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The Efficacy and Safety of Radiofrequency Ablation for Trachea-Adjacent cT1N0M0 Papillary Thyroid Carcinoma: a five-year follow-up study

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Abstract

Objective To assess the efficacy and safety of ultrasound-guided radiofrequency ablation (RFA) in treating clinical-T1N0M0 (cT1N0M0) papillary thyroid carcinoma (PTC) adjacent to the trachea.

Methods This study retrospectively analyzed 423 patients (563 cT1N0M0 PTC nodules) who underwent ultrasound-guided RFA at Xuanwu Hospital, Capital Medical University, between October 2020 and December 2023. All cases were confirmed as non-aggressive, without distant metastasis or concurrent malignancies, by RFA and imaging evidence. Based on the distance between the lesion and trachea (≤2 mm), the lesions were categorized into a trachea-adjacent group and a trachea-distant group. The study aimed to evaluate the efficacy and safety of RFA for cT1N0M0 PTC adjacent to the trachea. The rates of local recurrence, new lesions, lymph node metastasis (LNM), and complications are recorded and compared.

Results 1.Patient Distribution: The trachea-adjacent group included 102 cases (18.1%), while the trachea-distant group included 461 cases (81.9%).

2. There was no significant difference in the complete absorption rate and Disease-free survival rate (DFS) between the trachea-adjacent group and the trachea-distant group at different follow-up times (all p 0.05).

3. Disease Progression: Disease progression occurred in 10 patients (2.36%), including 8 cases of new lesions, 0 cases of residual lesions and 2 cases of LNM. The 8 new lesions happened at a mean detection time of (22.2 ± 1.1) months, with all underwent re-RFA, achieving complete absorption in all cases. After a mean follow-up of (37.6 ± 3.5) months, no additional new lesions or LNM were detected. There are no LNM in the trachea-adjacent group.

4. Comparative Outcomes Between Groups: No significant differences were observed between the trachea-adjacent and trachea-distant groups in terms of complete absorption rate, disease progression rate (all p> 0.05).

5. Complications and Risk Factors: Complications occurred in 15 patients (3.5%), with 11 cases in the trachea-adjacent group and 4 in the trachea-distant group, demonstrating a statistically significant difference (p< 0.05). All complications occurred within 3 months post-RFA. Multivariate Logistic regression analysis identified tumor location in the thyroid dorsal region and the extent of tracheal contact as independent risk factors for complications.

Conclusion With precise preoperative evaluation, operative techniques and assessment, RFA is a relatively effective and safe treatment for cT1N0M0 PTC located adjacent to the trachea, providing patients with an additional therapeutic option.

1 Introduction

Papillary thyroid carcinoma (PTC) is the most common type of thyroid malignancy, composed of approximately 80% of all cases[1]. Studies indicate that PTC is an indolent tumor characterized by low

invasiveness and a good prognosis[2]. Surgery remains the traditional gold standard treatment[3]. While some patients cannot tolerate surgery due to poor physical condition, or some patients cannot accept surgery because they are anxious about complications like hypothyroidism. In recent years, RFA has emerged as an invasive alternative, demonstrating efficacy and safety for low-risk, non-metastatic PTC. The guideline recommended that when performing RFA on low-risk PTC, the distance from the trachea should be ≥2mm[5]. However, a proportion of lesions are located in proximity to the trachea (< 2 mm). While these lesions are small in size, or patients may not be tolerant to surgery, or strongly refuse surgery, RFA may serve as a viable alternative treatment for such cases[9]. However, for lesions in close tracheal proximity (< 2 mm), which carry higher metastatic potential and risk of RFA-related complications, including recurrent laryngeal nerve damage, further research is needed to establish whether RFA can achieve both safe and complete tumor ablation. This study aims to: (1) validate the efficacy and safety of RFA for trachea-adjacent cT1N0M0 PTC (≤ 2mm from trachea); (2) analyze whether anatomical relationships between lesions and trachea influence ablation outcomes; and (3) identify risk factors for complications, thereby expanding the therapeutic options for patients with trachea-adjacent cT1N0M0 PTC.

2 Materials and Methods

2.1Patients

This cohort study was approved by the Ethics Committee of Xuanwu Hospital, Capital Medical University. The study cohort comprised patients who underwent ultrasound-guided RFA for cT1N0M0 PTC at the Ultrasound Department, Xuanwu Hospital, Capital Medical University between October 2020 and December 2023. As this was a retrospective analysis, written informed consent was waived for all participants.

