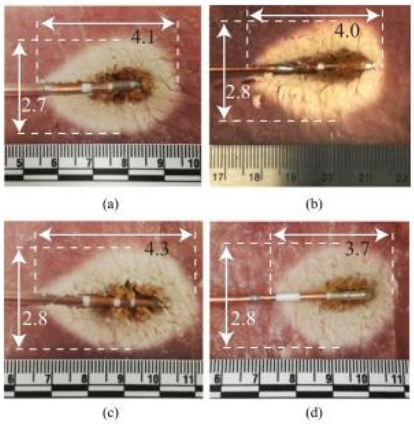
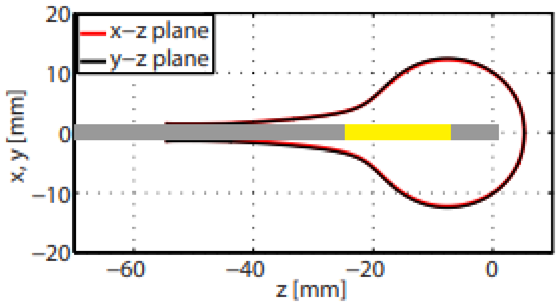
The monitoring will be done by sensing biological tissue complex permittivity using the antenna's return loss parameter and applying ML algorithm to further constitute the relationship between the permittivity and antenna parameter. Since it has been cited in various literature that tissue conductivity and its permittivity change with an increase in temperature, establishing a relationship between biological parameters with antenna parameters may provide better insight into the degree of cell necrosis.

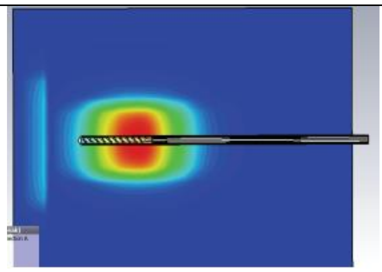
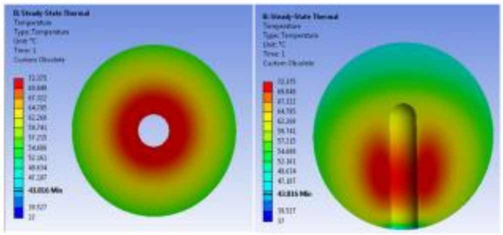
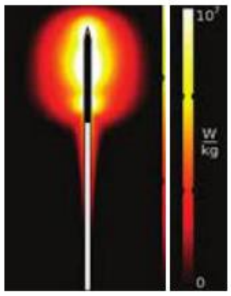
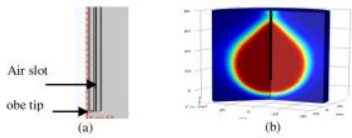
Further development of such a technique may further facilitate real-time monitoring of tumour ablation through a treatment antenna.

Additionally, this kind of antenna applicator may be utilized to identify tissue cancers near the antenna peripheral. Once the approximate location of the tumour is determined using image-guided systems (i.e., thermal imaging), the inserted antenna can accurately detect the tumour location for maximum ablation and also monitor the application time by sensing the tissue dielectric difference (between healthy and ablated tissue), which may help prevent over or under-ablation and limit tumour recurrence.

2.1 WORK DONE IN DIFFERENT COUNTRIES:

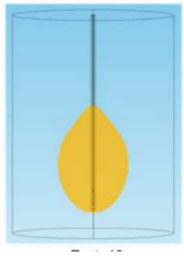
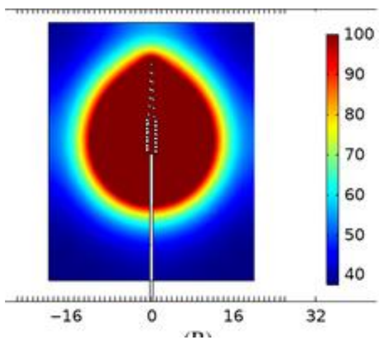
Current updates in machine learnir in the prediction of the therapeutic outcome of hepatocellular carcinoma [2021]	The study suggests th ML models demonstrate improvec predictive performanc in the prognostic stud of HCC. This promising method wi be widely accepted in clinical practice in the future.	

