

# “Assessment of Safety and Usability of Microwave Ablation Systems in Tumor Treatment: Insights from Real-World Clinical Experience”

Minocha Dr. Pramodkumar, Kothwala Dr. Deveshkumar, Shah Khusboo,  
\*Modi Darshita, Durani Ovesh, Bankeli Aakil,

Meril Medical Innovations Pvt. Ltd, Bilakhia House, Survey No.879, Muktanand Marg, Chala, Vapi, Dist-  
Valsad, 396191, India

---

## Abstract

**Background:** Microwave ablation (MWA) has become a minimally invasive treatment option for the management of solid tumors in patients unsuitable for surgical resection. MWA is superior in energy delivery, with larger and more consistent ablation zones and less sensitivity to the heat-sink effect, particularly in the vicinity of vascular structures. The success of the technology lies mainly on the compatibility and performance of the microwave generator and electrode system.

**Objective:** To assess the clinical performance, safety, and usability of a microwave generator and electrode system in real world tumor ablation.

**Methodology:** Five patients with liver or uterine tumors underwent the ultrasound guided MWA. Parameters evaluated included ease of insertion, handling, durability, generator electrode compatibility, safety, and overall satisfaction. Follow up imaging occurred at 1st, 3rd, and 6th month for post operative procedures.

**Results:** All of the procedures were completed without any intra-operative complications. Across all case studies, tumor size reduction was consistently observed. Generator-electrode compatibility and safety were rated as excellent, while ease of insertion, handling, and durability received overall positive feedback ranging from good to excellent.

**Conclusion:** The evaluated microwave ablation system demonstrated high safety, ease of use, and clinical efficacy for tumor ablation, supporting its role as a minimally invasive treatment option for non-surgical candidates.

## Keywords

Microwave ablation (MWA) System, Lateral Double Diffused Metal Oxide Semiconductor (LDMOS), Computed Tomography (CT), Magnetic Resonance Imaging (MRI).

---

Date of Submission: 08-06-2026

Date of Acceptance: 19-06-2026

---

## I. Introduction

Tumor growths are a very varied and non-uniform tissue class that results from the excessive multiplication of cells [1]. Tumors can be classified into two broad categories - benign and malignant [2]. Benign tumors, in general, grow slowly and invade the tissues nearby to a limited extent, while malignant ones, or cancers, exhibit the capacity of the former plus even more drastic actions such as spreading (metastasis) to remote places and evading (assaulting) the normal regulatory mechanisms that control cell proliferation and death. The global cancer incidence keeps going up, thus posing the already heavy healthcare burden to get even heavier.

Traditional treatment options, such as surgery, chemotherapy, radiotherapy, and not the least, targeted or immune-therapies which are becoming more and more common, are still the mainstay of cancer management. Surgery is still the gold-standard curative treatment for localized tumors, with complete tumor resection and low recurrence when feasible being the results obtained. Radiation therapy effectively treats localized malignancies and some advanced-stage cancers by inducing DNA damage, whereas chemotherapy targets systemic disease but carries the risk of off-target toxicity [3].

New ways of treatment like tyrosine kinase inhibitors, monoclonal antibodies, and checkpoint inhibitors have given more and more options of therapy to the previously untreated patients by specifically removing the ‘cancer’ pathways and the immune system [4]. But, still a lot of patients have to be given non-surgical treatment due to their health conditions, advanced age, or the location of the tumor, thus the demand for safe, less invasive treatments persists. An objective of a study is to scrutinize the microwave ablation (MWA) method as a less

invasive treatment for solid tumors. The major aims of the study are the evaluation of the safety, effectiveness, and reliability of the MWA method in actual patient situations followed by the assessment of its use in comorbid patients as well as in patients older than 70 years.

### **Microwave Generator**

A solid-state microwave generator is the focal point of the system, utilizing high-performance lateral double diffused metal oxide semiconductor (LDMOS) technology in order to provide regulated electromagnetic energy at a reliable operating frequency of 2450 MHz ( $\pm 5$  MHz). The frequency range falls into the ISM band, commonly utilized for medical ablation [5]. The generator has a continuously adjustable output power range of 0.5W to 150W so that the clinician can optimize treatment parameters based on lesion size and tissue type [6]. The smallest adjustable increment is 0.1W so that energy delivery can be finely controlled. A characteristic of this system is the integrated peristaltic cooling pump, which is used to control the temperature inside the microwave electrodes during therapy. This provides thermal protection for adjacent tissues and minimizes the probability of electrode charring or carbonization. The system also features real-time safety monitoring, with automatic shutdown in case of temperature overshooting above 45°C, providing an important additional layer of patient safety [7].

