Observational Study

Medicine®

OPEN

Ultrasound guided microwave ablation of thyroid nodular goiter and cystadenoma

A single center, large cohort study

Gao Honglei, MD[a], Muhammad Shahbaz, PhD[b,c,d], Zeeshan Farhaj, MD[e], Muhammad Ijaz, MD[f], Sun Yu Kai, MD[a], Carlos Federico Davrieux, MD[g,h], Sun Zuo Cheng, PhD[a,*]

Abstract

Thyroid nodules are one of the most common entities that affect the thyroid gland. Traditionally, their treatment was surgery. Currently, ablation combination with percutaneous procedure became a good option.

To analyze safety, efficacy, and describe our experience in microwave-ablation using ultrasound-guidance for benign thyroid nodules.

A total of 304 patients with 1180 thyroid nodules (thyroid cystadenoma and nodular goiter) were studied retrospectively. Two hundred sixty-seven patients who underwent microwave-ablation successfully in our hospital were enrolled in this study. The baseline, follow-up nodule volume, thyroid function tests, thyroid antibodies, and posttherapy complications were analyzed. The informed written consent was obtained from patients or guardians. The study was approved by the ethics committee of our hospital.

The average age was 50.1 ± 11.7 (21–83 years), 214 were women (80.1%) and 53 (19.9%) were men. The average number of nodules per patient was 4.02 ± 1.8 (1–8), 9.86%, 6.13%, and 84% located in the right thyroid lobe, left lobe, and bilateral, respectively. The average size of the nodules was 5.28 cm^2 ± 3.63 (0.09–23.45 cm^2). The average ablation time was 11 minutes ± 5.36 (3–20 minutes). The hospitalization period was 24 hours ± 10.16 (7–48 hours). Eighteen complications were reported. Postablation volume reduction rate was 54.74% and 93.3% at 3 and 12 months follow-up respectively ($P < .05$). The thyroid function tests, pre and postablation showed no significant changes ($P > .05$).

Ultrasound-guided microwave-ablation of thyroid nodules is safe and effective. More clinical trials are needed to define the true use of microwave-ablation.

Abbreviations: MWA = microwave ablation, US = ultrasound, VRR = volume reduction rate.

Keywords: ablative thyroid treatments, microwave ablation, thyroid nodules, ultrasound-guided ablation

1. Introduction

Thyroid nodules are one of the most common entities that affect the thyroid gland.[1] These nodules frequently occur in the form of multinodular goiter and thyroid cystadenoma. The prevalence is higher in young women, especially in environmental regions with iodine deficiency. Nodules can be accompanied by alterations in thyroid hormone functions (hyperthyroidism and hypothyroidism). Their diagnosis requires an exhaustive physical examination, complete thyroid function tests, and images of the thyroid gland (ultrasound, scintigraphy, others).[2] The management of thyroid nodules requires a multidisciplinary approach. A team in charge must engage clinicians, endocrinologists, and

Editor: Gaurav Malhotra.

GH, MS, and ZF contributed equally to this work.

The study was approved by the ethical committee of Weifang People's Hospital and was performed under the Helsinki Declaration (1964).

The authors have no funding and conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are included in this published article.

[a] Department of General Surgery, Weifang People's Hospital, Shandong, China, [b] Department of Radiology, Qilu Hospital, Shandong University, China, [c] Research Center for Sectional and Imaging Anatomy, Digital Human Institute, School of Basic Medical Sciences, Shandong University, Jinan, Shandong, China, [d] Department of General Surgery, Qilu Hospital affiliated to Shandong University, Jinan, Shandong, China, [e] Department of Cardiovascular Surgery, Shandong Provincial Qianfoshan Hospital, Cheeloo College of Medicine, Shandong University, Jinan, Shandong, China, [f] Department of Pharmacology, Shandong University, School of Pharmaceutical Sciences, China, [g] DAICIM Foundation, Teaching, Research, Assistance in Minimal Invasive Surgery, Buenos Aires, Argentina, [h] Sanatorio de la Mujer, Rosario, Argentina.

[*] Correspondence: Sun Zuo Cheng, Department of General Surgery, Weifang People's Hospital, Weifang, Shandong 261041, China (e-mail: szcwy123@163.com).

How to cite this article: Honglei G, Shahbaz M, Farhaj Z, Ijaz M, Kai SY, Davrieux CF. Ultrasound guided microwave ablation of thyroid nodular goiter and cystadenoma: a single center, large cohort study. Medicine 2021;100:34(e26943).

