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ORIGINAL SCIENTIFIC REPORT

Percutaneous Microwave Ablation of Metastatic Lymph Nodes from Papillary Thyroid Carcinoma: Preliminary Results

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Abstract

Background Our purpose is to assess the effectiveness and safety of ultrasound-guided percutaneous microwave ablation (MWA) for lymph node metastases (LNMs) from papillary thyroid carcinomas (PTC).

Methods In total, 14 patients with recurrent PTC were enrolled in this retrospective study. The vascularity within the ablation zone was evaluated by contrast-enhanced ultrasonography (CEUS) after MWA. Patients were followed up with measurement of the size and volume of tumor, serum thyroglobulin, and clinical evaluation at 7 days, 1, 3, 6 months, and every 6 months thereafter.

Results Twenty-one LNMs were confirmed by biopsy and successfully treated by MWA in a single session. No incomplete ablation was detected by CEUS after treatment. The average largest diameter and volume of the tumors were reduced from 10.1 ± 4.7 mm (range, 3.1–20.0 mm) and 291.9 ± 255.6 mm^3 (range, 11.6–766.6 mm^3) to 0.9 ± 1.6 mm (range, 0–4.1 mm; $p < 0.05$) and 4.0 ± 9.0 mm^3 (range, 0–31.6 mm^3; $p < 0.05$) at the final follow-up. Neither progression of treated tumors nor newly suspicious LNMs could be detected after treatment. The overall complication rate was 7.1% (1/14).

Conclusions Ultrasound-guided MWA can effectively control LNMs from PTC, but it is less safe for tumors in the central compartment. MWA may become an alternative therapy in selected PTC patients, who were ineligible or refused to undergo repeated neck explorations.

Abbreviations

LNMs	Lymph node metastases
PTC	Papillary thyroid carcinoma
US	Ultrasound
CEUS	Contrast-enhanced ultrasonography
MWA	Microwave ablation
FNAB	Fine-needle aspiration biopsy

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Introduction

The incidence of thyroid cancer has rapidly increased in recent decades. Most patients can be cured by a near-total thyroidectomy and neck dissection; however, 20–30% of patients will experience a recurrence and lymph node metastases after surgery [1–3], and 8% of the patients will die from their disease [2]. Currently, if non-radioiodine-avid metastatic lymph nodes are revealed by ultrasound (US) and fine-needle aspiration biopsy (FNAB), most patients will undergo repeated surgery [4]. Although reoperation has been regarded as a treatment method to improve long-term survival for most recurrent lesions, it is usually challenging in the neck because of normal tissue plane distortion secondary to postoperative fibrosis and

scar formation subsequent to previous operation, resulting in a higher rate of postoperative complications, such as hypocalcemia and hoarseness [5]. Moreover, small-sized nodal metastases may be difficult to identify without US guidance during operation.

In recent years, US-guided percutaneous treatments such as ethanol ablation (EA), laser ablation (LA), and radiofrequency ablation (RFA) have been suggested as mini-invasive therapies for metastatic lymph nodes (LNMs) from papillary thyroid carcinomas (PTC), particularly for patients with high risk for an operation or for patients who are unwilling to undergo reoperations [6–9]. Percutaneous ablation had several advantages, such as local anesthesia, less invasiveness, lower complication rates, and the possibility of repeated treatment. Percutaneous microwave ablation (MWA) is a relatively novel and non-surgical method that has been applied to benign and malignant tumors in renal, liver, and lung tumors [10–12], and it has also been used to treat malignant thyroid nodules with good results [13]. With regard to the use of MWA in LNMs from thyroid cancer, the experience is limited. To the best of our knowledge, only 17 cases of LNMs from thyroid cancer treated with MWA have been reported [14]. To expand on these findings, the aim of the present study was to evaluate the efficacy and safety of US-guided MWA for PTC patients with LNMs in the neck.