The generator interface has a touch screen with user-friendly navigation, preloaded prescription protocols, and intelligent self-test functions to guarantee functionality prior to each procedure. Clinicians are able to use the device either in continuous or pulsed wave output modes, according to clinical needs. Moreover, the programmable timer enables ablation times from 0.1 to 15 minutes with automatic shut-down once the set time has expired.

### **Microwave Electrode and Needle**

The disposable microwave ablation electrode is a sophisticated medical device designed for single-patient use in combination with the generator unit [8]. Its architectural elements include a radiating antenna tip, ergonomic handle with a temperature sensor integrated into it, coaxial transmission cable, and dual cooling tubes for closed-loop saline-based cooling. The temperature measurement cable is directly plugged into the generator, enabling continuous thermal feedback during energy delivery. One of the most notable aspects is its smart antenna recognition feature, which adjusts generator settings automatically for optimal ablation when the electrode is attached. The electrode is designed for effective energy transfer with a low standing wave ratio (SWR) to prevent power loss and provide consistent heating [9]. It provides advanced cooling technology to reduce the occurrence of Eschar (carbonized tissue), and the high-temperature-resistant antenna sheath increases strength and safety with long-term use.

To accommodate a variety of clinical scenarios, electrodes are available in multiple lengths and sizes, providing versatility for treating tumors in different organ systems and anatomical locations [10].

MWA or microwave ablation method works by sending high-frequency electromagnetic waves (the range of 900 MHz to 2.45 GHz) straight into the tumor via thin tube-like needles made for that purpose [11]. The way the energy transmits creates rapid oscillations of water molecules in the tissue resulting in the production of heat through the friction that raises the temperature of the local area high enough for coagulative necrosis and irreversible death of the tumor cells to take place. MWA, in comparison with RF, is a thermal ablation technique that has several advantages such as heating the tissue up faster, having larger and more uniform ablation areas and also not being as much affected by the cooling of blood flow in the surrounding area [12]. Thus, MWA is a method of choice for the management of tumors that are close to blood vessels or located in areas that have difficult anatomy since it is important to be precise and able to predict the outcome of the ablation. Besides, the MWA procedure being minimally invasive also results in shorter time spent in the operation, quicker recovery, and less risk of complications when compared with surgery [13].

The MWA method has been significantly expanded to its full potential due to the incorporation of new technologies [14]. The latest systems are equipped with antennas that are internally cooled, variable active tip lengths, and sophisticated energy distribution patterns for the development of ablation zones of different sizes and locations. The use of ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI) in real-time imaging makes it easy to position the probe accurately, to supervise continually the zones of ablation, and to detect early the complications of the procedure. MWA has been shown in clinical trials to be effective in treating primary and metastatic tumors of the liver, lung, kidney, bone, and soft tissues, for example in the hepatocellular carcinoma and, liver metastas [15].

Microwave ablation has brought about a new era in interventional oncology, as it integrates perfectly in terms of precision, efficiency, and adaptability to provide minimally invasive tumor control in a wide range of anatomical sites. MWA has already established its position as a game-changer turning some patient's situations around and also complementing existing oncological treatments. By evaluating MWA's clinical performance,

not only will the validation of its utility take place but also the refinement of the procedural protocols and the widening of its application in the management of solid tumors.

## **II. Literature**

Microwave technology underwent a series of transformations starting from the earlier radiofrequency and vacuum tube studies performed throughout the 20th century [16]. The invention of both magnetron and cavity magnetron opened the doors for high power microwave generation. At first radar and communications were the main fields of application for microwaves but later on post-war applications spread into industrial heating and eventually medical therapy which was made possible by advancements in solid-state devices that provided reliability, compactness, and precise control of energy.

Microwave energy in medicine has been an option for the tumor ablation that is considered minimally invasive, so it has the power over radiofrequency ablation limitations like dependency on tissue conductivity and being affected by the heat-sink [17]. During experiments and clinical tests, it was found and also proved that microwave ablation (MWA) can cause the tissue necrosis that is faster, deeper, and more uniform; therefore, tumors in the liver, lung, kidney, thyroid, bone, and prostate can be treated. The advancements in the design of the antennas, cooling systems, and real-time monitoring ensured that the procedures are safe and precise for the treatment [18].

MWA has transitioned from oncology to other fields such as dermatology, gynecology, and pain management, frequently joined with imaging guidance and advanced navigation technologies [19]. Current systems are based on solid-state generators equipped with digital interfaces and very accurate frequency control, which makes it possible to perform extremely controlled and targeted therapies. The development of microwave ablation has shown its flexibility, efficiency, and gradually increasing acceptance as a minimally invasive procedure in various medical specialties [20].

