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INTERVENTIONAL RADIOLOGY

ORIGINAL ARTICLE

Percutaneous radiofrequency ablation for hepatic tumors: factors affecting baseline impedance

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PURPOSE
We aimed to evaluate factors that affect baseline impedance of percutaneous radiofrequency ablation.

METHODS
In this retrospective study, we analyzed 51 patients with 55 hepatic tumors from November 2015 until April 2018. We measured the baseline impedance nine times with three adjustable tip sizes (2 cm, 2.5 cm, 3 cm) and three different pad locations (two pads attached on the thigh, four on the thigh, two on the back). The first roll-off time was measured with two grounding pads attached on the back. Body mass index, cirrhotic or non-cirrhotic liver parenchyma, previous procedure, tumor location, artificial ascites, active tip size, and the pad location were evaluated as potential factors affecting baseline impedance using the Mann–Whitney U test, t-test and analysis of variance test.

RESULTS
Complete radiofrequency ablation was achieved in 51 patients. Body mass index ($p = 0.897$), cirrhotic or non-cirrhotic liver parenchyma ($p = 0.767$), previous procedure ($p = 0.957$), tumor location ($p = 0.906$), and artificial ascites ($p = 0.882$) did not significantly affect baseline impedance. Grounding pads located on the back showed the lowest baseline impedance ($p < 0.001$). Increase in active tip size showed gradual decrease in baseline impedance ($p = 0.016$).

CONCLUSION
The factors affecting baseline impedance were the pad location and the tip size. Positioning pads on the back lowers the baseline impedance and can shorten the first roll-off time, ultimately resulting in reduced total ablation time.

Hepatocellular carcinoma (HCC) continues to be the most prevalent primary liver malignancy and is the third leading cause of cancer-related deaths worldwide (1–3). According to the 2018 European Association for the Study of the Liver clinical practice guidelines (4), ablation is the standard of care for patients with very early stage HCC (Barcelona clinic liver cancer staging system, BCLC-0), and can be adopted as first-line therapy even in surgical patients. Additionally, thermal ablation in single tumors sized 2 to 3 cm is an alternative to surgical resection based on tumor location and patient condition (4). Baseline impedance of radiofrequency ablation (RFA) is measured with a single monopolar electrode before ablation automatically (5). The impedance-controlled mode is generated with an initial set value, which can be adjusted by means of a radiofrequency (RF) output control (5). The first roll-off occurs when the impedance is increased 60% over the initial value (5). Hence, low baseline impedance suggests a short first roll-off time, which is expected to eventually reduce the entire ablation time (6). The aim of this study was to evaluate factors that significantly affect baseline impedance during RFA.

Methods

Patients and diagnosis

This retrospective study was approved by our Institutional Review Board (2018-04-017-008), and the requirement for informed consent was waived. We enrolled patients from

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November 2015 to April 2018 who were diagnosed with hepatic tumor at our institute. Before RFA, all patients underwent contrast-enhanced computed tomography (CT) or magnetic resonance imaging (MRI) for tumor staging. All patients underwent quadruple-phase multidetector CT including the unenhanced, arterial, portal venous, and equilibrium phases with a 320-slice Aquilion Prime CT scanner (Canon Medical Systems Corporation). CT scans were obtained in the craniocaudal direction after an injection of 120 cc of iomeprol-400 (Iomeron®, Bracco U.K. Ltd.) at a rate of 3 mL/s using an automatic power injector. Arterial phase imaging was performed 19 s after achieving 100 HU attenuation of the descending aorta measured using a bolus tracking method. A 33 s delay after the arterial phase was used for portal venous phase acquisition. The delay time was 180 s for equilibrium phase imaging following administration of a contrast medium. Abdominal MRI was performed on a 1.5 T system (Magnetom Avanto and Aera, Siemens Healthcare) with a routine protocol including the following sequences: coronal and axial T2-weighted, axial fat-saturated T2-weighted, axial T1-weighted Dixon (in-phase, opposed phase, water-weighted, and fat-weighted images), diffusion-weighted imaging, unenhanced and contrast-enhanced multiphase coronal, and axial T1-weighted sequences. The parameters of T1-weighted sequences were kept identical within each examination. Gadoxetic acid (Primovist®, Bayer) at a dose of 0.05 mmol/kg was administered intravenously (IV) by means of a power-injected bolus at 2 mL/s followed by a bolus of 20 mL of saline flush at the same rate. After IV administration of contrast agent, a bolus-tracking technique was used to capture the late hepatic arterial phase, followed by two other acquisitions performed at 70 and 180 s after administration of the contrast agent.

