La radiologia medica (2024) 129:1916–1925
https://doi.org/10.1007/s11547-024-01927-3

ONCOLOGY IMAGING

Percutaneous microwave ablation of HCC: comparison between 100 and 150 W technology systems

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Received: 11 July 2024 / Accepted: 29 October 2024 / Published online: 8 November 2024

Abstract

Purpose To evaluate the differences in efficacy and safety between the 100 and 150 W percutaneous microwave ablation (MWA) systems in the treatment of hepatocellular carcinoma (HCC).

Methods We retrospectively reviewed all patients who underwent percutaneous MWA (Emprint™ HP Ablation System, Medtronic) between January 2021 and May 2023. We divided the cohort into two groups: Group 1, treated with MWA at 100 W power system, and Group 2, treated with 150 W one. Effectiveness was defined as the absence of residual disease at 1-month CT follow-up; safety was defined as the absence of grade II-VI complications.

Results A total of 135 HCC nodules were treated with MWA in 87 patients with a median age of 66 ± 10 years: 76 procedures in 42 patients were carried out in group 1, while 59 procedures in 45 patients in group 2. Cases treated with 150 W had a shorter ablation time (p: 0.002; mean 227.37 ± 92.5 vs 180.51 ± 75.6 s (100 vs 150 W)) and a larger ablation volume (p 0.008; mean $13{,}920.0 \pm 10{,}723.2$ vs $21{,}241.4 \pm 18{,}374.7$ mm^3 (100 vs 150 W)), and a major effectiveness at 1-month CT follow-up (p: 0.013). A higher rate of complications (grade II and III) was observed in Group 2 ($p < 0.001$).

Conclusions In conclusion, these preliminary results showed a good correlation between intended-to-treat area and ablation volume and intended-to-treat area and ablation time for both Groups. A minor ablation time, and major ablation volume, but also a higher incidence of complications was observed in 150 W Group.

Keywords Microwave ablation · Liver · Percutaneous ablation · Hepatocellular carcinoma (HCC)

Abbreviations

BCLC	Barcelona Clinical Liver Cancer
CA	Cryoablation
CR	Complete response
CBCT	Cone-beam CT
HCC	Hepatocellular carcinoma
EDD	Extrahepatic distant disease
IDD	Intrahepatic distant disease
IRE	Irreversible electroporation
LTP	Local tumor progression
MWA	Microwave ablation
MRI	Magnetic resonance imaging
mRECIST	Modified response criteria in solid tumors
RFA	Radiofrequency ablation
PS	Performance-status
TS	Technical success
US	Ultrasound

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Introduction

Hepatocellular carcinoma (HCC) is the most frequent primary malignant tumor of the liver and the sixth most prevalent malignancy, typically associated with cirrhosis and more common in men than women (ratio 8:1). The global incidence of HCC is rising, with Asia and Africa reporting the highest rates [1, 2].

Surgical resection, orthotopic liver transplantation, thermal ablation, trans-arterial therapies, chemotherapy, and targeted molecular therapies are nowadays considered the standard treatment options for HCC [3].

According to EASL-EORTC guidelines and the Barcelona Clinical Liver Cancer (BCLC) system, the thermal ablation treatments are indicated as first-line curative strategies for both very early-stage HCC—defined as a solitary HCC nodule within 2 cm and without vascular invasion or extrahepatic spread in a patient with preserved liver function and no cancer-related symptoms (PS-0)—(BCLC-0), and early stage HCC—defined as solitary HCC irrespective of size or as a multifocal HCC, no more than 3 nodules (none of them over 3 cm), without macrovascular invasion, extrahepatic spread or cancer-related symptoms (PS-0)—(BCLC-A) [4, 5].

Different types of ablative techniques exist with the same purpose to achieve the necrosis of target tumoral tissue while safely maintaining ablation margins by thermal energy (radiofrequency, RFA; microwave ablation, MWA; laser ablation; cryoablation, CA) or non-thermal energy (irreversible electroporation, IRE; chemical ablation) [6–10].

For the treatment of HCC, the most widely used ablative techniques are RFA and MWA, which are distinct for their different mechanism of energy deposition.

RFA uses electric current generating frequencies of 450–500 kHz to frictionally heat the tissue immediately adjacent to the electrode. Because RFA relies on resistive heating through an electrically conductive route, it is limited in tissues with low electrical conductivity.