This retrospective study reviewed the electronic medical records of cT1N0M0 PTC patients who underwent ultrasound-guided RFA at Xuanwu Hospital, Capital Medical University, between October 2020 and December 2023. Inclusion criteria comprised: (1) PTC confirmed by fine-needle aspiration (FNA) with a maximum diameter of ≤ 2 cm; (2) no evidence of extrathyroidal extension (ETE), cervical LNM, or distant metastasis on ultrasound or chest CT (cT1N0M0); (3) no evidence of high-risk PTC subtypes on biopsy; (4) ineligible for or refused SR or AS; (5) ≥ 6 months of follow-up. Exclusion criteria included: (1) PTC > 2cm; (2) childhood or adolescent neck radiation exposure; (3) coagulation disorder or severe organ dysfunction; (4) the history of thyroid surgery or RFA; (5) inadequate follow-up (< 6 months or incomplete data). Based on the inclusion and exclusion criteria, 447 patients were ultimately included in the study cohort.

Based on whether the distance to the trachea was < 2 mm, we categorized the lesions into a trachea-adjacent group and a trachea-distant group. Within the trachea-adjacent group, lesions were further classified based on their contact range with the trachea into: no contact (< 2 mm), partial contact (contact area < 50%), extensive contact (contact area ≥ 50%), Fig. 1.

2.2 Preoperative Assessment

Comprehensive preoperative assessments were conducted for all patients, including ultrasonography, laboratory tests, and ultrasound-guided RFA. Preoperative ultrasound evaluation was performed by an

experienced radiologist (who performed all RFA procedures) to record tumor characteristics, exclude ETE and cervical LNM, and determine clinical TNM (cT1N0M0) staging in conjunction with other clinical evidence. Laboratory investigations comprised thyroid function, serum calcitonin, complete blood count, coagulation function, blood glucose levels and infectious disease screening. FNA procedures were performed by three experienced radiologists skilled in puncture techniques.

2.3 Equipment and Techniques

2.3.1 Equipment

Ultrasound was performed using Philips EPIQ5 and Mindray Resona R9 systems with linear array probes. RFA was conducted using a Maide RFA system (S-1500) with an 18G internally cooled electrode (active tip: 5–10 mm, power output: 10–60 W). Contrast-enhanced ultrasound (CEUS) was employed using SonoVue (Bracco), diluted in 5 mL of saline, and injected intravenously (2.4 mL).

2.3.2 RFA Procedure

Before the procedure, detailed preoperative counseling was conducted to explain the principles, therapeutic effects, and potential complications of RFA to alleviate patient anxiety and promote cooperation during treatment. All RFA procedures were performed by the same experienced radiologist (Yang JC, MD), with the ablation range and surgical approach determined based on preoperative ultrasound evaluation. During ablation, patients were continuously monitored with electrocardiography for heart rate, blood pressure, and oxygen saturation. With the neck fully exposed and after routine disinfection and draping, local anesthesia was administered via subcutaneous injection of 1% lidocaine hydrochloride. Hydrodissection (0.9% saline) was used to protect adjacent structures[5]. Under ultrasound guidance, the electrode needle was inserted into the target lesion. Ablation was performed from the deep to superficial portions until the entire lesion was covered by hyperechoic gasification. Post-ablation contrast-enhanced US (CEUS) confirmed complete ablation (Fig. 2).

2.3.3 Follow-up

Postoperative surveillance was conducted by two experienced radiologists (Yang JC and Chang Y) at 1, 2, 3, 6, 9, 12, 15, 18, 24, 36, 48 and 60 months. During each follow-up, both ultrasound and CEUS were performed to evaluate the volume reduction rate (VRR) of the ablation zone (Fig. 3). Complete tumor ablation was defined as the absence of enhancement in the ablation area on CEUS immediately after RFA and during the absorption period, with no suspicious lesions detected in the original ablation area after complete absorption. Disease progression comprised pathologically confirmed local tumor persistence, new lesions, and cervical LNM. Local tumor persistence was defined as the persistence of PTC at the original ablation site. New lesions referred to PTC emerging in other regions of the gland. DFS was calculated based on the disease progression events.