Received: 19 July 2019 / Received in final form: 13 July 2021 / Accepted: 15 July 2021

http://dx.doi.org/10.1097/MD.0000000000026943

surgeons, among others. When a patient is diagnosed and lobectomy or total thyroidectomy is decided upon, the therapeutic options may include open, video-assisted, or even robotic approaches.[3,4] In recent years, the percutaneous ablative treatments of thyroid disease have been developed. It consists of percutaneous access to the thyroid gland utilizing ultrasound guidance, intimately accompanied by ablation therapies.[5] The most commonly used thyroid ablative treatments, for thyroid lesions are radiofrequency ablation, microwave ablation (MWA), high-intensity focused ultrasound, laser ablation, and ethanol injection.[6–8] Whereas the radiofrequency is the standard of treatment in line with the development of percutaneous procedures and with ablation therapies administered to thyroid diseases. The radiofrequency ablation has evolved for over 2 decades and it is used mainly for ablation nowadays. MWA is new in the ablation procedures and our center has an experience of over 2 years in MWA.

MWA is an active ablation and radiofrequency ablation is a passive ablation. In vivo, microwave conduction does not need to depend on the electrical conductivity of tissue. It is less affected by tissue carbonization and dehydration as compared to radiofrequency. The ablation range is larger, and the temperature in the tumor is high enough. The ablation time is shorter, tumor inactivation is more complete.

Compared with radiofrequency ablation, MWA is less affected by the cooling effect caused by blood perfusion, and can also uniformly inactivate the tumor target area near the blood vessel. Multiple microwave energy sources can be applied at the same time, without the mutual interference phenomenon as in radiofrequency ablation, and can achieve a larger ablation range in a short time. While the radioactive iodine is still used widely in some regions, its main use and side effects require no introduction. For an adenoma it costs 5000–6000 RMB (760–900 USD), and for thyroid cancer 20,000–30,000 RMB (3000–4600 USD).

The radiofrequency ablation costs around 16,000 RMB (2400~ USD) on average, whereas the MWA costs 14,000 RMB (2100~ USD). In this article, we present our results of MWA therapy, applied to benign thyroid nodules in a secondary care hospital in China. This study aimed to analyze the safety, efficacy, and describe our experience in MWA under ultrasound guidance for thyroid nodules.

2. Materials and methods

2.1. Patient selection

This study was conducted at Weifang People's Hospital, Shandong, China. Retrospectively, from January 2017 to January 2019, a total of 304 patients with benign thyroid nodules were recorded. The diagnosis was established with the physical examination, blood analysis, and thyroid biopsy (fine needle aspiration). Before the procedure, all patients were followed up for 6 months up to 1 year to monitor the size of thyroid nodules. Patients who presented with an increase in the size of ≥20% from the first day of the examination underwent therapy.

The patients (n = 267) who underwent MWA under ultrasound guidance were selected for this study. The patients undergoing different treatment and the patient with other medical issues requiring detailed attention were excluded from the study. The study was approved by the ethics committee of our hospital.

2.1.1. Inclusion criteria.

Nodules associated with symptoms (neck discomfort due to lump; general examination found thyroid lump causing psychological discomfort; and dysphagia), nodules classified as TIR1-TIR3[9] on fine-needle aspiration, growing nodules' size as confirmed by the follow-up.

2.1.2. Exclusion criteria.

Irradiation and/or surgery on the head and neck, malignant nodules, pregnancy and lactation, and noncompliant patients.

2.2. Microwave ablation system and ultrasound guidance

The MWA system consists of a generator, a flexible cable, and an antenna. It uses electromagnetic energy in the form of high-frequency waves ranging between 915 MHz and 2450 GHz.[10] This energy produces oscillation of water molecules, the friction of which generates an increase in temperature inducing coagulative necrosis of the target tissue. The generated heat dissipates around the tip of the antenna, in a variable ablation area determined by the power and the time of application. Cellular destruction is caused by the denaturing of intracellular proteins and the cell membrane. When the tissue registers temperatures of 60 to 100 °C, coagulative necrosis begins. With temperatures above 100°C, tissue vaporization and carbonization may occur.[11] The MWA system used was KY-2000 (Kangyou Medical, China) (Fig. 1A). The microwave antennas were KY-2450A-1 - 1.6 mm/130 mm/7 mm (Kangyou Medical, China) (Fig. 1B). Ablation time depended on the size and number of nodules. According to the standardized protocol in our hospital and the manufacturer's recommendation, we used a 40 W power for MWA. Its application in the clinical process can fulfill the objective (Fig. 1C). Ultrasound equipment was LOGIQ e (General Electric Co.), with a 7.5 MHz flat transducer (Fig. 2A).