MWA uses electromagnetic fields that generate higher frequencies (915 MHz to 2.45 GHz) to directly heat tissue to 150 °C through dielectric hysteresis [7].

Because MWA is predominately based on direct heating rather than the thermal conductance of RFA, it achieves potentially faster and larger ablation zones with the advantage of being less susceptible to the heat-skin effect compared to RFA [11]. Thus, MWA has become one of the most used technique to percutaneously treat many different lesions in different body districts [12–21].

Currently, technological advancements in interventional radiology for the treatment of hepatocellular carcinoma (HCC) are becoming increasingly sophisticated. These advancements include the use of artificial intelligence softwares and high-performance machineries [22–25].

The new MWA system, such as e Emprint™ Ablation System with Thermosphere™ Technology (Covidien, Boulder, CO, USA) designed to create predictable large spherical zones of ablation and makes the ablation area more predictable [24].

Every MWA system consists of a generator, a cable, and an applicator. Power is generated from the generator which can have varying frequencies ranging from 915 MHz to 2.45 GHz. MWA systems operating at 2.45 GHz generally result in greater power deposition with larger ablation volumes in a shorter time than those operating at 915 MHz [25].

Several studies have evaluated the in-vivo and ex-vivo efficacy and safety of 100 W and 140 W systems, but only a few studies have demonstrated the role of the newest 150 W MWA systems [26].

This study aims to evaluate the differences in terms of efficacy and safety between the 100 and 150 W microwave ablation (MWA) systems in the treatment of early-stage HCC.

Methods

Patients

We retrospectively reviewed all patients who underwent percutaneous liver MWA between January 2021 and May 2023. We divided the cohort into two groups: Group 1 included patients treated with 100 W system, and Group 2 patients treated with the 150 W one's.

All subjects gave their consent for inclusion in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of IRCCS Ca' Granda Policlinico di Milano (Project identification code: OSMAMI-23/05/2023-0021942-U).

The indication for treatment was established by a multidisciplinary team during weekly meetings, including surgeons, hepatologists, and interventional radiologists. Patients were hospitalized, at least, from one day before the procedure to one day after.

Inclusion criteria were age ≥ 18 years; very early-stage HCC (BCLC-0) and early-stage HCC (BCLC-A) according to standard guidelines [4, 5]. Exclusion criteria were the presence of refractory ascites; coagulopathies not susceptible to medical correction; patient's refusal to sign informed consent.

For each patient, we evaluated laboratory analyses and calculated the Child–Pugh score.

Procedures details

The ablation system device used consisted of a microwave generator (Emprint™ HP Ablation System, Medtronic) capable of producing up to 150W of power at 2.45 GHz, connected by coaxial cable to a 13-gauge straight microwave antenna with a length of 15 or 20 cm. The antenna was continuously perfused with saline solution to prevent overheating.

The position of patients (supine or prone) and the use of different imaging guidance modalities were decided based on lesion visibility and operator preference.

The generator's output was moved straight up to 100 W or 150 W from the beginning at a continuous wave of 2.45 GHz. To reduce the risk of seeding and the risk of hemorrhages the cauterization of the needle track was made after each ablation (Fig. 1).

At the end of the procedure, all patients were transferred to the radiology recovery room for observation. One hour after the procedure, an abdominal US to check the presence of periprocedural complications was performed.

Lesion characteristics and treatment data

For each group lesion volume (mm^3, calculated with the formula $V = \pi D^2 L/6$, where "V" is the volume, "D" is the largest diameter on the axial plane, and "L" is the diameter orthogonal to "D" on the axial plane), peripheral/central lesion (> or < 3 cm from capsule), the post-treatment ablation volume ($V = \pi D^2 L/6$), the ablation time (s), the power of ablation (W), the length of the antenna used (cm) were evaluated [27].

We also evaluated in each case the imaging modality of guidance (US, CBCT, combination of US and CBCT, fusion imaging).

Follow-up

Standard imaging follow-up at 1-month post-procedure was carried out with multiphase CT (pre-contrast, arterial, portal-venous, and delayed venous phases) or MRI with intravenous administration of a hepatocyte-specific contrast agent, with the acquisition of T2-, diffusion- and T1-weighted sequences, before, during and after the administration of contrast agent, completed by the hepato-biliary phase scans. The choice to use MRI instead CT was made because some patients were allergic to the CT contrast media agent.