## **III. Materials and Method**

The microwave ablation system is used in the cutting-edge technology, which is used for the minimally invasive treatment of solid tumors, and mainly in organs like the liver, thyroid, lungs, and uterus (fibroids) [21]. It comprises two primary elements: the microwave generator with built-in cooling system and the single-use microwave ablation electrode. Both of these work together as an accuracy ablation platform that provides high-efficiency energy delivery and increased procedural safety.

### **Clinical Procedure**

Microwave ablation (MWA) system is designed to deliver efficient and safe tumor ablation through a streamlined, user oriented workflow [22]. The procedure begins by coupling the coaxial interface of the electrode to the microwave output port of the generator, followed by connection of the temperature monitoring and cooling tube interfaces. The saline tubing is aligned correctly within the peristaltic pump to ensure optimal fluid circulation.

Prior to the initiation, the electrode tip is wrapped with water- saturated gauze, and the “One Key Electrode Test” function may be employed to verify system integrity and functionality. Under real time imaging guidance such as ultrasound (B-scan), computed tomography (CT), or fluoroscopy the electrode is percutaneously inserted into the target lesion [23]. The operator then selects a pre- programmed ablation protocol via the generator interface, activates the peristaltic pump, and initiates microwave energy delivery. Upon completion of energy transmission, the system’s “ Electrode Withdrawal” mode facilitates safe and controlled removal of the problem from the lesions site, after which the generator is powered down to conclude the procedure.

The MWA system integrates the precise energy control, advanced thermal safety mechanisms, and ergonomic design, making it a state of the art platform for interventional oncology [24]. Its intelligent feedback system, efficient cooling mechanisms, and versatile electrode configuration enable accurate and reproducible ablation while minimizing the risk of collateral thermal injury. Through compatibility with real time imaging modalities and customizable treatment protocols, the system supports clinicians in achieving high procedural confidence, consistency, and favorable clinical outcomes.

### **Clinical Evaluation**

The clinical evaluation procedure was conducted on the five patients ranging from 28 to 66 years, who were went under the microwave ablation for treatment of the fibroid or liver tumors at the different clinical centers. The cases included contain both male and female patients with lesions size varying. The information regarding the patients and case study were given below;

**Table 1. Demographic and Clinical Parameters of Tumor Ablation Cases**

Case No.	Location	Age (Years)	Gender	Disease	Power Utilized
Case-1	Indore	33	Female	Uterine Fibroid, 45mm	60 Watts, 05 mins
Case-2	Bhopal	56	Female	Liver Tumor, 20mm	70 Watts, 05 mins
Case-3	Dehradun	64	Male	Liver Tumor, 30mm	60 Watts, 6.5 mins
Case-4	Bhopal	28	Female	Liver Tumor, 25mm	70 Watts, 06 mins
Case-5	Indore	66	Male	Liver Tumor, 35mm	70 Watts, 05 mins

**Case-1**

A 33-year-old woman from Indore, Madhya Pradesh who was diagnosed Uterine Fibroid of diameter 45 mm. The physician recommended patient for microwave ablation therapy as a less invasive treatment approach. Microwave Ablation procedure was successfully carried out using an ultrasound-guidance of 16G disposable microwave electrodes with 11 mm active tip and a shaft length of 15 cm. The Microwave Generator was programmed to supply 60 watts of power for a total ablation time of 05 minutes. The operation procedure conducted without any technical complications or intra-operative errors.

The patient was monitored closely after the procedure with follow-ups at 1st, 3rd, and 6th months. Images at those periods of follow-ups showed progressive decreases in fibroid size, validating the success of the ablation. There was no evidence of damage to the surrounding uterine or pelvic structures, demonstrating a localized and precise delivery of energy.



**Figure: 1 Ultrasound Image of Uterine Fibroid before Ablation**



**Figure: 2 Ultrasound Image of Uterine Fibroid after Ablation**

**Case-2**

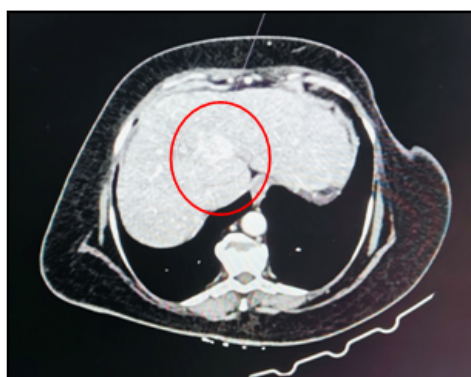
A 56-year-old lady patient from Bhopal, Madhya Pradesh, with tobacco chewing and smoking habit was diagnosed with 02 cm diameter liver tumor. As the lesion was of large size and location, the attending physician recommended microwave ablation therapy instead of surgical resection as a less invasive approach. The procedure was performed under CT-scan guidance to avoid misplacement of the ablation probe.