Inclusion criteria were as follows: (*i*) single hepatic tumor less than 2 cm; (*ii*) the tumor could be treated by single ablation without overlapping. A total of 55 patients met the above criteria and were enrolled in this study. However, 4 patients were excluded due to failure in measuring baseline impedance. Among the remaining 51 patients, 16 patients with 18 hepatic tumors had previous transarterial chemoembolization, and 11 patients with 12 hepatic tumors had previous RFA between the index tumor and grounding pad. Four patients with 6 hepatic tumors underwent ablation of hepatic metastasis from colorectal cancer. As a result, 51 patients were enrolled, and a total of 55 tumors were treated since 4 patients were treated for two different tumors at the same time (Fig. 1).

Equipment

Conventional 15 G (Proteus®; STARmed) monopolar electrodes were used with 2, 2.5, and 3 cm adjustable active tips with a 200 W radiofrequency generator (VIVA RF generator; STARmed). Initial baseline impedance was detected when a 150 mA current was applied between the electrode and grounding pad before ablation. The impedance-controlled mode is generated with an initial set value, which can be adjusted by means of a RF output control. The first roll-off occurs when the impedance is increased 60% over the initial value. The electrodes were cooled internally by delivering chilled saline with a peristaltic pump (VIVA pump; STARmed).

Ablation procedures

Before the ablation, we performed IV infusion of pethidine HCl (pethidine hydrochloride 50 mg/mL) with 50 mL of saline. After confirming the index tumor by sonography, we injected 2% lidocaine to the puncture site. By the time the 15 G electrode was placed into the index tumor, we measured the baseline impedance a total of 9 times with a combination of 3 different adjustable active tip sizes (2 cm, 2.5 cm, and 3 cm) and three pad locations (T2, two pads attached to the thigh; T4, four pads attached to the thigh; B2, two pads attached to the back). The pad consists of an electrical conductor coated by polymer gel (Fig. 2) (7). The ablation was performed at the grounding pad location with the lowest baseline impedance.

Depending on the tumor's location estimated by contrast-enhanced CT or MRI, we induced artificial ascites (5% dextrose in water) optionally for better visibility and prevention of collateral thermal injury (8). We set the RF generator at the auto impedance-controlled mode and started the electric current at 50 W. The current was increased stepwise

Main points

- Baseline impedance of radiofrequency ablation (RFA) with single monopolar electrode is measured before the ablation automatically, and the first roll-off occurs when the impedance is increased 60% more than baseline.
- Factors significantly affecting baseline impedance during RFA were the location of the grounding pad ($p < 0.001$) and active tip size of the electrode ($p = 0.016$).
- Positioning grounding pads on the back, instead of conventional thigh position, lowers baseline impedance and can shorten first roll-off time, ultimately resulting in reduced total ablation time.

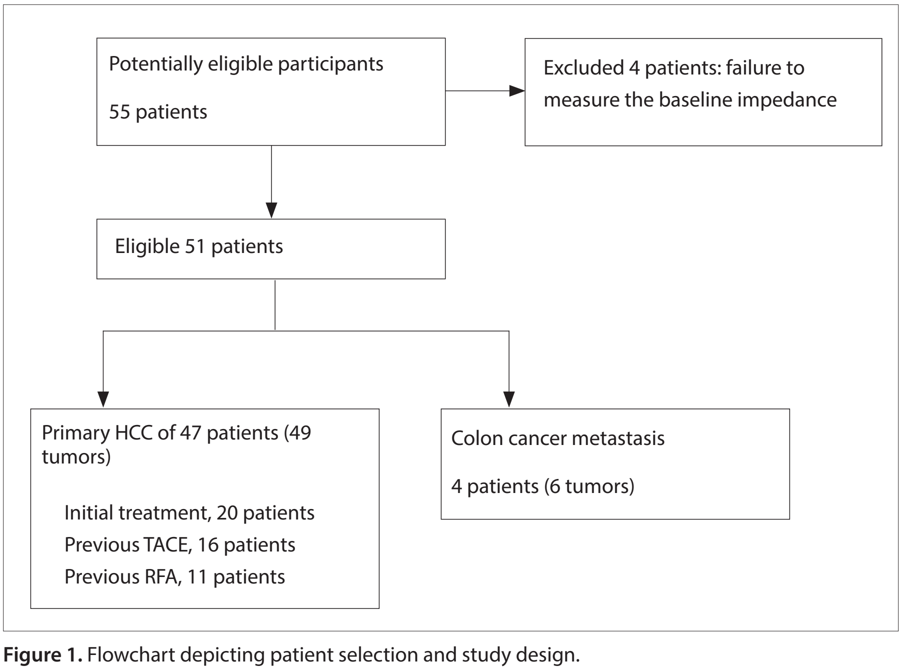

Figure 1. Flowchart depicting patient selection and study design.