Outcome measures

Technical Success was defined as the correct antenna placement within the tumor.

At 1-moth CT/MRI follow-up the following parameters were evaluated: the effectiveness, defined as the absence of residual disease; Intrahepatic Distant Disease (IDD) as the occurrence of HCC within the liver at locations not contacting the ablation zone; Extrahepatic Distant Disease (EDD) as metastases outside the liver. The complications were evaluated according to CIRSE classification and classified according to the timing into perioperative or post-procedural, where post-procedurals are defined as those observed at least 1-month after operation [28]. Retreatment was defined as the need to schedule a second procedure on the same nodule based on the findings of the 1-month CT/MRI follow-up.

Safety was defined as the absence of grade II-VI complications (complications influencing the normal post-therapeutic course).

Statistical analysis

Mean ± standard deviation (SD) was provided for normally distributed variables, median ± interquartile range (IQR) for non-normally distributed variables, and number and percentage for categorical variables. The Shapiro–Wilk test assessed normality.

Outcome measures between Group 1 and Group 2 were sought by contingency tables and Pearson's Chi-square test. Differences between group 1 and group 2 were investigated by contingency tables and Fisher's exact test or

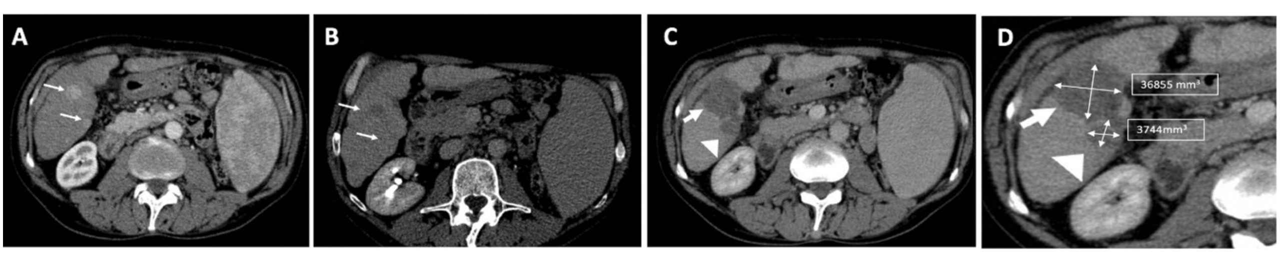

Fig. 1 **A**–**D** CT scan of two HCC nodules in the 6th hepatic segment in the arterial (**A**) and delayed (**B**) phase treated with MWA. Post-treatment CT scan revealed the ablation areas (**C**) after MWA at 100 W (arrowhead) and 150 W (arrow) and ablation volumes (**D**)

Pearson's Chi-square test, when appropriate, for categorical variables, by Student's T-test for continuous normally distributed variables, and by Mann–Whitney U-test for continuous non-normally distributed variables. Pearson's correlation coefficient and linear regression analysis were used to correlate continuous normally distributed variables. All tests were run on a lesion-based analysis. Two-tailed tests were preferred whenever possible. p values were considered significant when < 0.05. SPSS v25.0.0 (IBM, Armonk, New York, USA) was used for all statistical analyses.

Results

Patients

Between January 2021 and May 2023, a total of 135 HCC nodules were treated with percutaneous MWA in 87 patients with a median age of 66 ± 10 years (range 46–88): 76 procedures in 42 patients were carried out with 100 W system (group 1), while 59 procedures in 45 patients with 150 W system. Descriptive statistics are reported in Table 1.

Follow-up findings

All patients underwent 1-month follow-up imaging (CECT or MRI) after the procedure (drop-out rate: 0.0%). In Group 1 in three cases (3/42, 7.1%) MRI was used as a follow-up imaging modality, while CECT was performed in thirty-nine cases (39/42, 92.9%). In Group 2 in all patients (100%) CECT was used.