2.3. Procedure

All patients signed the informed consent for the procedure. We ablated all targeted nodules in 1 setting one by one. The procedure was performed in the ambulatory operating room. Patients were placed in a dorsal decubitus position with the arms extended to the side of the body, and the neck in hyperextension

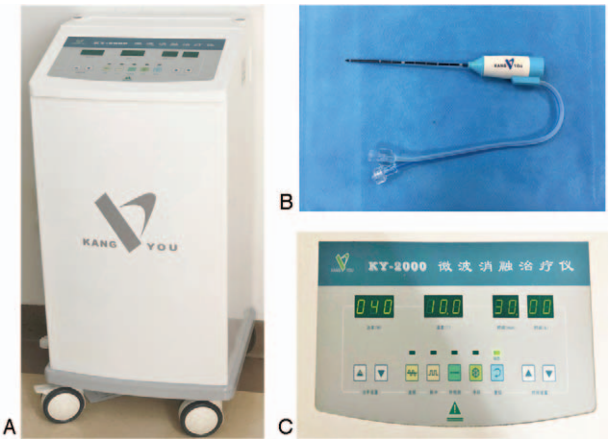

Figure 1. Microwave ablation system. (A) The generator of the ablation system. (B) Microwave the antenna used during the procedures. (C) Ablation system set-up used during the procedures.

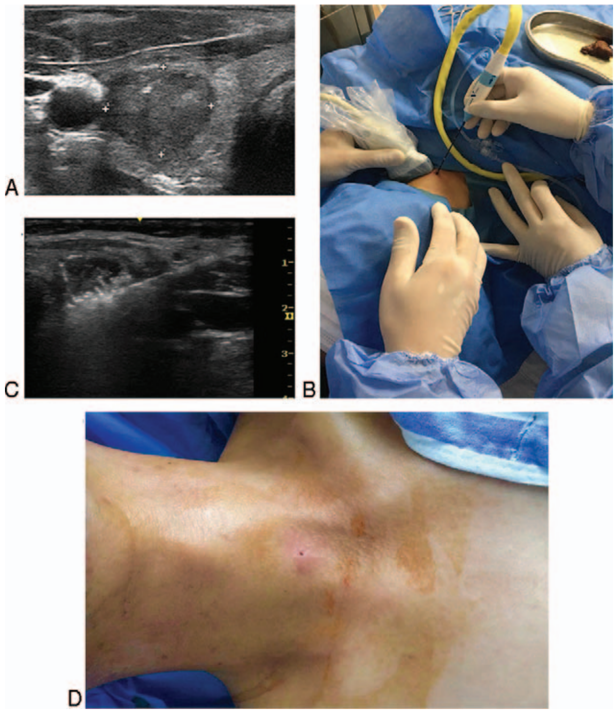

Figure 2. Operative settings. (A) Ultrasound equipment and probe used during the procedures. (B) Patient in dorsal decubitus with the extended neck. The silhouette of a thyroid nodule can be seen. (C) The position of the patient and equipment set-up in the operating room.

(Fig. 2B). Peripheral intravenous access was placed, and monitoring of heart rate, respiratory rate, blood pressure, and oxygenation was performed during the procedure. The skin was cleansed with iodine and the sterile field was placed around the neck, leaving the area of the thyroid free. Lidocaine 2% associated with a small amount of epinephrine mixed with a saline solution was used as a local anesthetic. We injected it into the skin, deep planes, and into the superficial thyroid's layer. Patients given non-steroidal anti-inflammatory drugs before procedure might benefit more from local anesthetic agent effects. In the procedure room, the US equipment was placed to the left of the patient while the ablation system was placed to the right (Fig. 2C). Structures such as the trachea and neck vessels were identified to prevent injuries during punctures. A safe pathway was projected between the skin and the thyroid nodule to be treated. In addition to the important nerves and blood vessels, the tumors were separated from the blood vessels and nerves by hydrodissection. The puncture site in the anterior area of the neck was determined next to the thyroid cartilage (Fig. 2D). In this place, a subcutaneous local anesthetic agent was deposited and then a 2 mm incision was made in the skin through which the microwave antenna was introduced.