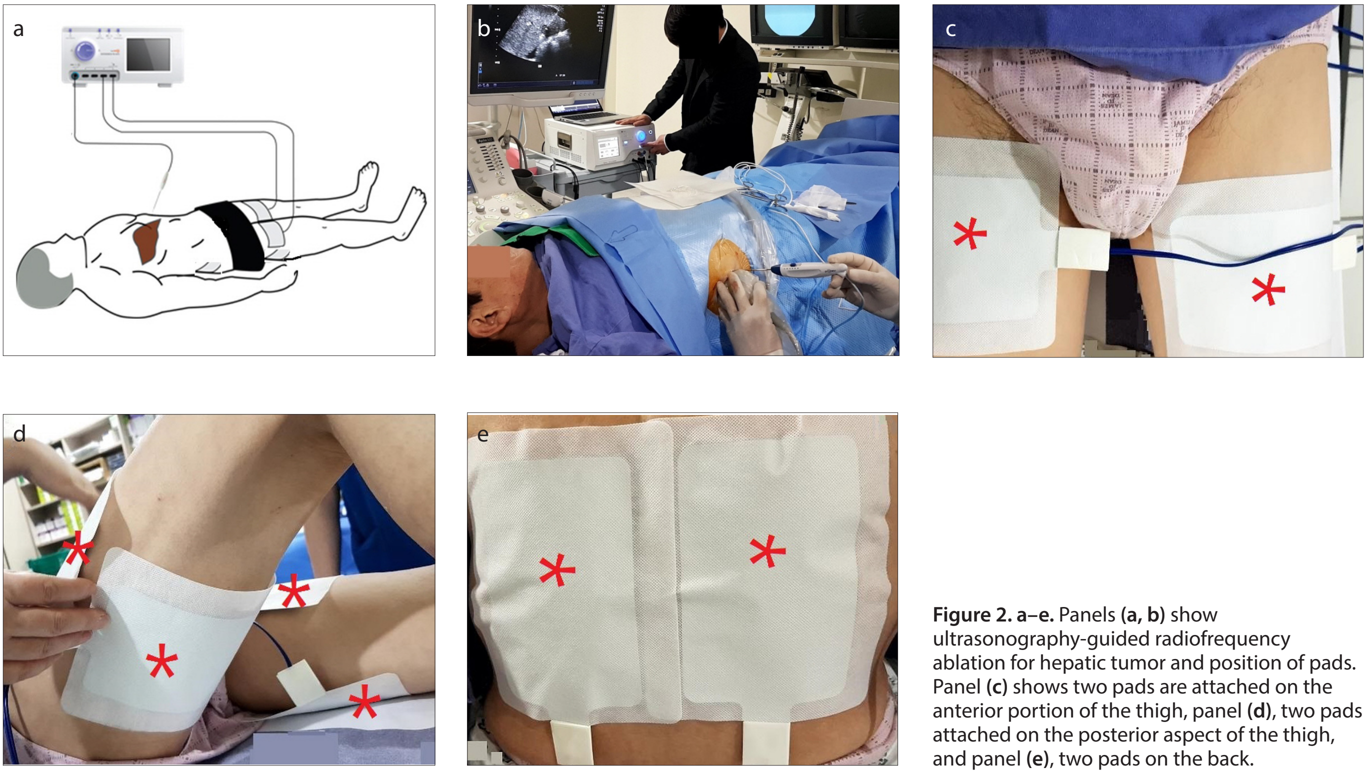

Figure 2. a–e. Panels **(a, b)** show ultrasonography-guided radiofrequency ablation for hepatic tumor and position of pads. Panel **(c)** shows two pads are attached on the anterior portion of the thigh, panel **(d)**, two pads attached on the posterior aspect of the thigh, and panel **(e)**, two pads on the back.