Outcome measures

Student's T-test showed no differences in lesion volume between Group 1 and 2 (3329.5 ± 4668.1 vs. 3800.1 ± 5674.2; $p > 0.05$ at Student's T-test). Instead, significant differences were found in ablation area, higher for Group 2 ($13{,}920.0 \pm 10{,}723.2$ mm^3 vs. $21{,}241.4 \pm 18{,}374.7$ mm^3 at 100 and 150 W, respectively; p: 0.008), and ablation time, lower for Group 2 (227.4 ± 92.5 s vs. 180.5 ± 75.6 s, respectively; p: 0.002). No other significant differences were identified among both groups by T- and U-test. Detailed data are provided in Table 2.

Technical Success (TS) was achieved in all the procedures both in Group 1 and Group 2 (100%).

Intrahepatic Distant Disease (IDD) was significantly different among groups 1 and 2 with a lower rate in the 150 W group (32.43% vs. 13.79%; p: 0.013). No significant differences were found among residual disease (35.14% vs 24.14%), EDD (0.0% vs 3.45%), and Retreatment (40.54% vs 26.92%). Detailed data are provided in Table 3.

Among categorical variables, contingency tables, Fisher's exact test, and Pearson's Chi-square test showed no significant difference for sex, peripheral/central location of the tumor, type of imaging guidance, and length of antenna used (Table 4). Pearson's correlation coefficient and linear regression analysis demonstrated a significant correlation between the volume of the lesion and the ablation area (p: 0.016; R^2: 0.04) and between the ablation area and the ablation time (p: 0.001; R^2: 0.08) (Fig. 2).

Safety

Safety was significantly lower in the 150 W Group (χ^2: 14.15; $p < 0.001$): 97.4% in Group 1 (2/76 cases: 2 grade II complications) and 76.3% in Group 2 (14/59 cases: 8 grade II and 6 grade III complications). Regarding grade III complications in Group 2 were identified a super-infection of the ablation area with hyperpyrexia and rising of inflammatory laboratory tests (CRP 12.5 mg/dL), resolved with antibiotic therapy; a bilateral pleural effusion treated with the insertion of bilateral drainage tubes); and 4 cases of segmental portal vein thrombosis (3 for branches of VIIIs and 1 for branch of VIIs), resolved with anticoagulation therapy.

Regarding grade II complications, peri-hepatic effusion was registered in 2/76 of cases in Group 1 (2.6%) and 13/59 (22.0%) in Group 2 (in 5 cases in association with grade III complications).

For grade II complications in each group (2 patients in Group 1 and 8 patients in Group 2), an extended observation period, including an additional overnight stay, was required.

For grade III complications, observed only in Group 2, one patient with a super-infection of the ablation area, accompanied by hyperpyrexia and elevated inflammatory markers, required an additional 48 h of hospitalization. For patients with segmental portal vein thrombosis, home therapy was provided, without the need for further hospitalization. A patient with pleural effusion who was treated with bilateral drainage tubes required a new hospitalization, which involved an additional 48 h of hospitalization.

Discussion

Over the other thermal ablation techniques, RFA in particular, MWA has several advantages which include the higher intra-tumoral temperatures, larger tumor ablation volumes, faster ablation times, ability to use simultaneously multiple applicators, optimal heating of cystic masses and lesions

Table 1 Descriptive statistics

Variable	N (%)	Shapiro–Wilk (*p* value)	Mean ± SD	Median ± IQR	Range
Watt					
100	76 (56.3)				
150	59 (43.7)				
Age		0.057	–	66 ± 10	46–88
Sex					
Women	32 (23.7)				
Man	103 (76.3)				
Hepatic lobe					
Right	101 (74.8)				
Left	34 (25.2)				
Lesion site					
Central	26 (19.3)				
Subcapsular	109 (80.7)				
Lesion diameter (mm)		< 0.001	18.39 ± 8.08	–	7–45
Lesion volume (mm^3)		< 0.001	3840.18 ± 5911.06	–	127.4–31,590
Antenna					
15 cm	111 (87.4)				
20 cm	16 (12.6)				
Missing	8				
Ablation time (s)		0.011	201.86 ± 91.43	–	60–480
Ablation area (mm^3)		< 0.001	17,020.15 ± 15,125.99	–	0–72783.36
AFP		< 0.001	197.7 ± 1216.18	–	1–8685
PT (s)		< 0.001	13.26 ± 2.51	–	10.1–25.4
aPTT (s)		< 0.001	33.67 ± 7.46	–	1.26–61.4
INR		< 0.001	1.83 ± 4.73	–	0.88–34.9
PLT		0.006	125.86 ± 57.84	–	38–278
Albumin		0.084	–	4.28 ± 0.7	3–5.7
Bilirubin		< 0.001	1.23 ± 0.89	–	0.27–4.47
AST		< 0.001	57.08 ± 44.92	–	9–184
ALT		< 0.001	35.82 ± 19.74	–	13–113
GGT		< 0.001	84.39 ± 84.86	–	9.4–478
Child–Pugh					
A5	96 (83.5)				
A6	8 (7)				
B7	10 (8.7)				
B8	1 (0.9)				
Missing	20				
Technical success					
No	0 (0.0)				
Yes	135 (100.0)				
Effectiveness					
No	66 (50.4)				
Yes	65 (49.6)				
Missing	4				
LTP					
No	92 (69.7)				
Yes	40 (30.3)				
Missing	3				