A 16G, one-time use microwave electrode of an 11 mm active tip and shaft length 15 cm was utilized in the procedure. Microwave Generator was adjusted to offer 70 watts of power for 05 minutes. The ablation procedure was completed successfully with no technical issues or intra-operative complication, and the energy delivery was even and controlled in the entire procedure.

Follow-up post-procedure follow ups were taken at 1st, 3rd, and 6th months, during which imaging studies showed a persistent reduction in the size of the tumor, which showed an adequate response to the ablation. No indication of trauma to the adjacent liver or surrounding structures was observed, proving the accurate nature of the procedure.



**Figure: 3 CT-scan image of Liver Tumor before Ablation**



**Figure: 4 CT-scan image of Liver Tumor after Ablation**

### **Case-3**

Patient from Dehradun, Uttarakhand, who was a 64-year-old male and had a history of tobacco chewing, came to the hospital with a hepatic tumor measuring about 30 mm. Based on the general clinical condition along with the nature of the tumor, the attending physician suggested microwave ablation therapy as a least invasive and organ-sparing modality.

The intervention was performed under ultrasound guidance, enabling precise placement of the probe and real-time imaging during the procedure. An 11 mm active tip, 16G single-use microwave electrode with a 15 cm shaft was utilized in the intervention. Energy delivery was performed using the Microwave Generator, which was programmed to deliver 60 watts of energy for an ablation for at least 6.5 minutes.

The ablation was conducted without intra-operative complication. There were no technical issues, and the operation process was conducted efficiently throughout the procedure. Post-procedure follow-up examinations were performed at 1st, 3rd, and 6th months. Imaging during these clinic visits showed progressive and uniform reduction of tumor size, which established success with the ablation. No signs of thermal injury to contiguous hepatic or extra hepatic structures could be seen, testifying to the precision and accuracy of the targeted deposition of energy.

The case study shows the clinical effectiveness and therapeutic benefit of microwave ablation in the management of liver tumors. It identifies the capacity of cutting-edge ablation technology to provide an effective, safe, and minimally invasive treatment choice for hepatic tumor patients providing accuracy together with beneficial clinical results.



**Figure: 5 Ultrasound Image of Liver Tumor Pre Ablation**



**Figure: 6 Ultrasound Image of Liver Tumor Post Ablation**

**Case-4**

A 28-year-old female patient from Bhopal, Madhya Pradesh, was diagnosed with a 2.5 cm (20 × 25 mm) tumor in her liver. Due to the size of the tumor and its anatomical position, the attending physician recommended microwave ablation therapy as a minimally invasive measure to prevent surgery. The treatment was conducted under CT-scan guidance for achieve proper deployment of the probe and real-time monitoring system.

A single-use 16G electrode with an 11 mm active tip and 15 cm shaft was implemented for the ablation procedure. A Microwave Generator was programmed to employ the 70 watts of power for 6 minutes. The ablation procedure was conducted efficiently without any procedural complication or difficulty in energy delivery during the process.

The patient underwent follow-up imaging at 1st, 3rd, and 6th months. Imaging during these clinic visits showed progressive and uniform reduction of tumor size, which established success with the ablation. No signs of thermal injury to contiguous hepatic or extra hepatic structures could be seen, testifying to the precision and accuracy of the targeted deposition of energy.



**Figure: 7 CT-scan image of Liver Tumor before Ablation**



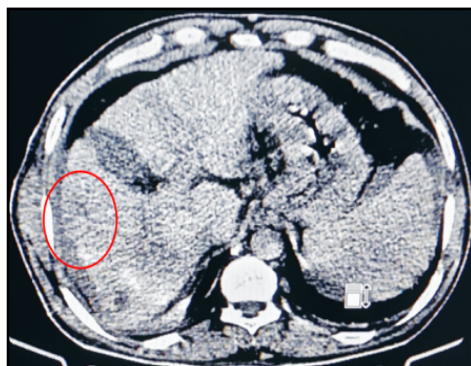
**Figure: 8 CT-scan image of Liver Tumor after Ablation**

**Case-5**

A 66-year-old Male patient from Indore, Madhya Pradesh, was diagnosed to have a liver tumor of 3.5 cm (32× 30 mm). Based on the size of the tumor and the anatomical site, the treating doctor suggested microwave ablation therapy over surgery. The procedure was performed under CT-scan guidance for ideal probe utilization and real-time monitoring.