Numerical Optimization of a Open-Ended Coaxial Slot Applicator for the Detection and Microwave Ablation of Tumours 2021	In this study, a multi-objective optimizatio method for a dual-mode microwave applicator is proposec Dual-modality means that microwaves are used apart from the treatment, and also fo the monitoring of the microwave ablation intervention	
Reduced-Diamete Designs of Coax-Fed Microwave Ablation Antenna Equipped with Baluns 2017	At design frequency c 7 GHz the S_{11} obtaine was -24 dB. Lesion area obtained was 4.1 x 2.7 cm^2.	Obtained higher reflection coefficient with reduc diameter by 15% but at a cost of the elongat ablation zone. 
A Minimally Invasive Coax-Fe Microwave Ablation Antenna with a Tapered Balun 2017	At the designed frequency of 6 GHz tl S_{11} obtained was -20 dB. Lesion area obtained was 4.6 x 3.5 cm^2.	Tapered balun reduced the surface current on t outer conductor resulting in more spherical ablati but SAR obtained was asymmetrical. Also there w 30 dB reduction in SAR as compared to convention design. 
Analysis of Coppe Tube Sleeve Coaxial Spiral Antenna for Interstitial Hepati	At the designed frequency of 2.45 GH the S_{11} obtained was - 37 dB.	A good reflection coefficient was obtained but t pattern obtained was rectangular and low operati frequency causes inhomogenous SAR patterns.

Microwave Ablation 2018	Lesion area obtained was 4.5 x 2 cm^2.	
Realization and Experimental Assessment of Baseball-Bat Microwave Antenna for Low Power Cancer Ablation [2020]	At designed frequency of 2.45 GHz the S_{11} was -20 dB. Lesion diameter obtained was 3-4 cm.	The obtained ablation pattern is very small as ve little input power is used and hence minimal ablati and slower heating are reached. Also, faster blo perfusion may lead to delayed ablation. 
About the Interstitial Microwave Cance Ablation: Principles, Advantages and Challenges [2020]	In this paper the autho reviewed several articles and concluded that elongated ablatio zone and slower heating is the main concern in MWA	The elongated ablation zone is observed which m further lead to axial heating of the antenna applicat and ablation of non-targeted healthy tissue 
Optimal Localization of a Novel Shifted 1T-Ring Based Microwave Ablation Probe in Hepatocellular Carcinoma [15] [2021]	In this paper, the design/model of a novel microwave ablation probe, namel a single slot with a shifted 1T-ring probe presented for HCC therapy	The ablation zone is reached with 80 W of pow which may pose threat to the power handling capaci of the applicator and also high-cost microwave pow source is required 

2.2 WORK DONE IN INDIA

Sensitivity analysi of critical parameters affecting the	In this paper, the present study aims at analysing the influence of six critical parameters, as follows,	The study aimed to analyze the different paramete that may affect ablation outcome However, tl article lacks a novel antenna design.

efficacy of microwave ablatio using Taguchi method [16] [2019]	relative permittivity, electrical conductivity, volumetric heat capacity, thermal conductivity, blood perfusion rate, and applied power on the ablation volume attained during MWA.	
Design of a novel externally-tapped intertwining helica antenna for microwave ablatio and its statistical analysis on tissue model [17] [2021]	In this article, a novel normal-mode helical anten based MWA probe is investigated for the effect o ablation diameter in the presence of five critical parameters	

III. METHODOLOGY

3.1 ANTENNA DESIGN

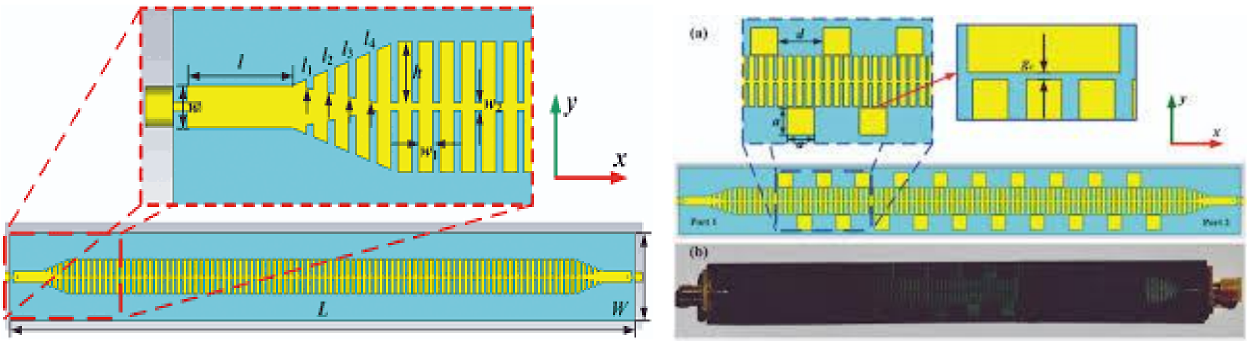
A conventional microwave ablation antenna consists of a thin long needle shape structure with single/multiple slots at the distal tip of the antenna structure to deliver electromagnetic waves to the targeted tissue. However, such structures suffer backward heating resulting in elongated ablation. This issue is addressed using the baluns at the surface of the antenna or using the π-matching network to match the antenna with the coaxial cable. The π-matching network improves the overall reflection coefficient but has structural complexity, and the overall bandwidth of the antenna is also compromised. Further, baluns increase the applicator's overall diameter, resulting in a more invasive structure.