After protecting the transducer with disposable and sterile plastic drapes, an US scan was performed to identify the thyroid gland and detect the nodules to be treated (Fig. 3A). The microwave antenna was placed percutaneously inside the thyroid nodule along its short axis under US guidance (Fig. 3B). The desired position was corroborated using the same method (Fig. 3C). Once the microwave antenna was found in its correct position, ablation began. Real-time US-guided ablation control

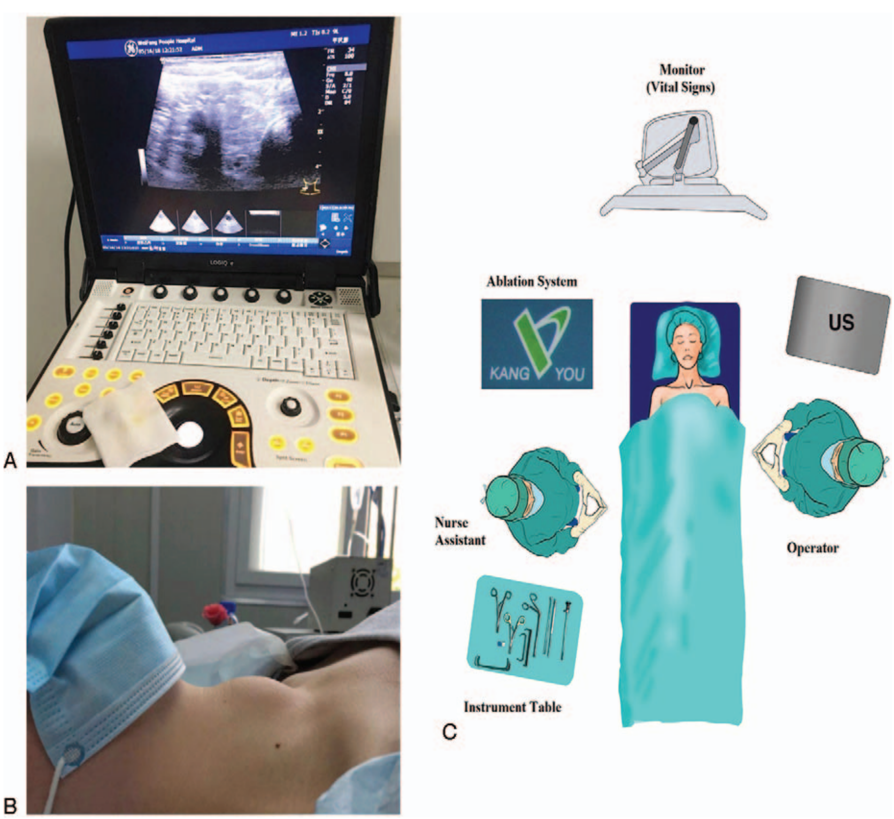

Figure 3. Intraoperative images. (A) Ultrasound scan of the thyroid gland before treatment. Identification of the thyroid nodule. (B) The introduction of the ablation antenna into a thyroid nodule was performed using ultrasound guidance. External view of the introduction of the ablation needle into the thyroid gland. (C) Ultrasound view showing the needle inside the thyroid nodule. (D) Skin appearance after ablative treatment.

was performed. The extension of the ablation zone corresponded to the echogenic change around the antenna. Should the hyperechoic zone fail to completely cover the nodule, the antenna was readjusted. At this moment, the treatment was resumed to complete the ablation. In the case of multiple lesions, we treated unblocked nodules first. We then ablated the remaining nodules once the gas was dispersed to achieve a complete ablation process. For nodules larger than 5 cm, special locations, or when nodules were retrosternal, MWA could be performed in stages to reduce complications. The complete procedure was carried out within a period of 1 to 2 hours. After ablation was over, the antenna was removed. At this time, an ultrasonographic assessment of the ablated area was performed. Only when the hyperechoic area has covered the entire nodule, we could interpret, the ablation was complete. We also ruled out bleeding or hematoma. The patient was then sent to a recovery room. Patients were discharged, after the observation period.

Postablation follow-up was performed every 3 months during 1 year, using US without contrast enhancement, and measuring the regression in size of the thyroid nodules. Additionally, thyroid function tests, antibodies against Tg, thyrotropin receptors, and thyroid peroxidase, were measured preprocedural, 24 hours after MWA (preprocedural and 24H-post termed Baseline), and every 3 months for a year coinciding with US follow-up.

2.1. Statistical analysis

The statistical software SPSS v.19.0 (SPSS IBM Corp.) was used to perform the analysis of the data. The quantitative data were expressed as mean ± standard deviation. The follow-up nodule volume and volume reduction rate (VRR) after MWA, were compared with the baseline volume. The thyroid-stimulating hormone, free triiodothyronine, and free thyroxine, pre and postablation were compared using independent sample *t* test. The $P < .05$ was considered statistically significant.