Table 1 (continued)

Variable	N (%)	Shapiro–Wilk (p value)	Mean ± SD	Median ± IQR	Range
IDD					
No	100 (75.8)				
Yes	32 (24.2)				
Missing	3				
EDD					
No	132 (98.5)				
Yes	2 (1.5)				
Missing	1				
Complications					
No	129 (95.6)				
Yes	6 (4.4)				
AFP (1-month)		< 0.001	11.1 ± 24.43	–	1.1–160
PT (1-month) (s)		< 0.001	14.58 ± 5.88	–	10–47.7
aPTT (1-month) (s)		< 0.001	34.34 ± 7.26	–	21.6–62
INR (1-month)		< 0.001	1.25 ± 0.48	–	0.85–4.02
PLT (1-month)		< 0.001	148.47 ± 75.45	–	47–373
Albumin (1-month)		< 0.001	4.03 ± 0.56	–	2.8–4.7
Bilirubin (1-month)		< 0.001	1.41 ± 1.37	–	0.3–8.6
AST (1-month)		< 0.001	44.04 ± 24.47	–	16–130
ALT (1-month)		< 0.001	34.08 ± 19.85	–	9–99
GGT (1-month)		< 0.001	109.71 ± 136.85	–	8–906

close to the vessels for its less susceptibility to the "heat-sink effect" [29].

Over the years, several innovations in ablation techniques have been introduced. In particular: the thermosphere technology leads to the achievement of a real predictable spherical ablation area through field control, thermal control, and wavelength control, and the high-power systems can produce a large zone of ablation in a shorter time [30].

In the present study, we reported a comparison in terms of efficacy and complication rate between the 100 W and 150 W microwave ablation (MWA) systems in the treatment of HCC. To our acknowledgment, this is the first experience that reports an in vivo comparison between these two groups of devices, used by the percutaneous approach.

The choice of the type of treatment was mainly based on the proximity of the lesion to critical structures (diaphragm/heart, stomach/esophagus, colon, duodenum, gallbladder), where the ablation with 100 W was preferred in those cases, and secondarily to the operator's experience.

A statistically significant correlation between volume lesion and ablation area (p: 0.016; R^2: 0.04) and a correlation between ablation area and ablation time (p: 0.001; R^2: 0.08) were observed.

We also found a shorter ablation time (227.4 ± 92.5 s vs. 180.5 ± 75.6 s; p: 0.002) and a larger ablation volume (13,920.0 ± 10,723.2 mm^3 vs. 21,241.4 ± 18,374.7 mm^3; p: 0.008) in patients treated with 150W system comparing with 100W system.

In our study, we have found a higher rate of complications (grade II and grade III) for Group 2, treated with 150 W.

Berber and Akbulut [31] published the first worldwide experience with a 150 W ablation system using both laparoscopically and open approaches. Our procedures were performed percutaneously, leading minimally invasive approach.

Differently from our previous work [32] where different types of tumors (kidney, lung, and liver) were included, in this new study, we have collected only cases of liver HCC, achieving a more homogenous cohort of patients.

Limitations of the study are represented by the short period of follow-up, the small sample of patients, and the retrospective design.