Materials and methods

Patients

This study was a retrospective study design and was approved by our institutional review board, and written informed consent to treatment was obtained from each patient prior to FANB and MWA. From January 2017 to April 2018, 14 patients with LNMs from PTC were treated by MWA. Of the 14 patients, three were men and 11 were women, and their mean age was 45.1 ± 12.1 years (range, 30–64 years). All patients had undergone total thyroidectomy or hemithyroidectomy, and at least a central compartment node dissection, followed by suppressive levothyroxine treatment. There were eight patients who had already undergone a second radical neck dissection or selective lateral neck dissection. The demographic and clinical information of 14 patients before MWA is summarized in Table 1, and the treatments before MWA are listed in Table 2.

The inclusion criteria for MWA were as follows: (1) confirmed LNMs by FNAB, (2) not more than three LNMs, (3) the patients at least underwent hemithyroidectomy and one subsequent neck dissection, (4) the absence of coarse calcification, which was defined as the maximum diameter of a strong echo larger than 2 mm, (5) patients with recurrences were ineligible or refused to undergo repeated neck explorations for high surgical risk or other reasons. Exclusion criteria: (1) pregnant women, (2) no appropriate puncture route on US, (3) coagulation disorder, (4) patients with severe respiratory failure or heart failure, (5) contralateral vocal cord paralysis.

Pre-ablation assessment

All LNMs were revealed during routine US follow-up and confirmed by US-FNAB, and the size, volume, location, vascularity, and characteristics of all the LNMs were carefully evaluated with real-time US systems (Resona 7, Mindray, China, Mylab 90, Esaote, Italy or Mylab Twice, Esaote, Italy), equipped with a high-frequency probe (4–13 MHz). Before MWA treatment, an appropriate puncture path was determined. All ultrasound examinations, contrast-enhanced ultrasonography (CEUS), and FNABs were carried out by two radiologists, who had more than 10 years of experience in thyroid US imaging. Three orthogonal diameters of the tumor were measured, the volume was calculated with the following equation: $V = \pi ABC/6$ (where V is volume, A is the largest dimension, and B and C are the other two perpendicular dimensions), and the volume reduction was calculated as follows: volume reduction ratio (VRR) = [(initial volume − final volume) × 100]/initial volume.

Laboratory tests included complete blood count, blood coagulation tests, thyroid function tests, as well as serum thyroglobulin (s-Tg), which was measured with thyroid-stimulating hormone suppression. Chest X-ray and electrocardiogram were routinely performed in all patients. No patient was taking warfarin sodium or anti-platelet medications for at least 2 weeks before treatment.

Procedures

MWA was performed by two radiologists with more than 10 years experience in interventional US. Detailed information including possible complications and considerations after MWA was given to the patients before treatment. The patients were supine on an operation bed with hyperextended neck, and a multiparametric monitoring device was used to monitor heart rate, blood pressure, and PO_2. A venous catheter was placed via the dorsal hand vein; however, no pre-medication was used before ablation.

The patient was given 2% lidocaine at the puncture site and along the puncture path. A small skin incision was made after local infiltrative anesthesia. To prevent thermal injury to vital organs (recurrent laryngeal nerve, vagus nerve, internal jugular vein, carotid artery, etc.), we usually

Table 1 Clinical data and ablation condition of patients

Patient	LN	Sex/Age (y)	Location/ Level	Power output (W)	Ablating time (s)	Size (mm)	s-Tg (before MWA)	Follow-up time (m)
1	LN1	M/48	R/III	40	188	15.6 × 9.6 × 8.7	8.10	18
	LN2		R/VI	35	35	6.7 × 5.8 × 7.8		
2	LN3	M/63	L/III	40	136	18.0 × 7.1 × 9.2	3.74	12
	LN4		L/III	35	60	9.1 × 5.1 × 5.5		
3	LN5	F/35	L/III	35	173	20.0 × 8.1 × 9.1	3.47	12
	LN6		L/III	35	62	6.7 × 3.4 × 3.9		
4	LN7	F/32	R/IV	40	52	13.7 × 9.2 × 9.5	0.13	12
5	LN8	F/32	L/III	35	68	10.4 × 5.5 × 11.4	2.65	12
6	LN9	F/33	L/III	35	120	8.9 × 7.1 × 8.2	1.38	6
	LN10		L/IV	35	30	3.0 × 3.1 × 2.4		
7	LN11	F/30	L/VI	35	81	7.2 × 4.4 × 5.1	11.4	6
8	LN12	F/53	R/IV	40	122	8.5 × 11.1 × 10.2	0.04	6
9	LN13	F/38	R/VI	40	162	12.1 × 9.1 × 9.6	3.95	6
10	LN14	F/44	L/VI	35	30	3.9 × 3.3 × 4.1	3.14	6
	LN15		L/VI	35	30	5.0 × 3.2 × 4.3		
	LN16		L/VI	35	40	6.3 × 3.1 × 4.0		
11	LN17	F/49	R/III	35	120	5.0 × 3.8 × 4.7	1.79	6
	LN18		R/III	35	190	14.0 × 4.4 × 6.5		
12	LN19	F/51	L/IV	35	44	12.0 × 8.3 × 9.8	0.04	6
13	LN20	F/64	R/II	40	165	14.0 × 5.9 × 10.0	0.45	6
14	LN21	M/60	L/III	35	64	6.9 × 3.7 × 4.9	7.39	3