2.4 Statistical Analysis

Statistical analysis was performed using SPSS 26.0 software. Normally distributed continuous variables were expressed as mean ± standard deviation and compared between groups using independent samples t-tests. Non-normally distributed continuous variables were presented as median (P25, P75) and analyzed with the Mann-Whitney *U* nonparametric rank-sum test. Categorical variables were described as frequencies and percentages, with intergroup differences assessed by chi-square tests or Fisher's exact test. Logistic regression analysis was used to identify risk factors influencing the complications. A two-sided $p < 0.05$ was considered statistically significant.

3 Results

3.1 Patient Characteristics

A total of 423 patients with 563 lesions were enrolled in this study. The mean age was (44.3 ± 11.5) years, comprising 305 female patients (mean age [45.1 ± 11.6] years) and 118 male patients (mean age [42.3 ± 11.0] years). Based on the lesion-to-trachea distance (≤ 2 mm), the 563 lesions were categorized into the trachea-adjacent group (102 lesions, 18.1%) and the trachea-distant group (461 lesions, 81.9%).

3.2 Disease Progression

3.2.1 Analysis of Outcomes in Both Groups

The technical success rate of RFA was 100% in all enrolled cases, with a follow-up period from 24 to 60 months, the number of patients followed at 24, 36, 48, and 60 months was 138, 92, 73, and 105, respectively. Between the follow-up time, in the trachea-adjacent group (96 patients), the complete absorption rates at 24, 36, 48 and 60 months were 93.5%, 98.5%, 100.0% and 100.0% respectively; the trachea-distant group (327 patients) showed the complete absorption rates at 24, 36, 48 and 60 months were 96.2% ,99.0%, 99.3% and 100.0% respectively. 21 patients exhibited incomplete absorption during follow-up (12 were followed for 12 months, 6 for 24 months, and 3 for 36 months), Table 1. Three patients exhibited slow absorption post-ablation, including 1 from the trachea-adjacent group and 2 from the trachea-distant group. At the 36-month follow-up, the residual volumes in these patients measured 0.92 cm^3, 0.38 cm^3, and 0.44 cm^3, respectively, which were distinguishable from scar-like changes. None of these patients experienced metastasis or recurrence, and contrast-enhanced imaging showed no enhancement at each follow-up time. Follow-up is ongoing.

Table 1
Comparison of Complete Absorption Rates Between the Trachea-adjacent Group and the Trachea-distant Group at Different Follow-up Time

After RFA	**Trachea-adjacent group(N = 96)**				**Trachea-distant group(N = 327)**			
Follow-up Time (months)	**24**	**36**	**48**	**60**	**24**	**36**	**48**	**60**
12	18/26 (69.2%)	27/36 (75.0%)	10/15 (66.7%)	12/16 (75.0%)	83/112 (74.1%)	42/56 (75.0%)	44/58 (75.9%)	65/89 (73.0%)
24	25/26 (96.2%)	35/36 (97.2%)	12/15 (80.0%)	15/16 (93.8%)	107/112 (93.7%)	53/56 (96.4%)	56/58 (96.6%)	87/89 (97.8%)
36		35/36 (97.2%)	15/15 (100.0%)	16/16 (100.0%)		56/56 (100.0%)	57/58 (98.2%)	88/89 (98.9%)
48			15/15 (100.0%)	16/16 (100.0%)			58/58 (100.0%)	88/89 (98.9%)
60				16/16 (100.0%)				89/89 (100.0%)

Among the 423 enrolled patients, disease progression occurred in 10 patients (2.36%), including 8 patients of newly developed lesions (3 in the trachea-adjacent group and 5 in the trachea-distant group) with a mean detection time of (18.5 ± 2.7) months. No residual lesions were detected. 2 patients developed LNM (both in the trachea-distant group), with a mean detection time of (3.5 ± 0.3) months, Table 2. Of the 10 patients with disease progression, all patients underwent re-RFA, achieving complete absorption in all cases. After a mean follow-up of (37.6 ± 3.5) months, no additional new lesions or LNM were detected.

Statistical analysis revealed no significant differences between the two groups in complete absorption or disease progression (all $p > 0.05$). The emergence time and size of new tumors in the two groups also demonstrated no statistically significant differences (all $p > 0.05$).