Table 1. Demographics and clinical characteristics of patients who received RFA

Clinical characteristics	Median or number of patients or number of tumors
Age (years), median (min–max)	65 (45–84)
Gender, n (%)	
Male	40 (78.4)
Female	11 (21.6)
Tumor diameter (cm), median (min–max)	1.5 (1.1–1.9)
BMI, n (%)	
18.5–24.9 kg/m^2	34 (67)
≥ 25 kg/m^2	17 (33)
Tumor location (hepatic segment), n*	
S3	4
S5	5
S6	19
S7	5
S8	22
Colon cancer with hepatic metastasis, n (%)*	6 (11.8)
Ablating with artificial ascites, n (%)*	25 (49.0)
Mean first roll-off time	
2 cm active tip (E2)	1 min 3 s ± 21.88 s
2.5 cm active tip (E2.5)	1 min 19 s ± 44.71 s
3 cm active tip (E3)	3 min 16 s ± 31.24 s
Mean total ablation time with B2	6 min 52 s ± 2 min 14 s

RFA, radiofrequency ablation; BMI, body mass index; B2, two grounding pads on the back.
*n represents the number of tumors.

by 10 W per minute until the first roll-off time occurred, which was measured while two grounding pads were attached to the back (B2). We performed ablation until the echogenic ablation zone completely covered the index tumor with safe margins (Figs. 3 and 4). The ablation was performed by a radiologist who had 15 years of experience.

Analysis of potential factors affecting baseline impedance

Factors that may potentially affect baseline impedance were analyzed in categorical groups as follows: body mass index (BMI, 18.5–24.9 kg/m^2, ≥25 kg/m^2), cirrhotic or non-cirrhotic parenchyma of underlying liver (HCC vs. metastasis from colorectal cancer), chemoembolization or ablation procedure for previous hepatic tumor between the index tumor and the grounding pads (no vs. yes), tumor location (S8, segment 8; S6, segment 6), induction of artificial ascites (no vs. yes), active tip size (2 cm, 2.5 cm, 3 cm), and pad location (2 pads on thigh, 4 pads on thigh, 2 pads on back). We evaluated the difference in baseline impedance between groups for each individual factor; if no significant difference was seen, that factor would be considered not to influence baseline impedance and would be excluded from the following analyses.