injected a mixture of 2% lidocaine and physiological saline solution (1:8 dilution) to achieve a 'hydrodissection technique'(Fig. 1a). After that, a 19-gauge cooled-shaft needle microwave antenna (MTC3, Weijing Medical, Nanjing, China) was percutaneously inserted into the lesion under US guidance. A power output of 35 or 40 W was used, depending on the volume of the tumor. Monosection ablation was performed for the small tumors (< 10 mm), but the ablation plane was adjusted for larger ones to achieve multisection ablation (Fig. 1b, c) in order to prevent persistent heat spreading to the surrounding tissue. We changed the exposure time case by case, trying to completely cover the original tumor. When the hyperechoic zone completely exceeded the target tumor, the therapy was stopped. After several minutes, a bolus of 2.4 ml contrast agents (SonoVue, Bracco, Italy) was administrated to assess the contrast-enhanced perfusion performance of the ablated area. If any enhancement was observed, a secondary ablation procedure was performed. In order to reduce the risk of tumor cell seeding, track ablation was performed during the final withdrawal of the antenna.

Post-ablation observation and follow-up

After treatment, each patient was monitored for approximately 1 h in the hospital. All the possible complications, including skin burns, hematoma, vagus nerve injury, brachial plexus injury, tracheal injury, status of voice, and esophageal perforation were evaluated carefully.

The patients were then followed up with a physical examination, conventional US and laboratory examination at 7 days, 1, 3, 6 months, and every 6 months thereafter. On conventional US, the largest diameter and volume of the lesion, regrowth of the ablated zone and newly developed recurrent lesions were carefully assessed. S-Tg was also measured with thyroid-stimulating hormone suppression for all patients. FNAB was performed in patients when the ablated area remained visible 1 year after MWA. If the patients exhibited persistently s-Tg after ablation, additional tests, such as chest CT, MRI of the spine, or positron emission tomography (PET), were conducted to exclude distant metastases.

Statistical analysis

Data were analyzed by using SPSS statistical software, version 13.0. Descriptive data were reported as

Table 2 Treatments for the patients before MWA

Patient	Type of operation	No. of surgery	No. of I^{131} therapy	Suppressive levothyroxine treatment	Reason for no surgery
1	Total thyroidectomy, central neck dissection, right lateral neck dissection	2	2	Yes	After surgery for lung malignant tumor
2	Total thyroidectomy, central neck dissection, left lateral neck dissection	2	1	Yes	Refuse reoperation
3	Right subtotal thyroidectomy, left total thyroidectomy, central and lateral neck dissection	2	0	Yes	Refuse reoperation
4	Total thyroidectomy, bilateral central and lateral neck dissection	2	1	Yes	Refuse reoperation
5	Total thyroidectomy, central neck dissection, left lateral neck dissection	2	1	Yes	Refuse reoperation
6	Total thyroidectomy, bilateral central and lateral neck dissection	1	1	Yes	Refuse reoperation
7	Right subtotal thyroidectomy, left total thyroidectomy, central and lateral neck dissection	1	0	Yes	Refuse reoperation
8	Total thyroidectomy, bilateral central and lateral neck dissection	1	1	Yes	Renal dysfunction
9	Total thyroidectomy, bilateral central and lateral neck dissection	1	1	Yes	Hypoparathyroidism after surgery
10	Total thyroidectomy, central neck dissection, left lateral neck dissection	1	1	Yes	Hypoparathyroidism after surgery
11	Total thyroidectomy, bilateral central and lateral neck dissection	2	1	Yes	Refuse reoperation
12	Total thyroidectomy, central neck dissection, left lateral neck dissection	2	1	Yes	Refuse reoperation
13	Total thyroidectomy, central neck dissection, right lateral neck dissection	2	1	Yes	Refuse reoperation
14	Total thyroidectomy, central neck dissection, left lateral neck dissection	1	2	Yes	Refuse reoperation