Table 2
Comparison of treatment outcomes between trachea-adjacent and trachea-distant groups

Complete absorption (N, %)	**Trachea-adjacent group (N = 96)**	**Trachea-distant group (N = 327)**	***p* value**
Yes	91(94.8)	311(95.1)	0.74
12 months	67(69.8)	234(71.6)	0.58
24 months	20(20.8)	68(20.9)	0.97
36 months	4(3.1)	6(1.7)	0.55
48 months	0(0.0)	2(0.6)	0.76
60 months	0(0.0)	1(0.3)	0.74
No	5(5.2)	16(4.9)	0.85
Disease Progression	3(3.1)	7(2.1)	0.55
Residual Lesion	0	0	-
New Lesion	3	5	0.39
Size (mm)	0.36 ± 0.03	0.39 ± 0.03	0.84
Time (months)	18.7 ± 3.4	18.0 ± 2.2	0.72
LNM	0	2	0.51
Size (mm)	-	3.1, 4.5	-
Time (months)	-	3.2, 3.8	-
*p<0.05;**p<0.01			

3.2.2 Comparative Analysis of Complications

Among the 423 patients included in the study, 15 (3.5%) developed complications. All complications occurred within 3 months post-RFA. In the trachea-adjacent group (N = 96), of the 11 patients (11.5%) who developed complications, 10 had unifocal lesions and 1 had multifocal lesions. In the trachea-distant group (N = 327), 4 patients (1.2%) developed complications. Statistical analysis revealed a significant difference in complication rates between the two groups ($p < 0.05$).

Due to the insufficient sample size in the T1b group, statistical analysis was not feasible. Therefore, this study focused on comparing differences between the complication and non-complication subgroups within the T1a group. Univariate analysis was performed to screen for factors associated with complications. The ablation time and maximum size were significantly different between cT1aN0M0 PTC and cT1bN0M0 PTC ($p < 0.05$). In the cT1aN0M0 group, analysis revealed that tumors located on the dorsal side of the thyroid, at

the lower pole of the left lobe, or in extensive contact with the trachea(≥ 50%) were associated with a higher incidence of complications. (all $p < 0.05$, Table 3).

Table 3
Univariate analysis for the risk factors of Complications in the Trachea-adjacent PTC Group

Variable	**Complications (N = 11, n = 12)**			**Non-complications (N = 85, n = 90)**			***P-value* of T1a[#]**
	T1a (N = 10, n = 10)	**T1b (N = 2, n = 2)**	***p-value***	**T1a (N = 73, n = 77)**	**T1b (N = 12, n = 13)**	***p-value***	
Sex							
Male	1(10.0)	1(50.0)	0.32	20(26.0)	6(50.0)	0.17	0.44
Female	9(90.0)	1(50.0)	-	53(74.0)	6(50.0)	-	-
Age (years)	41.5 ± 4.0	37.0, 39.0	0.72	44.6 ± 1.3	38.6 ± 2.7	0.07	
Maximum Size(cm)	0.51 ± 0.28	1.4, 1.1	**<0.01****	0.57 ± 0.20	1.31 ± 0.13	**<0.01***	0.84
Multifocality							
Yes	0(0.0)	0(0.0)	-	4(5.2)	1(8.3)	0.54	0.59
No	10(100.0)	2(100.0)	-	69(94.8)	11(91.7)	-	-
Nodule Location							
Left upper pole	0(0.0)	0(0.0)	-	6(7.8)	0(0.0)	0.59	0.47
Left middle pole	3(30.0)	1(50.0)	0.57	8(10.4)	3(23.1)	0.19	0.11
Left lower pole	3(30.0)	0(0.0)	0.55	6(7.8)	1(7.7)	0.74	**0.05***
Right upper pole	0(0.0)	0(0.0)	-	5(6.5)	1(7.7)	0.62	0.54
Right middle pole	0(0.0)	0(0.0)	-	16(20.8)	3(23.1)	0.72	0.20
Right lower pole	4(40.0)	1(50.0)	0.68	21(27.3)	4(30.8)	0.73	0.46
Isthmus	0(0.0)	0(0.0)	-	15(19.5)	1(7.7)	0.46	0.20
Nodule Location							
Dorsal	8(80.0)	0(0.0)	0.09	22(28.6)	3(23.1)	0.55	**<0.01****
Non-dorsal	2(20.0)	2(100.0)	-	55(71.4)	10(76.9)	-	-
Tracheal Contact							