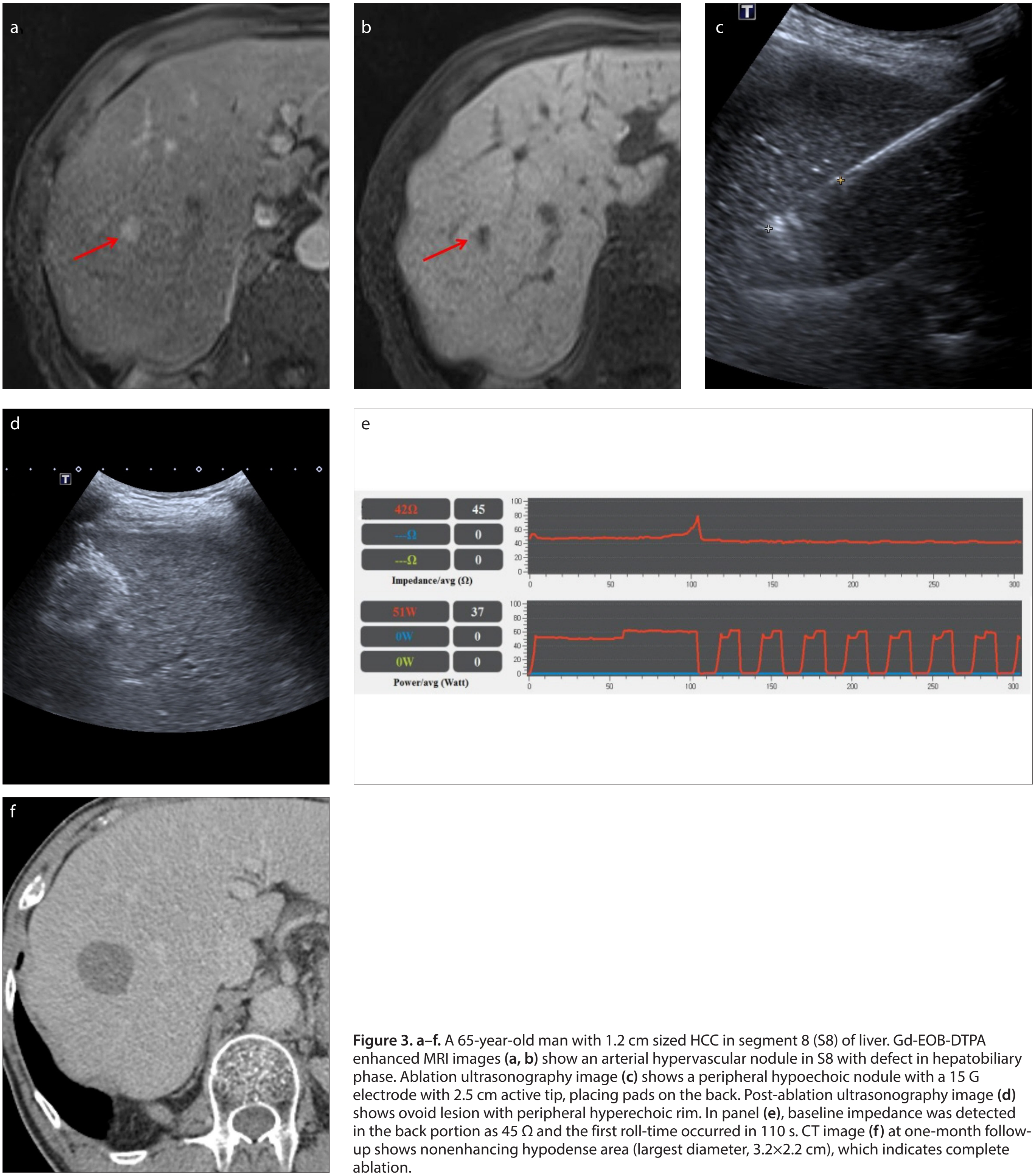

Figure 3. a–f. A 65-year-old man with 1.2 cm sized HCC in segment 8 (S8) of liver. Gd-EOB-DTPA enhanced MRI images **(a, b)** show an arterial hypervascular nodule in S8 with defect in hepatobiliary phase. Ablation ultrasonography image **(c)** shows a peripheral hypoechoic nodule with a 15 G electrode with 2.5 cm active tip, placing pads on the back. Post-ablation ultrasonography image **(d)** shows ovoid lesion with peripheral hyperechoic rim. In panel **(e)**, baseline impedance was detected in the back portion as 45 Ω and the first roll-time occurred in 110 s. CT image **(f)** at one-month follow-up shows nonenhancing hypodense area (largest diameter, 3.2×2.2 cm), which indicates complete ablation.

Statistical analysis

Continuous variables with non-normal distribution were expressed as median (min–max). Continuous variables with normal distribution were expressed as mean ± standard deviation (SD). The Kolmogorov–Smirnov test and Shapiro–Wilk test were applied to assess the normality of distribution. Between-group differences in non-normally distributed continuous variables were tested using the Mann–Whitney U test, while for normally distributed variables, the two-sample t-test and one-way analysis of variance (ANOVA) test were used. Since sample sizes were different in some cases, the Spjotvoll–Stoline test (Tukey's honest significant difference, HSD, for unequal N test; $\alpha = 0.05$) (SS test) was applied in post hoc comparisons. All statistical analyses were performed using SPSS version 18.0 (SPSS, Inc.). All significance tests were two-tailed,