mean ± standard deviation (SD) and range. Paired *t* test was used to compare changes in s-Tg, mean largest diameter and volume of the lesion between pre-MWA and post-MWA measurements. The level of statistical significance was defined as p-values < 0.05.

Results

A total of 21 LNMs were confirmed by FNAB and treated by MWA. The average number of ablated LNMs per patient was 1.5 (range, 1–3). A power output of 35 W was used in 15 lymph nodes, and 40 W was used in 6 lymph nodes. The mean time of ablation was 93.9 ± 56.9 s (range, 30–190 s). The follow-up period was 18 months in one patient, 12 months in four patients, 6 months in eight patients, and 3 months in one patient, respectively. The mean last follow-up time was 8.4 ± 4.1 months (range, 3–18 months).

Pre-ablation measurements

Of the 21 LNMs, fifteen were situated at the lateral compartment and six were at the central compartment. There was only one patient with lesions in both the lateral and central compartments. The average maximum diameter of the LNMs before treatment was 10.1 ± 4.7 mm (range, 3.1–20.0 mm), and the average volume was 291.9 ± 255.6 mm^3 (range, 11.6–766.6 mm^3).

Post-ablation measurements

Immediately after MWA, internal echo of the tumor became hyperechoic because of gas formation (Fig. 2a, b). A few minutes after treatment, the tumor appears to be a hypoechoic area, and vascular signal was absent on color Doppler in all the ablated zones (Fig. 2c). After administrating the contrast agent, all the ablated zones demonstrated an absence of enhancement. The areas with no blood supply on CEUS, which had completely