*$p<0.05$;**$p<0.01$

[#]means the comparison between the group with complications and the group without complications in the cT1aN0M0 group

Variable	Complications (N = 11, n = 12)			Non-complications (N = 85, n = 90)			*P-value* of T1a[#]
	T1a (N = 10, n = 10)	**T1b (N = 2, n = 2)**	***p-value***	**T1a (N = 73, n = 77)**	**T1b (N = 12, n = 13)**	***p-value***	
No contact	2(20.0)	1(50.0)	0.46	56(72.7)	9(69.2)	0.25	**<0.01****
Partial contact(<50%)	4(40.0)	0(0.0)	0.47	12(15.6)	3(23.1)	0.45	0.65
Extensive contact(≥50%)	4(40.0)	1(50.0)	0.58	9(11.7)	1(7.7)	0.56	**0.05***
Distance from Capsule							
<2mm	7(70.0)	2(20.0)	0.55	50(64.9)	10(76.9)	0.53	0.53
≥ 2mm	3(30.0)	0(0.0)	-	27(35.1)	3(23.1)	-	-
Ablation Power (W)	30(20,40)	45, 30	0.69	30(30,35)	30(30,40)	0.44	0.29
hydrodissection fluid (mL)	40(40,65)	40, 40	0.22	40(30,40)	40(40,60)	0.08	0.14
Ablation Time (s)	102.3 ± 50.2	167, 136	**0.02***	97.6 ± 37.5	173.6 ± 62.1	**<0.01****	0.75
Surgical Approach							
Lateral lobe puncture	9(90.0)	1(50.0)	0.32	55(71.4)	9(69.2)	0.55	0.28
Isthmus puncture	1(10.0)	1(50.0)	-	22(28.6)	4(30.8)	-	-
p*<0.05;*p*<0.01							
[#]means the comparison between the group with complications and the group without complications in the cT1aN0M0 group							

Multivariate analysis was performed to screen for factors associated with complications in the cT1aN0M0 PTC group. Both the extent of tracheal contact and dorsal thyroid location were identified as independent risk factors for complications (all $p < 0.05$, Table 4).

Table 4
Multivariate analysis for the risk factors of Complications in the cT1aN0M0 PTC Group

Variable	**β**	**OR**	**95%CI**	***p* value**
Nodule Location				
Left lower pole	1.037	2.820	0.346 ~ 22.985	0.33
Nodule Location				
Dorsal	0.723	0.485	0.104 ~ 2.266	**0.04***
Tracheal Contact				
No contact	0.912	10.646	1.782 ~ 63.585	**<0.01****
Partial contact(≥ 50%)	1.045	13.294	1.714 ~ 103.115	**0.01***
p*<0.05;*p*<0.01				

In the non-complication group, 10 lesions (11.1%) exhibited extensive contact with the trachea but did not develop complications. Comparative analysis revealed that lesions located in the left lower lobe were more frequent in the complication group. In contrast, lesions in the isthmus and the upper lobe were more frequent in the non-complication group (all $p<0.05$). Additionally, complications occurred more frequently in ablations performed before 2023($p<0.05$, Table 5).

Table 5
Univariate and multivariate analysis for the risk factors of Complications in the Extensive contact trachea PTC Group

Variable	**Complication(n = 4)**	**Non-complications(n = 10)**	***p-value***	**Multivariate analysis**		
				β	**OR**	***p-value***
Age(year)	36.5(33.5,39.5)	40(29,51)	0.34			
Sex						
Male	2(50.0)	7(70.0)	0.58			
Female	2(50.0)	3(30.0)	-			
Tumor Size						
T1a	3(75.0)	9(90.0)	0.51			
T1b	1(25.0)	1(10.0)	-			
Nodule Location						
Left upper pole	-	-	-			
Left middle pole	1(25.0)	0(0.0)	0.50			
Left lower pole	2(50.0)	0(0.0)	**0.02***	1.03	0.46	0.47
Right upper pole	-	-	-			
Right middle pole	0(0.0)	3(30.0)	**0.05***			
Right lower pole	1(25.0)	2(20.0)	0.67			
Isthmus	0(0.0)	5(50.0)	**0.04***	0.41	1.50	0.66
Nodule Location						
Dorsal	3(75.0)	5(50.0)	0.58			
Non-dorsal	1(25.0)	5(50.0)	-			
Distance from Capsule						
<2mm	3(75.0)	8(80.0)	0.67			
≥ 2mm	1(25.0)	2(20.0)				
Ablation Power (W)	35(30,45)	30(25,35)	0.13			
hydrodissection fluid (mL)	40(40,60)	40(20,40)	0.83			
Ablation Time (s)	143.5(64.5,243.0)	121.5(48.5,194.5)	0.56			
*p<0.05;**p<0.01						