A 16G disposable microwave electrode with an active tip of 11 mm and shaft length of 15 cm was used for the ablation. The Microwave Generator was set to a total treatment time of 5 minutes with a total of 70 watts of energy. The ablation was done without any complication; in fact, it was accomplished effectively with no procedural complication and ease in delivering the energy during the procedure.

The patient also received follow-up imaging at 1st, 3rd, and 6th months that, in each of the instances, showed normal reduction in tumor size proving the effectiveness of the ablation therapy. In terms of importance, no damage to the liver parenchyma or adjacent structure was observed, which proved the accuracy and safety of the procedure.



**Figure: 9 CT-scan Image of Liver Tumor before Ablation**



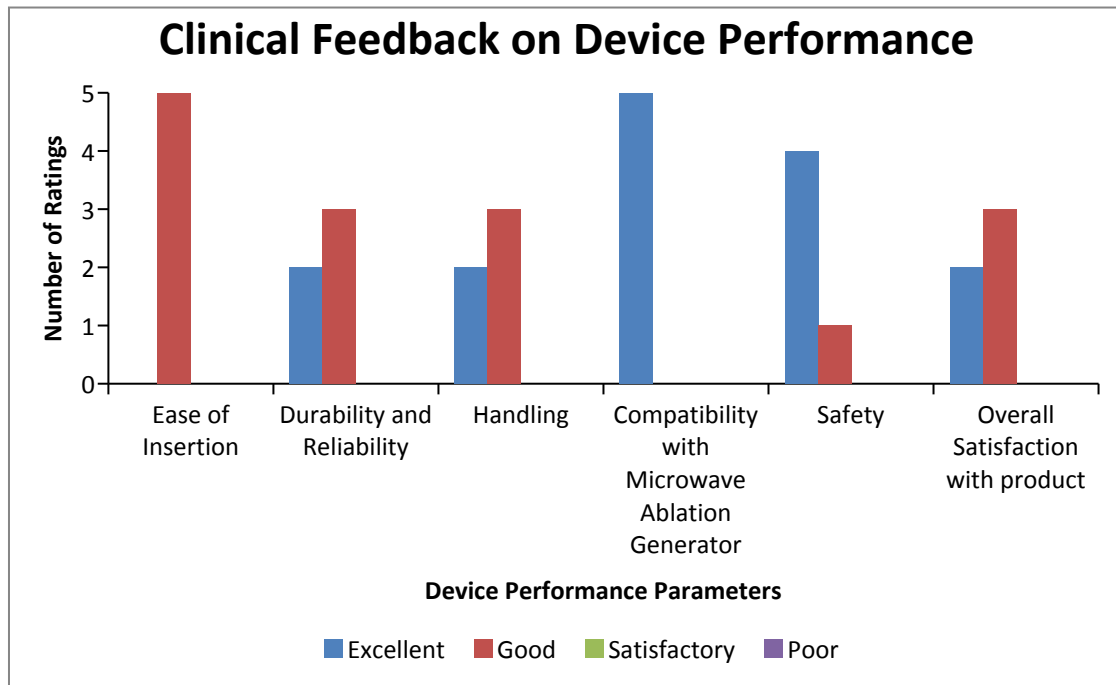
**Figure: 10 CT-scan Image of Liver Tumor after Ablation**

Across all five clinical cases, the referring physicians reported consistently favorable experiences with the Microwave Ablation (MWA) System. The device was commended for its ease of handling, precise

temperature regulation, and seamless integration between the electrode and the microwave generator. Throughout each procedure, the electrode demonstrated stable performance, and the system’s controlled power delivery enabled efficient and predictable ablation outcomes. These consistent findings highlight the clinical efficacy, reliability, and user-friendly design of the MWA technology across diverse anatomical and pathological conditions—including uterine fibroids and small hepatic tumors. Overall, the results reinforce the potential of microwave ablation as a safe, effective, and minimally invasive alternative to conventional surgical interventions, particularly in patients where organ preservation and rapid recovery are prioritized.

### Biostatistical Data

The biostatistical analysis of these case studies, encompassing device performance metrics and physician feedback, is presented in the accompanying graph.



Based on five clinical cases and physician feedback, the microwave ablation electrode system had an acceptable profile for six parameters of interest. Clinicians found ease of insertion to be "Good" in every case study mentioned, which represent that the device can easily be deployed in general. Reliability and strength were "Excellent" according to two case study results, while three case studies shows the satisfactory results. This reflects satisfactory results gave the reliability while highlighting areas for potential improvement.