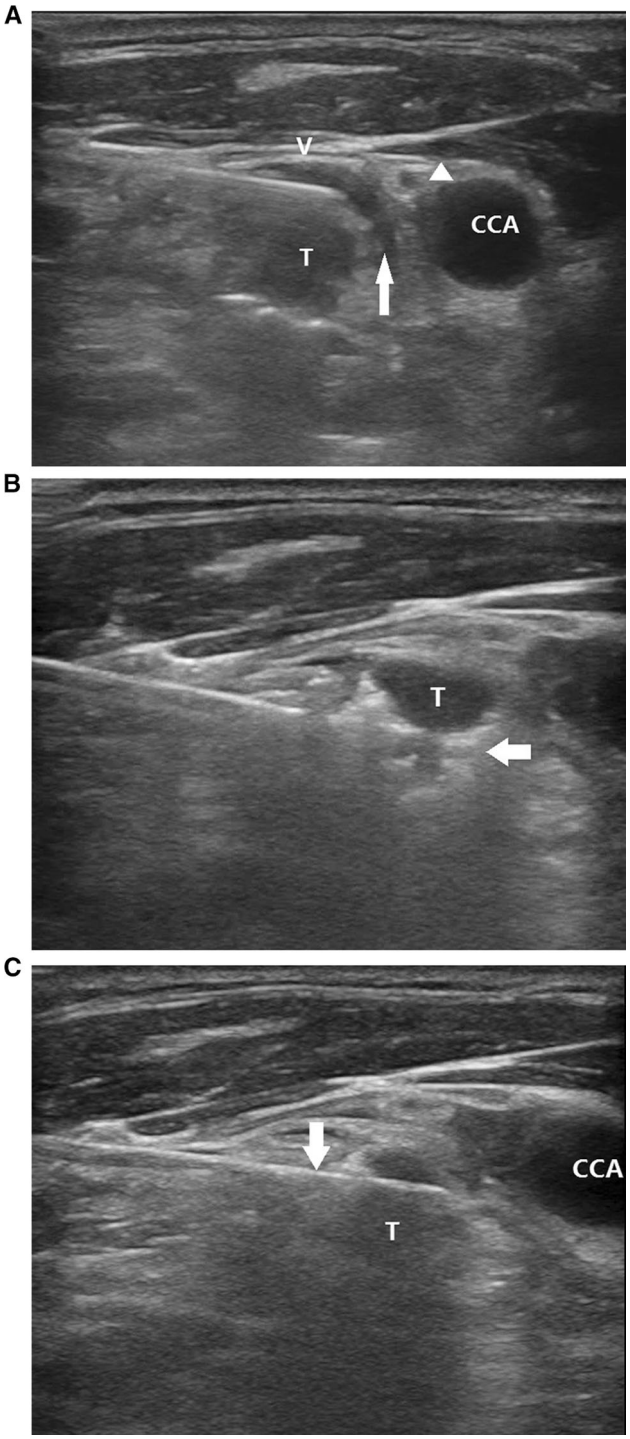


Fig. 1 **a** A 51-year-old woman had a metastatic lymph node (T) in the lateral compartment. After local anesthesia, a bolus of 2% lidocaine and physiological saline solution (arrow) was injected around the tumor to protect the common carotid artery (CCA), internal jugular vein (V), and vagus nerve (arrow head) from thermal injury. **b** A 19-gauge microwave antenna was inserted into the tumor (T) along the short axis of the lesion. The antenna was initially positioned in the deep portion (arrow) of the lesion to perform partial ablation. **c** After the deep portion of the tumor (T) was treated, the antenna (arrow) was moved back under US guidance and positioned in the superficial portion of the lesion to achieve multisection ablation

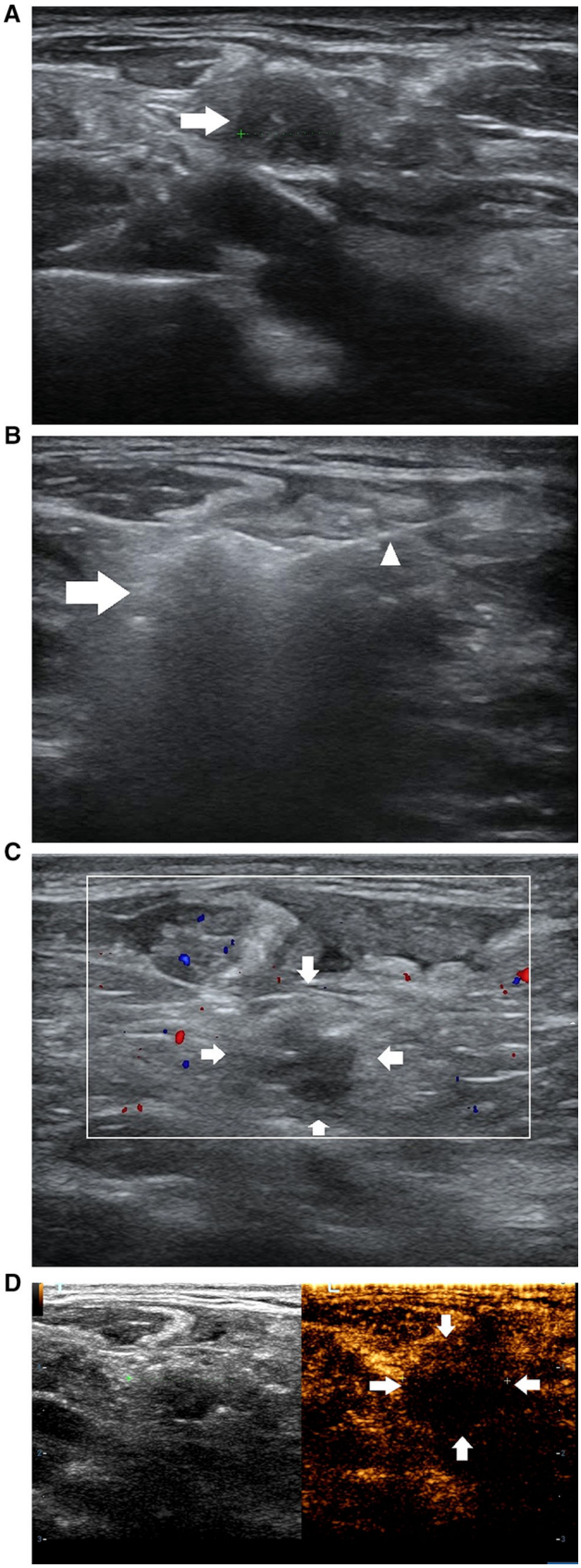
encompassed the pre-operation tumor, were more apparent than those on color Doppler ultrasound (Fig. 2d). The mean largest diameter and volume of the ablated area on CEUS were larger than those of pre-treatment on conventional US (11.0 vs. 10.1 mm, and 379.1 vs. 291.9 mm^3), but the difference was not statistically significant ($P>0.05$). No lesion received a secondary ablation.