Surface plasmon polaritons (SPPs) exist at a metal/dielectric interface due to the interaction between the plasma of electrons near the surface of the metal and the electromagnetic (EM) waves. At frequencies below the optical regime, SPPs are not supported on bare surface of metals which behave close to perfectly electric conductors (PECs) rather than plasmas. Metallic surfaces with sub-wavelength decorations have been developed to support the propagation of spoof (or ‘designer’) SPPs at microwave and THz frequencies. The spoof SPPs (SSPPs) possess natural

SPP-like dispersion properties and strong confinement of EM fields, and therefore is a special kind of slow waves with a propagation constant (k_{spp}) larger than that in free space (k_0). Meta surfaces have been developed to support the propagation of SSPP waves in a various of circumstances. In particular, a one-dimensional (1D) meta surface, saying, the metallic strip with designed sub-wavelength corrugations, could be viewed as a new type of transmission line (TL) for SSPP waves. The SSPP TL has flexible dispersion properties, strong sub-wavelength effects and low mutual couplings, and therefore may lead to new-concept compact circuits with exciting functionalities.

Because of momentum mismatch, the SPP mode cannot be directly transformed from the spatial mode. In view of this, converting sections have been created to feed SSPP TLs with different configurations. In these works, spatial waveguide modes are transformed to SPP modes with high efficiency. On the other hand, antennas are as important as TLs for wireless communications. Therefore, another question may arise that, is it possible to transform the propagating SSPPs to radiations and consequently realize antennas with demanded directivities. In view of this, efforts have been taken and a series of SSPP antennas have been reported, most of which can be categorized into two main kinds: the one based on periodic modulation and the other one based on EM coupling.

Further, since these antennas have end fire radiation patterns and are made in axial direction (needle-like shape) therefore, they can be used to detect and destroy tumours. The typical structure of the SSPP antenna is shown in the figure below



3.2 RATIONAL FUNCTION MODEL

This modelling was first introduced to solve the complex permittivity by calculating the aperture admittance at the contact point of biological tissue and the probe.

The positive real aperture admittance is given by: -

$$Y(s,\varepsilon) = \frac{\sum_{n=1}^{N}\sum_{p=1}^{P}\alpha_{np}\zeta^{p}(sa)^{n}}{1+\sum_{m=1}^{M}\sum_{q=1}^{Q}\beta_{mp}\zeta^{q}(sa)^{m}}$$

(1)

The coefficients α and β can be obtained from the nonlinear least-square fit model. However, since the probe is not inserted into the biological tissue the terminal admittance is based on the fringing field from the open-ended probe, Therefore, for the internal organ or in-vivo permittivity detection, such methodology in its current form fails to measure permittivity accurately. At this point, a better regressive model is required. Therefore, the authors propose a different comparative machine-learning algorithm to accurately predict the α and β and also further improve the equation (1) thereby making it more suitable for HCC tumour tissue permittivity measurement.

3.3 COMPUTATIONAL METHODOLOGY

The coefficient obtained in improved equation (1) using the novel antenna need to be evaluated at 5 GHz frequency and for measurement purpose two software namely, HFSS and COMSOL MULTIPHYSICS are required to accurately mimic the actual clinical environment. Further for ML analysis commercial software such as MATLAB and ANACONDA (or google collab) is required.

Software Requirement	1. HFSS 2. COMSOL MULTIPHYSICS 3. MATLAB 4. ANACONDA (or GOOGLE COLLAI

3.4 SUPERVISED MACHINE LEARNING SET-UP

The major objective of the system-based Supervised Machine Learning method is to generate an inductive hypothesis in which the function may learn from the outcomes supplied during the input phase and anticipate the desired results for all unprovided cases.