3. Results

All patients were followed for a required minimum of 1 year. A total of 267 patients underwent US-guided thyroid nodule MWA. There were 36, 186, and 45 patients with TIR 1, 2, and 3, respectively. There were 1075 nodules in 267 patients (Table 1). The average age was 50.1 ± 11.7 (range: 21–83 years). Of all patients, 214 were women (80.15%) and 53 (19.85%) were men. The average number of nodules per patient was 4.02 ± 1.8 (range: 1–8). In 9.86% of cases, the nodules were located in the right thyroid lobe (106 nodules, 22 patients), in 6.14% of cases in the left thyroid lobe (66 nodules, 17 patients), and in 84% of cases, nodules were bilateral (903 nodules, 228 patients). The average size of the treated nodules was 5.28 cm^2 ± 3.63 (range: 0.09–23.45 cm^2). The average time of MWA per patient was 11 minutes (range: 3–20 minutes). The average hospitalization period for MWA patients was 24 hours (range: 7–48 hours). The average follow-up period was 23 months (range: 16–29 months). Patients hospitalized for more than 12 hours were those who had complications.

Eighteen complications were reported, corresponding to 6.74% of the procedures (average of 0.06) (Table 2). When we analyzed the complication rate concerning the number of nodules, it was reduced to 1.67% (average of 0.016). 5/18 patients complained of nausea, 4/18 who had skin burn, 3/18 had a cough, and 2/18 for each, had transient voice change, local edema, and vomiting, respectively.

Postablation follow-up showed that the volumes of nodules were significantly reduced. The nodule area and VRR for both, nodular goiter and thyroid cystadenoma are depicted in detail (Fig. 4, Table 3). There was no statistical difference between the nodular goiter and thyroid cystadenoma VRR ($P > .05$). The cystic nodules were reduced by half in 3 months, and nodules almost disappeared in half a year. Solid nodules began to decrease in about 3 months and almost disappeared in 1 year. Cystadenoma size changed quickly while the nodular goiters showed a comparatively slower decrease in size. No recurrences were reported.

The thyroid function tests, pre, and postablation showed no statistical difference (Table 4). There were no other complications reported, immediately after ablation and during follow-up.

4. Discussion

The finding of thyroid lesions represents a challenge. Cystic, solid, or mixed lesions can be found. Cystic lesions can be

Table 1

Characteristics of the thyroid nodules.

	Total	Thyroid nodules TC	NG	TC + NG
Patients	*n* = 267	132	134	1
Percentage (%)		49.43%	50.18%	0.37%
Nodules	*n* = 1075	530	543	2
Percentage (%)		49.3%	50.5%	0.18%

NG = nodular goiter, TC = thyroid cystadenoma.

Table 2

Complications associated with the ablation.

Procedures (n)	Complications/adverse effects Nausea	Skin burn	Cough	Vomiting	Local edema	Transient voice change	Hypothyroidism	Hyperthyroidism	Death	Pain	Total
MWA (n = 267)	5	4	3	2	2	2	–	–	–	–	18
Percentage (%)	1.85%	1.48%	1.11%	0.74%	0.74%	0.74%	–	–	–	–	6.69% $CI_{95\%}$ = (0.039; 0.095)

CI = confidence interval, MWA = microwave ablation.

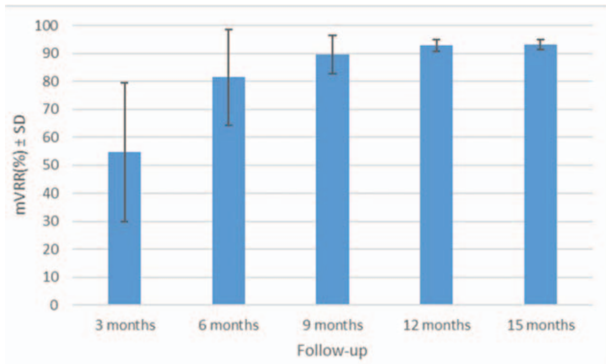

Figure 4. Thyroid volume follow-up. Mean VRR postablation follow-up. SD = standard deviation, VRR = volume reduction rate.

aspirated, in case of recurrence, patients are candidates for the interventional procedure such as radiofrequency ablation, ethanol injection, or MWA recently. Solid thyroid nodules require a more thorough assessment. Occasionally, when the nodules are functioning, therapeutic management requires pharmacological or other in practice treatments. On the other hand, when they do not respond to hormonal therapy presenting with compressive symptoms, or when malignant nodules are suspected, the most aggressive treatments should be considered, such as unilateral lobectomy, bilateral lobectomy, or total thyroidectomy.[1,2,12] According to Guo et al,[1] the prevalence of thyroid nodules, in China, was 46% in the general population, it showed an increment with the increasing age (>40 years). Another report[13] presented that nodular thyroid disease is detected in 3% to 75% of the general population, and between 20% to 70% in an ultrasound scan.