Compared with immediate treatment, the ablated area presented a similar appearance on US at the 7-day follow-up. During the subsequent follow-up, the volume of the ablated area gradually decreased. At the last follow-up, the average maximum diameter decreased from 10.1 ± 4.7 mm (range, 3.1–20.0 mm) to 0.9 ± 1.6 mm (range, 0–4.1 mm; $p < 0.05$), and the mean volume was reduced from 291.9 ± 255.6 mm^3 (range, 11.6–766.6 mm^3) to 4.0 ± 9.0 mm^3 (range, 0–31.6 mm^3; $p < 0.05$). The mean VRRs of the ablated area were − 66.9 ± 70.7%, 34.0 ± 67.6%, 77.6 ± 24.7%, 98.2 ± 3.1%, and 98.3 ± 4.2% at the 7-day, 1-month, 3-month, 6-month, and last follow-up visit, respectively (Fig. 3). Finally, 23.8% (5/21) of the tumors remained as small scar-like lesions, and 76.2% (16/21) of the lesions disappeared completely. All the patients showed no persistent increased s-Tg, and no additional examinations such as chest CT and PET were performed. Neither progression of treated tumors nor newly suspicious LNMs could be detected after treatment in this study.

In our series, s-Tg was detectable in 11 patients before MWA treatment. In these patients, the values decreased from 4.31 ± 3.31 ng/ml (range, 0.45–11.40 ng/ml) to 1.28 ± 1.74 ng/ml (range, 0.04–5.80 ng/ml; $p < 0.05$) at the last follow-up. It was undetectable (< 0.2 ng/ml) at 1-month follow-up in two patients, 6-month follow-up in one patient, and 12-month follow-up in one patient after treatment. Before treatment, s-Tg was undetectable in the other 3 patients, and it was still undetectable until the last follow-up.

Complications

All the patients tolerated the MWA procedure relatively well. Although eight patients complained of a sensation of slight pain in the neck after MWA, it was relieved within dozens of minutes. Regional neck swelling at the ablated site was reported in 11 patients, but it resolved without treatment within 1 week. The complication rate in our series was 7.1% (1/14). The complication was voice change, and it developed immediately after MWA. However, the patient recovered within 3 months spontaneously. No local infection, neck hematoma, skin burn, or damage to trachea, vagus nerve, and esophagus were observed.



◀**Fig. 2** **a** A 33-year-old woman had a metastatic lymph node (arrow) measuring 8.9 × 7.1 × 8.2 mm in the level IV region of the lateral compartment. **b** A sonogram showed that the tip of the antenna (arrow head) was surrounded by a hyperechoic region (arrow),which was caused by vaporization during treatment. **c** Color doppler flow image showed no blood flow signal in the ablated area (arrows) after treatment. **d** CEUS demonstrated that a necrotic area (arrow) with a well-defined border measuring 9.8 × 8.3 × 12.1 mm had completely covered the pre-operation tumor