From the five case studies two case studies results indicates “excellent” results and three case study results indicates the “Good” results. Microwave generator demonstrated the excellent results for its generator compatibility in all case studies with the best device generator fit. The device demonstrated a high level of safety, reflecting confidence in controlled energy transfer and minimal risk to surrounding tissue. Overall satisfaction among clinicians was positive, indicating broad clinical acceptability. No parameter was rated as “Satisfactory” or “Poor,” highlighting a consistently strong baseline performance. Generator-electrode compatibility was universally rated as excellent, and safety was consistently rated positively, confirming the system’s clinical dependability. Ratings for ease of insertion and handling were also favorable, though they suggest opportunities for further optimization to enhance overall user experience.

### IV. Result

The performance of the device was evaluated across six key parameters based on responses from five clinical cases. All parameters were rated positively, reflecting a consistently favorable clinical experience. Ease of insertion was rated as good by all assessors, indicating acceptable usability with minor opportunities for ergonomic improvement. Reliability and durability, as well as handling, were consistently rated as good to excellent, demonstrating stable intra-operative performance and effective user control. The highest uniformity of positive feedback was observed in compatibility with the microwave ablation generator, which was universally rated as excellent, highlighting seamless integration between the device and its corresponding energy platform. Effective and accurate energy delivery was also consistently confirmed across all cases. Overall, global

satisfaction was high, with clinicians reporting positive experiences in all aspects of device performance. These findings collectively demonstrate the clinical safety, efficacy, and usability of the system, while also identifying areas where further optimization of ergonomics and handling may enhance procedural efficiency.

## **V. Discussion**

The clinical evaluation of microwave ablation (MWA) showed a good safety profile, efficacy, and user-friendliness in the control of hepatic tumors and uterine fibroids. The procedures, comprising of five cases, were carried out without any intra-operative complications, and the imaging performed afterwards always displayed a decrease in the size of the tumor in all the cases. This has been pointed out as the case for the use of MWA as the invasive method of solid tumors treatment in the case of patients who cannot be surgically treated.

The current results are in line with earlier research that revealed the superiority of MWA over other thermal ablation methods. The procedure guarantees instant and even heating of the tissue that is not affected by local impedance, thereby creating predictable ablation areas and killing the tumor tissue efficiently. In this study, the physicians who performed the surgery highly appreciated the compatibility of the generator with the electrode and the usability of the procedure, thus emphasizing the consistency of the system and its adaptability to different anatomical sites.

From the safety point of view, MWA showed superior quality, as there was no sign of destruction of nearby tissues. The real-time CT-scan ultrasound-guided placement of the probe and stable thermal delivery worked together for very precise targeting and successful treatment. The short ablation time—less than seven minutes in all cases—also indicates the efficiency of MWA and its usability in outpatient or minimally invasive clinical settings.

Microwave ablation, from a clinical perspective, proves to be a therapeutic option that is safe, effective, and minimally invasive for the management of localized tumors with the possible advantages of shorter procedural time, faster recovery, and less collateral damage. Future studies need to confirm these results among bigger groups of patients, track long-term effects, and consider the use of MWA together with systemic or targeted therapies to make its clinical effectiveness even more potent.

The performance of the device was evaluated across six key parameters based on responses from five clinical cases. All parameters were rated positively, reflecting a consistently favorable clinical experience. Ease of insertion was rated as good by all assessors, indicating acceptable usability with minor opportunities for ergonomic improvement. Reliability and durability, as well as handling, were consistently rated as good to excellent, demonstrating stable intra-operative performance and effective user control. The highest uniformity of positive feedback was observed in compatibility with the microwave ablation generator, which was universally rated as excellent, highlighting seamless integration between the device and its corresponding energy platform. Effective and accurate energy delivery was also consistently confirmed across all cases. Overall, global satisfaction was high, with clinicians reporting positive experiences in all aspects of device performance. These findings collectively demonstrate the clinical safety, efficacy, and usability of the system, while also identifying areas where further optimization of ergonomics and handling may enhance procedural efficiency.

### **Advantages of Microwave Ablation**

Microwave ablation (MWA), generator technology, and specialized electrode design advancements have substantially contributed to the acceptance of MWA as a reliable minimally invasive procedure in the field of oncology and probably other clinical fields. MWA is a process of heating the biological tissues through the radiation of electromagnetic waves, typically within the frequency range of 915 MHz to 2.45 GHz. The rapid and even heating of tissues is one of the main advantages of the MWA method. The process and results of RFA treatments can be different because these are determined by tissue conductivity, and some situations may not allow for the use of radio frequency energy if the tissue is particularly resistant. The application of microwave energy is safer because it is done through the vibration of water molecules which gets the tissues heated frictionally without considering the local resistance. Hence, shorter ablation times and the possibility of treating large or multiple lesions effectively are the direct outcomes of this method.