Different minimally invasive procedures have been developed about thyroid conditions. One of them is endoscopic thyroidectomy via the axillo-bilateral breast approach, which was described with good results.[3] Similarly, the results of the totally transoral video-assisted thyroidectomy method have also been promising.[14] Following the same line, the application of robotic surgery in the transoral robotic thyroidectomy technique sought to overcome some of the limitations of the video-endoscopic approach.[4,15] Continuous development of medical technologies has made it possible to treat thyroid nodules using thermo-ablative therapies, such as radiofrequency ablation or MWA. When the 2 techniques were compared, their results showed no great differences.[16–22] In the treatment of benign thyroid nodules, the comparison of MWA with a control group concluded that it was effective in reducing the volume of benign thyroid nodules. It also improved clinical symptoms and obtained adequate cosmetic results.[6] Our study has shown similar results. Other types of ablation therapies were studied and applied to the thyroid gland, such as laser ablation and high-intensity focused ultrasound, showing promising results.[7,8] In this way, thermo-ablative therapies stand for an excellent option in the treatment of thyroid nodules. This coincides with the evolution of percutaneous procedures that therapeutic ablation can be performed percutaneously using ultrasound guidance.[5,23,24].

The reduction in the size of thyroid nodules occurred progressively. In the work of Wu et al,[23] it was reported that, at 3 months after ablation, the nodule VRR was 50%. In our study, we found that the VRR was almost the same (54%) in the same period. Other authors[15,25] reported similar results. On the other hand, when compared to surgery[22] the MWA was better than surgery in terms of the systemic stress response and visual analog score. Jin et al[24] found that there were significant differences between the MWA and thyroidectomy in terms of the stress response, intraoperative blood loss, operation time, postoperative hospitalization duration, and complications rate.

In this work, we present our experience in the treatment of thyroid nodules using US-guided MWA. From the results of this work, it was clear that the advantages of this technique were

Table 3

The changes in volume after microwave ablation >1-year follow-up.

	Baseline Nodule area (cm²)	VRR (%)	Follow-up # 1 (3 months) Nodule area (cm²)	VRR (%)	Follow-up # 2 (6 months) Nodule area (cm²)	VRR (%)	Follow-up # 3 (9 months) Nodule area (cm²)	VRR (%)	Follow-up # 4 (12 months) Nodule area (cm²)	VRR (%)	Follow-up # 5 (15 months) Nodule area (cm²)	VRR (%)
NG	4.7 ± 3.51	0	2.34 ± 2.52	50.22 ± 27.7	0.82 ± 0.30	82.56 ± 16.5	0.57 ± 0.15	90.3 ± 4.4	0.20 ± 0.08	91.2 ± 3.5	0.18 ± 0.06	92.0 ± 2.4
TC	5.87 ± 3.75	0	2.44 ± 2.26	59.29 ± 22.3	1.14 ± 1.27	84.31 ± 14.2	0.79 ± 0.19	91.4 ± 3.2	0.21 ± 0.10	93.5 ± 1.3	0.22 ± 0.09	93.8 ± 1.0
Total	5.28 ± 3.63	0	2.39 ± 2.35	54.74 ± 24.9	0.98 ± 1.14	81.44 ± 17.1	0.68 ± 0.27	89.8 ± 6.9	0.20 + 0.10	92.9 ± 2.0	0.16 + 0.07	93.3 ± 1.8
P value	.4842	0	.2450		<.05		<.05		<.05		<.05	

NG = nodular goiter, TC = thyroid cystadenoma, VRR = volume reduction rate.

Table 4

Thyroid function tests, follow-up, and comparison.

Timeline	TSH uIU/mL	FT3 pmol/L	FT4 pmol/L	T.abs	*P* value
Baseline	1.92 ± 0.64	4.66 ± 0.61	11.40 ± 3.1	Negative	–
3 months	2 ± 0.9	4.78 ± 1.1	13.37 ± 1.2	Negative	>.05
6 months	1.77 ± 0.7	4.1 ± 0.4	12.40 ± 1.1	Negative	>.05
9 months	1.8 ± 0.99	4.18 ± 1.20	14.40 ± 2.1	Negative	>.05
1 year	1.88 ± 1.0	3.89 ± 0.21	12.40 ± 0.9	Negative	>.05

FT3 = free triiodothyronine, FT4 = free thyroxine, T.abs = thyroid antibodies test, TSH = thyroid-stimulating hormone.

manifold: that is, effectiveness in reducing the size of the lesions treated,[26] the good cosmetic results (Fig. 3D), and a brief period of hospitalization of patients without major associated complications.[27] The technique does not only completely inactivate the lesion, but it also protects the patient's normal thyroid function from any inconvenience and trouble caused by the long-term use of the levothyroxine. This technique also proved efficient in primary hyperparathyroidism with parathyroid nodules treatment.[28] As for the disadvantages, we could observe that the complication rate, although not high, was higher than the one reported in other studies.[15] Yet the complications in our MWA cohort were lower than those reported, using MWA for the treatment of papillary thyroid carcinoma.[26] It is noteworthy to point, post radiofrequency follow-up ultrasonography[29] revealing ill-defined margins of a treated nodule were associated with low VRR at 6 months and 1-year follow-up, whether this is true for MWA, requires further investigation.