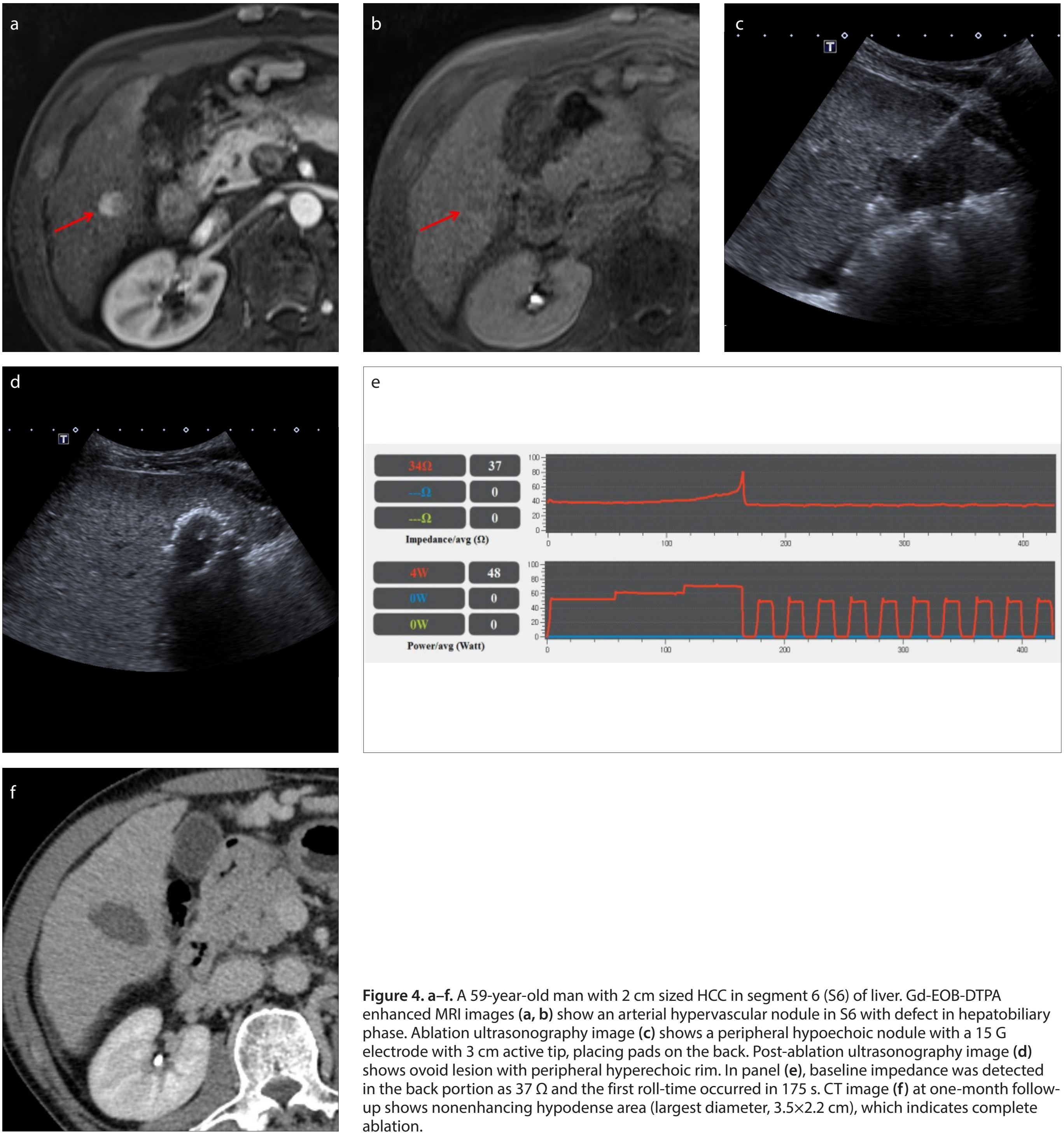

Figure 4. a–f. A 59-year-old man with 2 cm sized HCC in segment 6 (S6) of liver. Gd-EOB-DTPA enhanced MRI images **(a, b)** show an arterial hypervascular nodule in S6 with defect in hepatobiliary phase. Ablation ultrasonography image **(c)** shows a peripheral hypoechoic nodule with a 15 G electrode with 3 cm active tip, placing pads on the back. Post-ablation ultrasonography image **(d)** shows ovoid lesion with peripheral hyperechoic rim. In panel **(e)**, baseline impedance was detected in the back portion as 37 Ω and the first roll-time occurred in 175 s. CT image **(f)** at one-month follow-up shows nonenhancing hypodense area (largest diameter, 3.5×2.2 cm), which indicates complete ablation.

and differences with a *p* value less than 0.05 were considered statistically significant.

Results

The patient group included 40 males and 11 females aged 45–84 years (median, 65 years). The median tumor size was 1.5 cm (range, 1.1–1.9 cm). The BMI of 34 patients was between 18.5 and 24.9 kg/m^2, while BMI of the remaining 17 patients was ≥25 kg/m^2. Four nodules were located in hepatic segment 3 (S3), 5 were located in S5, 19 nodules were located in S6, 5 nodules were located in S7, and 22 nodules were located in S8. Nodules located in S4 closely abutting the hepatic vein were incorporated into S8 or S5 groups.

There were 6 hepatic metastases from colorectal cancer. Ablation of 25 tumors was performed with artificial ascites. The mean first roll-off time when placing the pads on the back was 1 min 3 s using the 2 cm active tip, 1 min 19 s for the 2.5 cm active tip, and 3 min 16 s for the 3 cm active tip. The mean total ablation time when placing the pads on the back was 6 min 52 s. These results are detailed in Table 1.

The baseline impedance results according to patients' demographics and proce-

Table 2. Demographics and clinical characteristics of patients who received RFA

Clinical characteristics	Median or number of patients or number of tumors
Age (years), median (min–max)	65 (45–84)
Gender, n (%)	
Male	40 (78.4)
Female	11 (21.6)
Tumor diameter (cm), median (min–max)	1.5 (1.1–1.9)
BMI, n (%)	
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3 cm active tip (E3)	3 min 16 s ± 31.24 s
Mean total ablation time with B2	6 min 52 s ± 2 min 14 s

RFA, radiofrequency ablation; BMI, body mass index; B2, two grounding pads on the back.
*n represents the number of tumors.

dural parameters are shown in Table 2. All procedures showed immediate full technical success. Contrast-enhanced CT or MRI one month after RFA showed 100% clinical success. No complications were observed, and there was no local recurrence at 2-year follow-up.

Patients with BMI >25 kg/m² had lower baseline impedance, except when measured with two pads on the back using 2.5 cm active tip and with two pads on the thigh using 3 cm active tip. However, the difference was not statistically significant.