In conclusion, these preliminary results showed a good correlation between intended-to-treat area and ablation

Table 2 Differences between group 1 and 2 for continuous variables

Variable	Watt	N	Value	p value	Test
Age	100	76	69.4 ± 9	> 0.05	Mann–Whitney U
	150	59	70.3 ± 9.5		
Lesion volume (mm^3)	100	75	3329.5 ± 4668.1	> 0.05	Student's T
	150	58	3800.1 ± 5674.2		
Ablation area (mm^3)	100	76	13,920 ± 10,723.2	0.008	Student's T
	150	58	21,241.4 ± 18,374.6		
Ablation time (s)	100	76	227.4 ± 92.5	0.002	Student's T
	150	59	180.5 ± 75.6		
AFP	100	61	59.6 ± 170.7	> 0.05	Student's T
	150	48	193.5 ± 1252.2		
PT (s)	100	76	13.4 ± 2.4	> 0.05	Student's T
	150	56	13.6 ± 2.4		
aPTT (s)	100	76	34.1 ± 9	> 0.05	Student's T
	150	56	32.6 ± 6.5		
INR	100	76	1.6 ± 3.9	> 0.05	Student's T
	150	55	1.2 ± 0.2		
PLT	100	76	148.2 ± 74.7	> 0.05	Student's T
	150	57	151.4 ± 150.6		
Albumin	100	70	4.1 ± 0.6	> 0.05	Mann–Whitney U
	150	54	4.1 ± 0.6		
Bilirubin	100	58	1.1 ± 0.7	> 0.05	Student's T
	150	52	1.2 ± 0.9		
AST	100	49	50.3 ± 27.3	> 0.05	Student's T
	150	44	50.6 ± 44.7		
ALT	100	70	35.9 ± 19.5	> 0.05	Student's T
	150	55	30.6 ± 15.8		
GGT	100	69	95.1 ± 87	> 0.05	Student's T
	150	55	95.8 ± 114.4		
AFP (1-month)	100	61	88.5 ± 454.2	> 0.05	Student's T
	150	46	9.9 ± 26.7		
PT (1-month) (s)	100	64	14.3 ± 5.3	> 0.05	Student's T
	150	43	14 ± 3.2		
aPTT (1-month) (s)	100	62	35.3 ± 9.5	> 0.05	Student's T
	150	42	33 ± 6.7		
INR (1-month)	100	69	2.2 ± 5.7	> 0.05	Student's T
	150	47	1.2 ± 0.2		
PLT (1-month)	100	74	151.2 ± 74.5	> 0.05	Student's T
	150	51	157.5 ± 95.3		
Albumin (1-month)	100	61	4.1 ± 0.5	> 0.05	Student's T
	150	48	4.7 ± 5		
Bilirubin (1-month)	100	67	1.2 ± 1	> 0.05	Student's T
	150	46	1.6 ± 1.5		
AST (1-month)	100	59	66.5 ± 113.6	> 0.05	Student's T
	150	43	49.8 ± 48.6		
ALT (1-month)	100	66	62.3 ± 190.2	> 0.05	Student's T
	150	49	33.1 ± 21.9		
GGT (1-month)	100	68	106.6 ± 127.5	> 0.05	Student's T
	150	49	104.7 ± 93.3		

Table 3 Outcome measures results

	100 W	150 W	Pearson X^2	*p* value
TS	76/76 (100%)	59/59 (100%)	–	–
Residual disease	26/74 (35.14%)	14/58 (24.14%)	1.862	> 0.05
IDD	24/74 (32.43%)	8/58 (13.79%)	6.151	0.013
EDD	0/76 (0%)	2/58 (3.45%)	2.66	> 0.05
Safety	74/76 (97%)	46/59 (89.8%)	14.15	< 0.001
Retreat-ment	30/74 (40.54%)	14/52 (26.92%)	2.492	> 0.05

volume and intended-to-treat area and ablation time for both Groups. A minor ablation time, and major ablation volume, but also a higher incidence of complications was observed in 150 W Group.

More data are needed to confirm our outcomes.