These satisfactory results led us to propose ablation therapy as a serious option in the treatment of this pathology.

4.1. Study limitations

We do not have the facility to conduct other ablative therapies such as radiofrequency ablation, laser ablation, and high-intensity focused ultrasound, etc. Our experience is limited in MWA which resulted in higher complications than another study.[16] We do not have a control group. Further work is needed to establish MWA's effectiveness, both in thyroid benign nodules and papillary thyroid carcinoma as reported.[26]

5. Conclusion

The US-guided MWA of thyroid nodules is safe and effective. It allows to perform treatment with control in real-time and as an outpatient procedure. We obtained good results with a relatively low rate of complications. Further studies are needed to establish a clear vision of different ablative therapies.

Acknowledgments

The authors wish to thank Guy Temporal, Iana Shutrova, and Christopher Burel, professional editors at IRCAD, France for their assistance in proofreading the manuscript. The authors would also like to wish special thanks to Prof. Mariano Giménez for reviewing this manuscript and giving his valuable comments.

Author contributions

MS, GH, CF, ZF, and SZC were involved in the conception and design of the study, in the collection, assembly, analysis and interpretation of the data and in the drafting of the article; they also provided statistical expertise, MS, ZF, MI, SK, and SZC contributed to final approval of the article, provision of study materials, technical and logistical support as well as critical revision of the article for important intellectual content.

Conceptualization: Muhammad Shahbaz, Gao Hong-lei, Carlos Federico Davrieux, Sun Zuo Cheng

Data curation: Muhammad Shahbaz, Gao Hong-lei, Zeeshan Farhaj, Muhammad Ijaz, Sun Yu Kai, Sun Zuo Cheng.

Formal analysis: Zeeshan Farhaj.

Investigation: Gao Hong-lei, Carlos Federico Davrieux, Muhammad Shahbaz, Zeeshan Farhaj.

Methodology: Gao Hong-lei, Sun Zuo Cheng, Muhammad Shahbaz.

Project administration: Sun Zuo Cheng.

Resources: Gao Hong-lei, Muhammad Shahbaz.

Supervision: Sun Zuo Cheng.

Validation: Sun Zuo Cheng.

Visualization: Sun Zuo Cheng.

Writing – original draft: Muhammad Shahbaz, Gao Hong-lei, Zeeshan Farhaj, Carlos Federico Davrieux.

Writing – review & editing: Gao Hong-lei, Muhammad Shahbaz, Zeeshan Farhaj.

References

[1] Guo H, Sun M, He W, et al. The prevalence of thyroid nodules and its relationship with metabolic parameters in a Chinese community-based population aged over 40 years. Endocrine 2014;45:230–5.

[2] Lawrence WJr, Kaplan BJ. Diagnosis and management of patients with thyroid nodules. J Surg Oncol 2002;80:157–70.

[3] Kim SK, Kang SY, Youn HJ, Jung SH. Comparison of conventional thyroidectomy and endoscopic thyroidectomy via axillo-bilateral breast approach in papillary thyroid carcinoma patients. Surg Endosc 2016;30:3419–25.

[4] Richmon JD, Kim HY. Transoral robotic thyroidectomy (TORT): procedures and outcomes. Gland Surg 2016;6:285–9.

[5] Mainini AP, Monaco C, Pescatori LC, et al. Image-guided thermal ablation of benign thyroid nodules. J Ultrasound 2016;20:11–22.

[6] Wu W, Gong X, Zhou Q, Chen X, Chen X. Ultrasound-guided percutaneous microwave ablation for solid benign thyroid nodules: comparison of MWA versus control group. Int J Endocrinol 2017;9724090.

[7] Korkusuz Y, Gröner D, Raczynski N, et al. Thermal ablation of thyroid nodules: are radiofrequency ablation, microwave ablation and high intensity focused ultrasound equally safe and effective methods? Eur Radiol 2018;28:929–35.

[8] Sui WF, Li JY, Fu JH. Percutaneous laser ablation for benign thyroid nodules: a meta-analysis. Oncotarget 2017;8:83225–36.

[9] Nardi F, Basolo F, Crescenzi A, et al. Italian consensus for the classification and reporting of thyroid cytology. J Endocrinol Invest 2014;37:593–9.