Patients with noncirrhotic liver parenchyma had higher baseline impedance compared with cirrhotic patients; however, the difference was not statistically significant. There was also no significant difference between patients with and without chemoembolization or RFA of previous hepatic tumor between the index tumor and the grounding pad.

In terms of tumor location, S8 tumors had lower baseline impedance compared to S6 except when measured with two pads on the thigh using 2.5 cm and 3 cm active tips, and with two pads on the back using 3 cm active tip. However, none of the above differences was statistically significant; the same was observed for the difference between patients with and without artificially infused ascites. As for the three active tip size groups, the lowest impedance was observed for 3 cm active tip. The baseline impedance showed a gradual decrease with increasing tip size, which were all statistically significant at each pad position ($p = 0.016$).

Among the three different grounding pad locations, two pads on the back showed the lowest baseline impedance. Therefore, the first roll-off time was measured with two grounding pads attached to the back and all ablations were performed with this pad location. Baseline impedance with two pads on the back was significantly lower compared with either two pads on the thigh and four pads on the thigh ($p < 0.001$, both). However, placing two or four pads on the thigh did not change the baseline impedance significantly ($p = 0.363$).

Discussion

The differences in baseline impedance may help determine optimal procedural settings. Some factors showed different trends than expected but the differences were not statistically significant.

Patients with higher BMI tended to have lower baseline impedance in most cases. This was contrary to our expectation since fatty tissue is known to be a poor conductor of electric current (9). We believe that our observation may be biased by the small sample size. The group with hepatic metastasis and non-cirrhotic parenchyma had higher baseline impedance than the cirrhosis group. We suggest that the cirrhotic group's decreased hepatic volume resulted in shorter distances between tumors and grounding pads. Lipiodol-laden transarterial chemoembolization or previously RF ablated lesions of previous hepatic tumor between the index tumor and the grounding pads did not show a significant baseline impedance difference. In terms of tumor location when using the four pads on the thigh configuration, the baseline impedance measured in S6 was higher compared with S8 regardless of tip size. These results are contrary to our expectations that the shorter distance between tumor and pads in S6 would lead to a lower baseline impedance. The increased number of pads may have caused the current receiving channel to widen, offsetting the effect of distance. With two grounding pads located on the back, the baseline impedance measured at S6 was higher except when using the 3 cm active tip. This result is also contrary to our expectations because the shorter distance between the tumor and pads in S6 should have led to a lower baseline impedance. We suggest that this was because the distance between the tumor and the back pads was not significantly different. However, all these trends were not statistically significant. The artificial ascites group (5% dextrose in water) showed higher baseline impedance, which can be explained by the nonionic nature of the dextrose water solution (10, 11).

As the tip size increase, the baseline impedance showed a gradual decrease which was statistically significant. This was probably due to the increase in electric current with the increasing tip size. In general, the

Table 3. Baseline impedance according to patient demographics and procedure condition