Discussion

The preferred treatment of LNMs from PTC recommended by the American Thyroid Association guidelines is typically surgical resection; however, given the risks of reoperation, the guidelines note that reoperation should be performed for lateral cervical metastases ≥ 10 mm and central cervical metastases ≥ 8 mm in the short-axis diameter, which can be exactly localized on high-resolution anatomic imaging [15]. In our study, many of the LNMs were smaller than 10 mm. Whether it is beneficial to treat small cervical metastases at all is unclear. Several studies suggested that most of the small-sized recurrent nodal disease in the neck can be stable over time, indicating that these tumors can be managed with active surveillance [16, 17]. The decision for further treatment is best derived through collaborative team approach, including endocrinology, surgery, and importantly the patient and family. However, a multidisciplinary team discussion was not performed in our series. In addition to size, several other factors such as patient motivation, comorbidities, and emotional concerns should also be taken into account when considering further treatment [15]. In actual clinical practice, it is usually hard for patients with elevated s-Tg to decide to observe the tumors regularly when the presence of nodal metastasis is identified by FNAB at follow-up [15]. If nodal recurrence is left untreated, it may cause considerable patient anxiety. Moreover, persistent or recurrent lesions could result in local progression, which could make future surgery more difficult [18]. If a minimal-invasive approach could locally control these small lesions, it may be an alternative therapeutic technique in these patients.

EA was once used as a minimally invasive and cheap method for local control of LNMs from PTC, and it has been proved to induce a volume decrease of tumors and s-Tg levels drop in several studies [6, 19]. However, EA is difficult to produce a predictable area of necrosis, and repeated injections may be necessary for a complete ablation. Compared to EA technique, thermal ablations including LA, RFA, and MWA, which could induce a definite area of necrosis, appear to be more advantageous in tumor ablation. US-guided LA and RFA have been

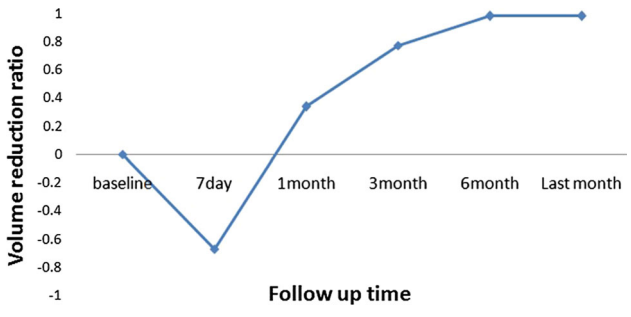


Fig. 3 Graph showed the changes of the mean volume at each follow-up visit after MWA

widely used to ablate benign thyroid nodules and LNMs from PTC [7–9, 20], and both of them are demonstrated to have promising results. With regard to MWA, it was mostly used to treat benign thyroid nodules in the past [21, 22]. Contraindications for this procedure include coagulation disorder, severe respiratory failure or heart failure, and contralateral vocal cord paralysis, and it is also contraindicated in pregnant women. As previously reported [23, 24], MWA seems to have some advantages such as less treatment time, a larger ablation zone, and more complete tumor kill. In particular, it has less susceptibility to the heat-sink effect which is related to the success rate of tumor ablation. Clinical experience is also important for creating an accurate ablation volume and reducing risk of local recurrence. A learning curve effect has been reported in the application of MWA for benign breast tumors. In order to obtain an accurate ablation, at least 30 consecutive cases training may be necessary [25]. Experience in this field was limited in our series, but we also recommend that more cases training is required for doctors without experience in MWA.

Recently, MWA has also been applied for local tumor control of recurrent thyroid carcinomas. In 2015, Yue et al. [14] firstly reported that seventeen patients with 23 recurrent PTCs were treated by MWA, yielding good results. At the 18-month follow-up, there was no recurrence at the treatment site, and the mean VRR of the tumors was 91 ± 14%. The values of s-Tg decreased significantly from 5.3 ± 4.1 ng/ml to 1.3 ± 1.0 ng/ml in nine patients. In this series, the mean VRR and the disappearance rate of the treated tumors were 98.9% and 76.2% at the last follow-up visit, respectively. These results indicated that MWA was an effective treatment method for locally controlling LNMs in patients with PTC. The average VRR and complete disappearance rate after RFA have been reported to range from 93 to 98.4%, and 50 to 77.8%, respectively [9, 19, 26], which were similar to those observed in our study. Baek et al. [26] reported that 9 of 10 patients with metastatic differentiated thyroid carcinomas were free from recurrence after RFA, but two patients had new lesions in the neck. Monchik et al. [27] also reported that three patients developed new metastatic tumors in a total of 16 patients. In comparison, the present study showed no evidence of local regrowth and newly developed metastatic tumors at the last follow-up. This difference is possibly due to the limited sample size in our study, and the mean follow-up time was 8.4 months, relatively short compared with that in the studies by Baek et al. [26] (23.0 months) and Monchik et al. [27] (40.7 months).