Table 4 Location of the tumor (peripheral/central), type of imaging-guidance, length of antenna for each group

	150 W	100 W
Peripheral/central	Central 18% (11/58)	Central 20% (15/75)
	Peripheral 82% (47/58)	Peripheral 80% (60/75)
Type of imaging guidance		US 41% (31/75)
	US 65% (38/58)	CEUS 1.3% (1/75)
	CBCT 3% (2/58)	CBCT 2.6% (2/75)
	US + CBCT 20% (12/58)	US + CBCT 40% (30/75)
	Fusion CT + US 8% (5/58)	Fusion CT + US 12% (9/75)
		Fusion MRI + US 2.6% (2/75)
Type of antenna	15 cm 89% (52/58)	15 cm 78% (59/75)
	20 cm 10% (6/58)	20 cm 22% (17/75)

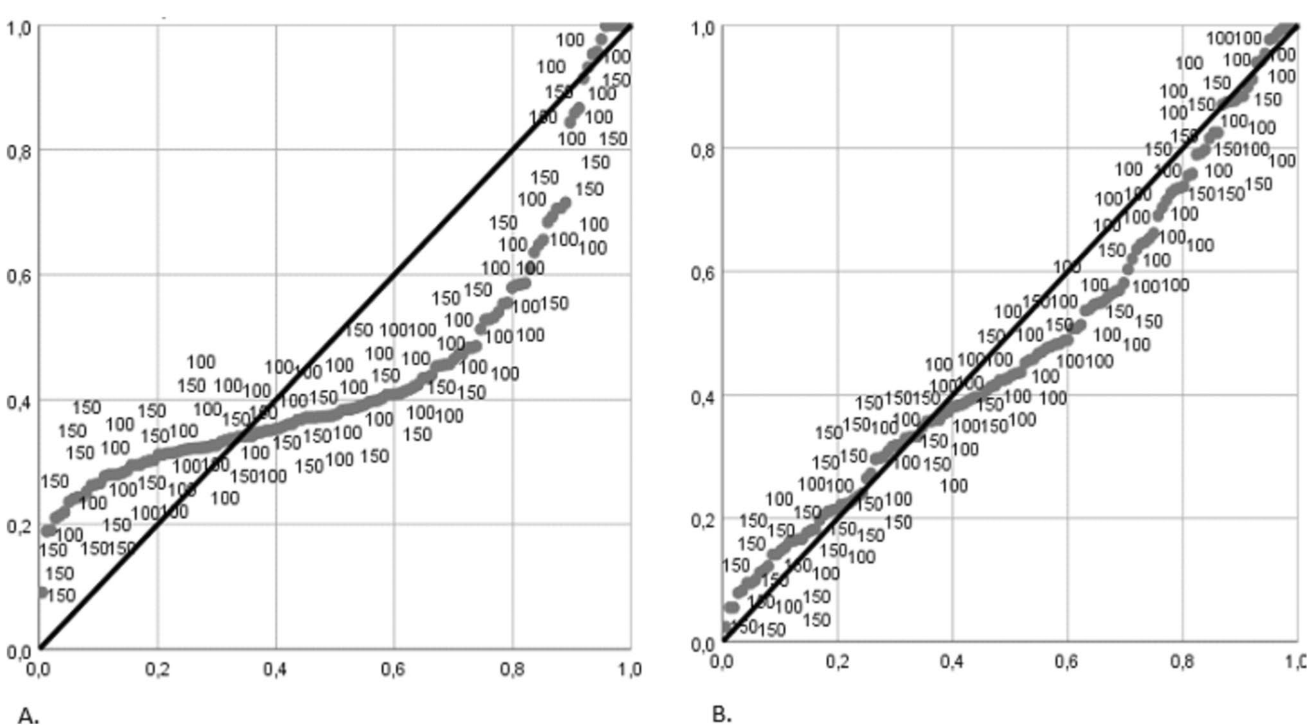

Fig. 2 **A**, **B** Normal probability plot (cumulative expected probability on the y-axis and cumulative observed probability on the x-axis) for lesion volume/ablation area (**A**) and ablation area/ablation time (**B**). As can be seen, no differences in the 100 W and 150W cases (dot noticles) distribution can be observed

Author contributions All authors contributed to the study conception and design. All authors contributed to study analysis and interpretation of data. All authors draft and revised the article. All authors have read and agreed to the published final version of the manuscript.

Funding The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Declarations

Conflict of interest Serena Carriero is an editor in this journal. The other authors have no conflict of interest to declare that are relevant to the content of this article.

Human participants or animals This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed written consent was obtained from all individual participants included in the study.

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