The goal of this study is to develop an effective machine learning model capable of forecasting output values from input parameters and correlating antenna parameters with tissue complex permittivity. Due to the lack of a direct relationship between the complex relative permittivity (tissue parameter) and the antenna reflection coefficient (antenna parameter), we will use machine learning to accurately predict the output parameter (permittivity) by defining an input parameter (antenna admittance) derived from known permittivities.

Once the terminal admittance is determined, we can accurately predict the permittivity of the tissue complex. Because the permittivity of biological healthy tissue and tumour tissue is different, the probe can detect and monitor the tumour location, allowing stage 2 (i.e., ablation of targeted tissue) to be accomplished efficiently using the novel antenna applicator. For this procedure, we will consider a task, where the training set T consists of a set of known primitivities (ε_r) and terminal admittance (Υ) obtained using the novel antenna probe. The dataset will be further partitioned into k subsets. The single sub-set will be used for validation whereas, the remaining k-1 will be used for training data. The analysis process training the datasets will be done through an improved Levenberg Marquardt algorithm.

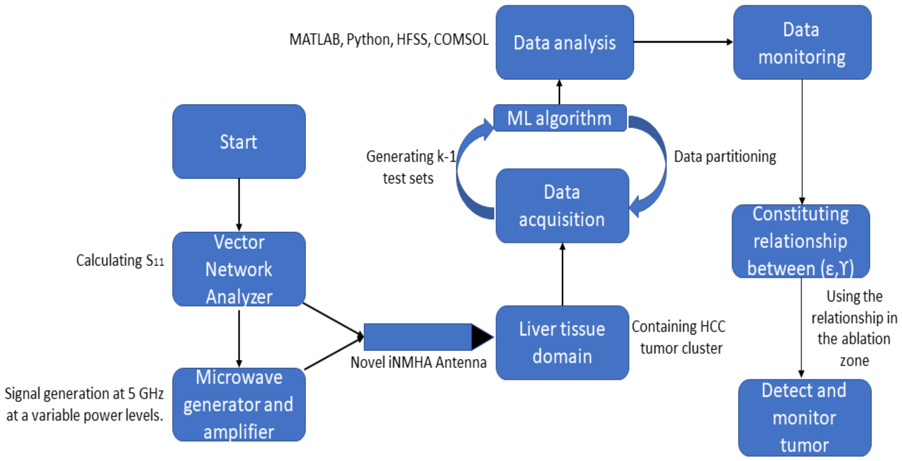
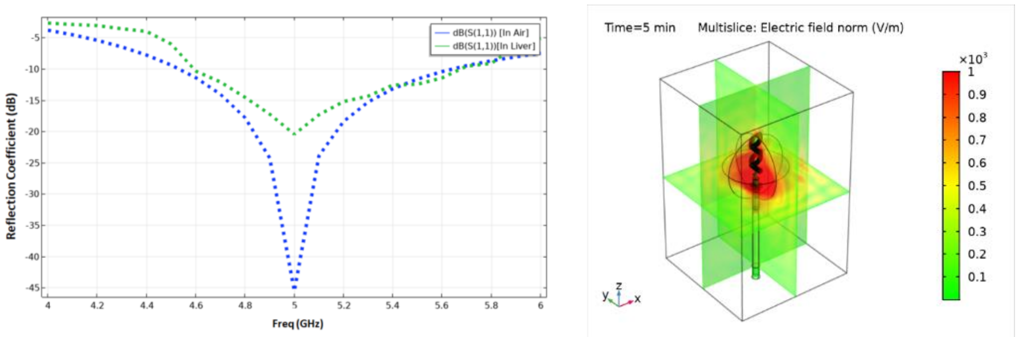