After treatment, it is very important to evaluate the local therapeutic effect as soon as possible so that any residual tumor tissue could be detected and retreated promptly. CEUS is a useful method to characterize a focal lesion by assessing the microvascularization with contrast microbubbles. It shows high sensitivity, specificity, and accuracy for evaluating the ablative response of tumors, especially for renal tumor [10] and hepatic carcinoma [11]. In a previous study [7], CEUS showed residual enhancement in three tumors immediately after LA treatment which were not detected on color Doppler, indicating an incomplete ablation. A secondary ablation was then performed. In the present study, CEUS showed no residual enhancement in the ablated area. No lesion required a second ablation. In the subsequent follow-up, s-Tg measurement was regarded as a valuable method to assess the efficacy of ablation in PTC patients [7, 9, 19]. However, it is less useful in those patients with suppressed thyroid-stimulating hormone values who are taking levothyroxine sodium. Stimulated s-Tg measurement with T4 withdrawal might be more sensitive in the detection of recurrences, but it is not always accepted by patients due to hypothyroidism [1]. T4 withdrawal was not performed in our series, and three patients had undetectable s-Tg before MWA. However, in the remaining 11 patients with detectable s-Tg, the level of s-Tg significantly decreased after MWA, indicating an effective treatment.

Voice change caused by recurrent laryngeal nerve injury is a serious complication of ablation. Transient dysphonia after LA and RFA treatment has been reported in several studies [7, 26, 27]. Yue et al. [14] also reported that one patient had dysphonia after MWA for recurrent PTC in the surgical bed. One method to prevent thermal injury is to use the moving shot technique [28]. It was named in contrast to the "fixed-needle technique." The tip of microwave antenna was initially inserted into the most remote and deepest portion of the tumor. When a hyperechoic zone appeared within about 5–10 s, the tip of microwave antenna was moved backward to an untreated area in order to prevent heat injury to the vital surrounding tissue. In our study, the majority of the lymph nodes were not large enough to use the moving shot technique. Instead, we adjusted the ablation plane to achieve multisection ablation

for lesions larger than 10 mm. Another method is to inject spacer fluid between the tumor and the possible location of the nerve, which was regarded as an effective thermal barrier [29]. In our series, a compound spacer solution was used in all patients; however, dysphonia occurred in one patient with three lesions in the thyroid bed. Compared with the vagus nerve, the recurrent laryngeal nerve is not always visible on US. Moreover, the nerve may be in close proximity to the tumor due to severe fibrosis secondary to previous surgery. Hence, we suggest that hydrodissection technique is less useful for lesions in the surgical thyroid bed, and MWA for the tumor in the central compartment should be more cautious. Although the complications in the current series occurred at a low frequency, MWA has not been shown to be better than the gold standard, which is reoperation, with a complication rate of 4.7% [30], and safety of surgery after MWA is not known either.

Some limitations of this study should be illustrated. First, a small sample of patients was enrolled in this study, and the size of the majority tumors was relatively small. Second, s-Tg without T4 withdrawal was used to evaluate the effectiveness of MWA treatment, and stimulated s-Tg measurement may be more sensitive. Third, patients were off anti-coagulation/anti-platelet therapy for 2 weeks which is long time and increases the risk of thrombotic events around the time of the procedure. Finally, the time of follow-up of patients was short, and the long-term follow-up results are not certain. This efficacy should be further compared with other treatments.

In conclusion, MWA was effective for patients with LNMs from papillary thyroid carcinoma after surgery; however, it is less safe for tumors in the central compartment. The results of the present study indicate that MWA may become an alternative therapy for LNMs in selected PTC patients, who were ineligible or refused to undergo repeated neck explorations.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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