[10] Petre EN, Sofocleous C. Thermal ablation in the management of colorectal cancer patients with oligometastatic liver disease. Visc Med 2017;33:62–8.

[11] Vogl TJ, Nour-Eldin NA, Hammerstingl RM, Panahi B, Naguib NNN. Microwave ablation (MWA): basics, technique and results in primary and metastatic liver neoplasms - review article. RoFo Fortschr Geb Rontgenstr Nuklearmed 2017;189:1055–66.

[12] Efremidou EI, Papageorgiou MS, Liratzopoulos N, Manolas KJ. The efficacy and safety of total thyroidectomy in the management of benign thyroid disease: a review of 932 cases. Can J Surg 2009;52:39–44.

[13] Gharib H, Papini E, Paschke R, et al. American Association of Clinical Endocrinologists, Associazione Medici Endocrinologi, and European Thyroid Association medical guidelines for clinical practice for the diagnosis and management of thyroid nodules: executive summary of recommendations. J Endocrinol Invest 2010;33(Suppl 5):51–6.

[14] Benhidjeb T, Wilhelm T, Harlaar J, Kleinrensink GJ, Schneider TA, Stark M. Natural orifice surgery on thyroid gland: totally transoral video-assisted thyroidectomy (TOVAT): report of first experimental results of a new surgical method. Surg Endosc 2009;23:1119–20.

[15] Lee HY, You JY, Woo SU, et al. Transoral periosteal thyroidectomy: cadaver to human. Surg Endosc 2015;29:898–904.

[16] Yue WW, Wang SR, Lu F, et al. Radiofrequency ablation vs. microwave ablation for patients with benign thyroid nodules: a propensity score matching study. Endocrine 2017;55:485–95.

[17] Cheng Z, Che Y, Yu S, et al. US-guided percutaneous radiofrequency versus microwave ablation for benign thyroid nodules: a prospective multicenter study. Sci Rep 2017;7:9554.

[18] Vorländer C, David Kohlhase K, Korkusuz Y, et al. Comparison between microwave ablation and bipolar radiofrequency ablation in benign thyroid nodules: differences in energy transmission, duration of application and applied shots. Int J Hyperthermia 2018;35:216–25.

[19] Zheng BW, Wang JF, Ju JX, Wu T, Tong G, Ren J. Efficacy and safety of cooled and uncooled microwave ablation for the treatment of benign thyroid nodules: a systematic review and meta-analysis. Endocrine 2018;62:307–17.
[20] Nixon IJ, Angelos P, Shaha AR, Rinaldo A, Williams MD, Ferlito A. Image-guided chemical and thermal ablations for thyroid disease: review of efficacy and complications. Head Neck 2018;40:2103–15.
[21] Zhi X, Zhao N, Liu Y, Liu JB, Teng C, Qian L. Microwave ablation compared to thyroidectomy to treat benign thyroid nodules. Int J Hyperthermia 2018;34:644–52.
[22] Yan J, Qiu T, Lu J, Wu Y, Yang Y. Microwave ablation induces a lower systemic stress response in patients than open surgery for treatment of benign thyroid nodules. Int J Hyperthermia 2018;34:606–10.
[23] Wu W, Gong X, Zhou Q, Chen X, Chen X, Shi B. US-guided percutaneous microwave ablation for the treatment of benign thyroid nodules. Endocr J 2017;64:1079–85.
[24] Jin H, Fan J, Liao K, He Z, Li W, Cui M. A propensity score matching study between ultrasound-guided percutaneous microwave ablation and conventional thyroidectomy for benign thyroid nodules treatment. Int J Hyperthermia 2018;35:232–8.
[25] Wei Y, Qian L, Liu JB, Liu Y. Sonographic measurement of thyroid nodule changes after microwave ablation: relationship between multiple parameters. Int J Hyperthermia 2018;34:660–8.
[26] Teng DK, Li HQ, Sui GQ, et al. Preliminary report of microwave ablation for the primary papillary thyroid microcarcinoma: a large-cohort of 185 patients feasibility study. Endocrine 2019;64:109–17.
[27] Barile A, Quarchioni S, Bruno F, et al. Interventional radiology of the thyroid gland: critical review and state of the art. Gland Surg 2018; 7:132–46.
[28] Liu C, Wu B, Huang P, et al. US-guided percutaneous microwave ablation for primary hyperparathyroidism with parathyroid nodules: feasibility and safety study. J Vasc Interv Radiol 2016;27: 867–75.
[29] Ahn HS, Kim SJ, Park SH, Seo M. Radiofrequency ablation of benign thyroid nodules: evaluation of the treatment efficacy using ultrasonography. Ultrasonography 2016;35:244–52.