Figure 2 Proposed work block diagram

IV. RESULT AND CONCLUSION

RESULT

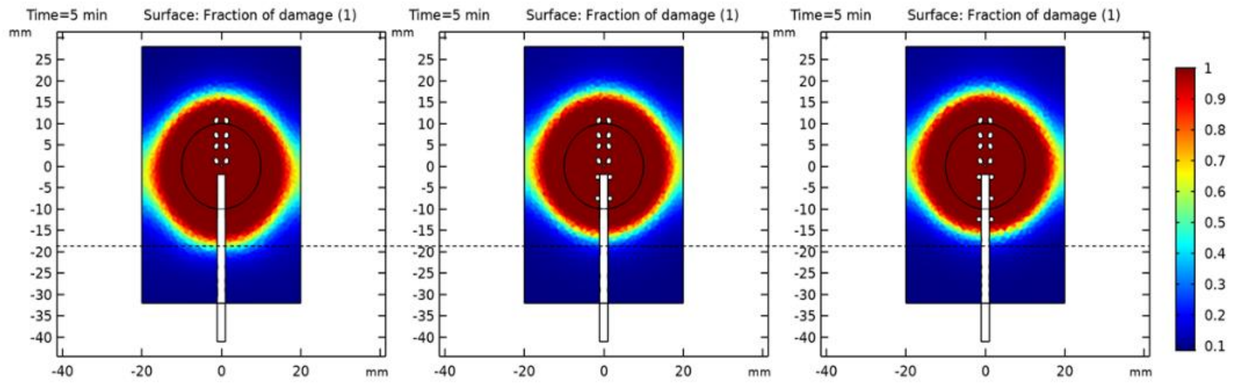
In contrast to the above-mentioned designed constraints, the investigators have successfully designed two novel antennas for microwave ablation which can be further incorporated in the monitoring of the ablation zone and detection of tumours in the targeted zone. However, an ex-vivo trial on bovine liver needs further external funding.



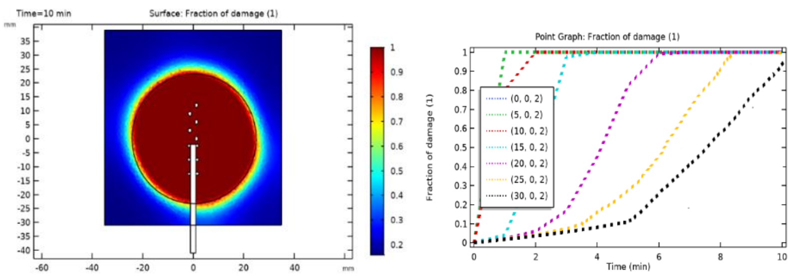
(a) (b)

Fig. 3(a) Reflection coefficient in air and liver domain (b) Field distribution in tumour domain

The designed antenna provided promising reflection properties as shown in Fig. 2(a),(b) in a simulated environment and hence can be further used to define terminal admittance and tissue permittivity. As shown in Fig. 3(a) the proposed antenna achieved spherical ablation which solves the problem of elongated patterns along the axial direction. Further Fig. 3 (b),(c) shows faster and more successful ablation in 10 min. time for tumour size of 4 c.m. as compared to recently published articles. Further discussion remains classified as the work is still in the advanced stage of peer review.



(a)



(b) (c)

Fig 4 (a) spherical ablation zone achieved (b) maximum ablation in 10 min. time and (c) rate of ablation **taken from our under-review article**

CONCLUSION

Thermal ablation refers to the destruction of maligned tissue by elevating tissue temperature. The elevation in tissue temperature can be achieved by using radiofrequency ablation of microwave ablation. Both these methods use image-guided applicators that are inserted into the tissue through the skin. Since RFA (radiofrequency ablation) lacks control over the ablation zone and has a slower heating problem, MWA (microwave ablation) comes up with better treatment modalities. The heat generated by electromagnetic waves at microwave frequency destroys the targeted tissue. This technique is an effective treatment option for patient who has difficulty in surgical resection for small tumour diameters. The proposed work aims to predict the best treatment location and also monitor tumour location by exploiting machine learning algorithms. The in-built monitoring mechanism for tumours located inside the liver not only reduces the burden on other image-guided mechanisms such as CTs or MRIs but also guides the ablation applicator to accurately target the tumorous cell without inflicting damage on healthy tissue thereby improving the clinical outcomes.

V. INNOVATION IN THE PROJECT

Conventional microwave ablation antennas face challenges of backward heating, which can result in elongated ablation zones. Solutions such as baluns and π-matching networks are used. The end fire radiation pattern and axial design of needle-like microwave ablation antennas make them suitable for tumour detection and destruction. Further advancements are needed to overcome these limitations and enhance microwave ablation techniques. Noval Antenna based on SSPP (spoof surface plasmon polariton) will be designed and a Novel model will be incorporated for the Permittivity detection.

VI. FUTURE SCOPE

Once the successful ex-vivo trail is completed with accurate ML implementation (with P-value <0.05), the investigators may further proceed with ex-vivo/in-vivo trial on animal subject and correlation between ex-vivo and in-vivo will be established. Lastly, with all the supporting research, the investigators will present their study in front of ethical board. The investigator will further plan to patent the design and the concept.