MWA further facilitates the generation of extensive, symmetric re-epithelial zones. The electrodes fitted with internal cooling systems provide the depth of energy penetration without the burning away of the outer tissues, thus making the treatment even in larger tumors uniformly effective. This method is not greatly affected by the heat-sink effect; therefore, it is quite efficient for cancers that are very close to the blood vessels. Its capability has voted for its widespread acceptance in various non-oncological and surgical fields that include dermatology for skin tightening and sweating, gynecology for non-hormonal endometrial ablation, and pain management for nerve ablation. A large number of MWA procedures are easily done under local anesthesia in outpatient settings, providing quicker healing process and lower risk of complications than conventional surgical methods.

### **Disadvantages and Limitations of Microwave Ablation**

Even though MWA has several advantages, there are also important drawbacks. Among them, the cost is the most influential one, as sophisticated systems having internal cooling or real-time monitoring usually cost more than other thermal ablation methods. Also, intricate electrode configurations not only elevate the manufacturing cost but also need to be handled with extreme care to avoid breakage. Furthermore, another downside is the risk of accidental tissue death. High-power supply and good penetration can result in unintended damage if the position of the probes is not correct or if the time for ablation is longer than necessary. While some systems do give one temperature or impedance feedback, the real-time showing of the ablation zone is still not as good as in the other methods, thus making operator skill and accurate imaging guidance crucial for a safe and successful treatment.

From a logistical point of view, the majority of microwave electrodes are designed for one-time use, which consequently raises the costs of the procedure even more. Moreover, MWA is a procedure that demands that the radiologist undergoes a learning curve especially when dealing with anatomically complex lesions or operating sophisticated equipment. The potential of coming technologies like robotic navigation and AI-assisted planning to enhance safety and accuracy is great, but these advancements are not yet available to ordinary medical facilities and are restricted to specialized centers only. In conclusion, while Microwave Ablation (MWA) presents certain limitations compared to conventional thermal ablation methods—such as longer preparation times, less uniform heating, and reduced efficacy in high-impedance tissues or regions adjacent to large vascular structures—it remains a promising therapeutic technology. Although the system is relatively expensive and requires skilled operators due to its technical complexity, these challenges can be effectively addressed through appropriate operator training, careful patient selection, and meticulous procedural planning. Despite its cost, MWA technology warrants further development and clinical adoption as a medical device for the treatment of various diseases, given its potential to provide safe, precise, and minimally invasive therapeutic outcomes.

### **VI. Conclusion**

This clinical performance assessment of the Microwave Ablation system and its electrodes in cancer care demonstrates the technology to be highly safe, efficient in energy delivery, and well-integrated with imaging and power systems. The absence of complications and consistent post-procedure tumor reduction across all five cases confirms its significant therapeutic efficacy. Generator-electrode compatibility and safety were consistently rated positively, underscoring the system’s clinical value in treating tumors in challenging anatomical sites. While incremental improvements in ease of insertion and manipulation could further optimize operator convenience, the device provides a reliable and reproducible alternative to conventional surgery, particularly for patients with unresectable tumors. As the demand for minimally invasive cancer treatments grows, technologies such as microwave ablation are poised to play an increasingly important role. Further multicenter studies are continued with larger cohorts and extended follow-up will help validate these findings and expand the clinical applications of this platform.