		Size of active tip								
		E2			E2.5			E3		
Baseline impedance according to BMI		18.5–24.9 (n=5, 62.5%)	≥25 (n=3, 37.5%)	*p*	18.5–24.9 (n=6, 66.7%)	≥25 (n=3, 33.3%)	*p*	18.5–24.9 (n=6, 66.7%)	≥25 (n=3, 33.3%)	*p*
	T2	76.60	73.67	1	68.17	67	0.897	63.67	65.67	0.604
	T4	74.60	69.33	0.786	68.67	63.67	0.437	64.67	59.67	0.437
	B2	57	55.33	0.786	50	50.33	1	45.67	45.67	1
Baseline impedance according to cirrhotic vs. non-cirrhotic parenchyma of underlying liver		HCC (n=3, 60%)	Meta (n=2, 40%)	*p*	HCC (n=4, 66.7%)	Meta (n=2, 33.3%)	*p*	HCC (n=2, 40%)	Meta (n=3, 60%)	*p*
	T2	68.33	78.50	0.248	67	73.50	0.348	62	69	0.564
	T4	70.33	71.50	0.767	63.50	66.50	0.481	52	62	0.083
	B2	51.67	54	0.564	48.50	49.50	0.634	44.50	45.33	1
Baseline impedance according to TACE or RFA lesion for previous hepatic tumor between index tumor and grounding pads		No (n=18, 72%)	Yes (n=7, 28%)	*p*	No (n=21, 70%)	Yes (n=9, 30%)	*p*	No (n=20, 76.9%)	Yes (n=6, 23.1%)	*p*
	T2	74.44	70.29	0.250	67.76	65.44	0.226	63.25	57.33	0.175
	T4	71.22	73.71	0.957	65.14	66.89	0.609	59.60	61	0.737
	B2	54.44	54.86	0.921	48.86	49	0.639	44.50	42.67	0.681
Baseline impedance according to tumor location		S8 (n=5, 33.3%)	S6 (n=10, 66.7%)	*p*	S8 (n=6, 35.3%)	S6 (n=11, 64.7%)	*p*	S8 (n=5, 27.8%)	S6 (n=13, 72.2%)	*p*
	T2	72.40	74.60	0.572	69.17	67	0.906	66.20	62.77	0.671
	T4	70.80	70.90	0.902	64.50	66	0.706	58	60.85	0.260
	B2	52.60	55.40	0.357	48.83	49.27	0.866	45	44.46	0.143
Baseline impedance according to artificial ascites		No (n=26, 51%)	Yes (n=25, 49%)	*p*	No (n=21, 41.2%)	Yes (n=30, 58.8%)	*p*	No (n=20, 43.5%)	Yes (n=26, 56.5%)	*p*
	T2	71.65	73.28	0.560	66.62	67.07	0.882	60.45	61.88	0.612
	T4	67.96	71.92	0.087	63.38	65.67	0.271	58.10	59.92	0.388
	B2	52.11	54.56	0.130	47.33	48.90	0.323	42.65	44.08	0.283
Baseline impedance according to active tip size		n=51	*p*		n=51	*p*		n=46	*p*	
	T2	72.45	(E2 vs E2.5) 0.014		66.88	(E2.5 vs. E3) 0.016		61.26	(E2 vs. E3) <0.001	
	T4	69.90	(E2 vs E2.5) 0.002		64.73	(E2.5 vs. E3) 0.001		59.13	(E2 vs. E3) <0.001	
	B2	53.31	(E2 vs E2.5) <0.001		48.25	(E2.5 vs. E3) <0.001		43.46	(E2 vs. E3) <0.001	
Baseline impedance according to grounding pads location		n=51	*p*		n=51	*p*		n=46	*p*	
	T2	72.45	(T2 vs. T4) 0.255		66.88	(T2 vs. T4) 0.363		61.26	(T2 vs. T4) 0.336	
	T4	69.90	(T4 vs. B2) <0.001		64.73	(T4 vs. B2) <0.001		59.13	(T4 vs. B2) <0.001	
	B2	53.31	(T2 vs. B2) <0.001		48.25	(T2 vs. B2) <0.001		43.46	(T2 vs. B2) <0.001	

Impedance unit, Ω.
E2, percutaneous RFA performed with the electrode of 2 cm active tip; E2.5, percutaneous RFA performed with the electrode of 2.5 cm active tip; E3, percutaneous RFA performed with the electrode of 3 cm active tip; T2, two grounding pads attached on the thigh; T4, four grounding pads attached on the thigh; B2, two grounding pads attached on the back; BMI, body-mass index; HCC, hepatocellular carcinoma; Meta, metastasis; TACE, transarterial chemoembolization; RFA, radiofrequency ablation; S8/S6, hepatic segments 8 and 6.

factor that determines active tip length is the index tumor size including the safe margins.

The baseline impedance was significantly lower with two grounding pads on the back by 25% compared with conventional position (mean impedance was 64.59 Ω with four pads on the thigh, 48.34 Ω with two pads on the back). This may be due to the shorter path between the index tumor and the pads. The mean first roll-off times with two pads on the back were 1 min 3 s using 2 cm tip, 1 min 19 s using 2.5 cm tip, and 3 min 16 s using 3 cm tip; these times are shorter than the conventional approximate first roll-off times with four pads on the thigh of about 3 min using 2 cm tip, about 4 min using 2.5 cm tip, and about 5 min using 3 cm tip (12), even though these data were not statistically compared. The mean total ablation time was 6 min 52 s with the pads located on the back, which was approximately 43% shorter than the conventional ablation time of approximately 12 min (12), although not statistically compared. Our result is consistent with the results of a previous study conducted by placing pads on the back instead of the conventional thigh position (6). Therefore, applying the ground pad position depending on the operator's choice in the actual procedure is considered to be advantageous regarding the first roll-off time.

The present study had limitations such as the possibility of selection bias due to the small subset of patients included and the retrospective design. Further prospective studies about the clinical results of RFA with pads attached to the back are needed.

In conclusion, the significant factors affecting baseline impedance were the location of the pad and active tip size of the electrode. Positioning pads on the back lowers baseline impedance and can shorten first roll-off time, ultimately resulting in reduced total ablation time.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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