### **References**

- [1]. Bianco V, Valentino M, Pirone D, Miccio L, Memmolo P, Brancato V, Coppola L, Smaldone G, D’Aiuto M, Mossetti G, Salvatore M. Classifying breast cancer and fibroadenoma tissue biopsies from paraffined stain-free slides by fractal biomarkers in Fourier Ptychographic Microscopy. *Computational and Structural Biotechnology Journal*. 2024 Dec 1;24:225-36.
- [2]. Patel A. Benign vs malignant tumors. *JAMA oncology*. 2020 Sep 1;6(9):1488-.
- [3]. Viktorsson K, Rieckmann T, Fleischmann M, Diefenhardt M, Hehlhans S, Rödel F. Advances in molecular targeted therapies to increase efficacy of (chemo) radiation therapy. *Strahlentherapie und Onkologie*. 2023 Dec;199(12):1091-109.
- [4]. Daly RJ, Scott AM, Klein O, Ernst M. Enhancing therapeutic anti-cancer responses by combining immune checkpoint and tyrosine kinase inhibition. *Molecular cancer*. 2022 Sep 29;21(1):189.
- [5]. Amini A, Ricotti G, Malcovati P, Bonizzoni E. High-Voltage TX/RX Switches for Efficient Sensor Interfaces Across Various Technologies in Ultrasound Imaging and Beyond: A Review. *IEEE Access*. 2025 Jul 25.
- [6]. Muharb R. *Study and Design of an Electro-Surgical Generator* (Doctoral dissertation, University of Babylon).
- [7]. Shuvo II, Decaens J, Lachapelle D, Dolez PI. Smart textiles testing: A roadmap to standardized test methods for safety and quality-control. In *Textiles for Functional Applications 2021 Mar 19*. IntechOpen.
- [8]. De Vita E, Presti DL, Massaroni C, Iadicicco A, Schena E, Campopiano S. A review on radiofrequency, laser, and microwave ablations and their thermal monitoring through fiber Bragg gratings. *IScience*. 2023 Nov 17;26(11).
- [9]. Xiong H, Ma X, Wang BX, Zhang H. Design and analysis of an electromagnetic energy conversion device. *Sensors and Actuators A: Physical*. 2024 Feb 1;366:114972.
- [10]. Zhu M, Wang H, Li S, Liang X, Zhang M, Dai X, Zhang Y. Flexible electrodes for in vivo and in vitro electrophysiological signal recording. *Advanced Healthcare Materials*. 2021 Sep;10(17):2100646.
- [11]. Simonazzi M, Reggiani U, Sandrolini L. Standing wave pattern and distribution of currents in resonator arrays for wireless power transfer. *Energies*. 2022 Jan 17;15(2):652.
- [12]. Ashour AS, Guo Y, Mohamed WS. *Thermal Ablation Therapy: Theory and Simulation*. Academic press; 2021 May 18.

- [13]. El\_Badawy HB, Saleh MI, Elashry MG, Youssef Saleeb JS. Endovenous Microwave Ablation (MWA) for Varicose Veins: A Promising Minimally Invasive Treatment. *Journal of Current Medical Research and Practice*. 2025 Jan 1;10(1):39-46.
- [14]. Valori M, Rebaioli L, Marrocco V, Modica F, Bonelli F, Pascazio G, Portosi V, Prudenzano F, Fasano A, Lampignano V, Fassi I. Manufacturing challenges and technological solutions for microwave ablation (MWA) probe prototyping. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 2023 Feb;237(3):481-91.
- [15]. Abu Zahra S, Nadeem A, Kundu A, Gibson N, Haggaz A, Sato KT, Lewandowski RJ, Gordon AC. Recent Advances in Ablative Therapies for Hepatocellular Carcinoma. *Cancers*. 2025 Oct 7;17(19):3251.
- [16]. Pozar DM. *Microwave engineering: theory and techniques*. John Wiley & sons; 2021.
- [17]. Ashour AS, Guo Y, Mohamed WS. *Thermal Ablation Therapy: Theory and Simulation*. Academic press; 2021 May 18.
- [18]. Zaltieri M, Massaroni C, Cauti FM, Schena E. Techniques for temperature monitoring of myocardial tissue undergoing radiofrequency ablation treatments: an overview. *Sensors*. 2021 Feb 19;21(4):1453.
- [19]. Floridi C, Cellina M, Irmici G, Bruno A, Rossini N, Borgheresi A, Agostini A, Bruno F, Arrigoni F, Arrichiello A, Candelari R. Precision imaging guidance in the era of precision oncology: an update of imaging tools for interventional procedures. *Journal of Clinical Medicine*. 2022 Jul 12;11(14):4028.
- [20]. Pfannenstiel A, Iannuccilli J, Cornelis FH, Dupuy DE, Beard WL, Prakash P. Shaping the future of microwave tumor ablation: a new direction in precision and control of device performance. *International Journal of Hyperthermia*. 2022 Dec 31;39(1):664-74.
- [21]. Zhao Z, Hu Y, Xu LX, Sun J. Advancements in deep learning for image-guided tumor ablation therapies: a comprehensive review. *Progress in Biomedical Engineering*. 2025 Aug 22.
- [22]. Pfannenstiel A. *Applicators and methods to achieve precise spatial control of the treatment zone during microwave ablation*. Kansas State University; 2020.
- [23]. Zaffino P, Moccia S, De Momi E, Spadea MF. A review on advances in intra-operative imaging for surgery and therapy: imagining the operating room of the future. *Annals of Biomedical Engineering*. 2020 Aug;48(8):2171-91.
- [24]. Huo Y, Yang L, Xu T, Sun D. Design, control, and clinical applications of magnetic actuation systems: Challenges and opportunities. *Advanced Intelligent Systems*. 2025 Mar;7(3):2400403.