Variable	Complication(n = 4)	Non-complications(n = 10)	*p-value*	Multivariate analysis		
				β	OR	*p-value*
Surgical Approach#						
Lateral lobe puncture	2(50.0)	4(40.0)	0.59			
Isthmus puncture	2(50.0)	6(60.0)	-			
Ablation Period[#]						
Pre-2023	3(75.0)	2(20.0)	**0.04***	1.504	0.22	0.31
Post-2023	1(25.0)	8(80.0)	-			
p*<0.05;*p*<0.01						

[#] means ablation procedures were performed during 2021–2023, with 2023 as the demarcation point for comparison.

4 Discussion

Current clinical guidelines have not explicitly endorsed RFA for trachea-adjacent PTC, likely due to concerns regarding potential risks of extrathyroidal extension, possible tracheal infiltration and increased complication rates[5]. Nevertheless, for those patients with RFA indications or those who were intolerant to surgery, RFA was still performed. To further evaluate the efficacy and safety of RFA in trachea-adjacent cT1N0M0 PTC, this study compared the complete absorption rate and DFS in the trachea-adjacent group and the trachea-distant group, and there was no significant difference between the two groups at different follow-up times (all $p>0.05$). Follow-up results demonstrated that neither LNM nor permanent complications occurred in these cases. This demonstrates that the vast majority of cT1N0M0 trachea-adjacent PTC are indolent cancers, for which RFA is a relatively safe and effective treatment option.

In the trachea-adjacent group, disease progression occurred in 3 cases (2.94%), with all lesions successfully treated by re-RFA, and no LNM occurred. During the mean follow-up period of (17.6 ± 3.5) months, no new lesions or LNM were detected, these findings demonstrate the efficacy of RFA for treating trachea-adjacent cT1N0M0 PTC. However, long-term follow-up is still required.

A significant difference in complication rates between the two groups ($p < 0.05$). In the trachea-adjacent group, complications occurred in 11 patients, all of which resolved within 3 months without permanent recurrent laryngeal nerve injury. These findings are consistent with previous studies[18]. Multivariate logistic regression confirmed that dorsal thyroid location was the independent risk factor for complications (all $p < 0.05$), aligning with existing literature[19][20]. This discrepancy may be attributed to the RLN courses close to the posterior thyroid capsule, particularly near the tracheoesophageal groove. During RFA, thermal energy may spread to the nerve, leading to a transient. The result also confirmed that the extent of tracheal contact

was an independent factor. During the ablation procedure, a larger contact area between the lesion and the trachea necessitates a broader ablation zone to ensure adequate coverage, which inevitably increases the risk of complications due to potential injury to adjacent nerves. Therefore, for nodules located in high-risk anatomical sites—such as those on the dorsal aspect of the thyroid, the lower pole of the left lobe, or those with extensive contact with the trachea—a lateral lobar puncture approach is recommended. This study compared the incidence of complications before and after 2023, during which the operator modified the technique. The results indicate that the lateral lobe puncture offers an advantage in reducing the risk of complications. This technique allows more precise control over ablation temperature, duration, and extent, thereby minimizing unnecessary extension of the ablation zone. Therefore, RFA for trachea-adjacent cT1N0M0 PTC requires a high level of an experienced radiologist. In this study, all procedures were performed by a single experienced radiologist (Yang JC, MD), thereby eliminating variability in technical proficiency.

The hydrodissection technique has been routinely employed in RFA to create a protective fluid barrier between the lesion and surrounding tissues, thereby safeguarding critical anatomical structures. Previous studies have demonstrated that insufficient fluid insulation along the medial capsule may predispose to recurrent laryngeal nerve injury[19], while adequate hydrodissection combined with low-power ablation has been established as a safe and effective approach for treating cT1N0M0 PTC in the danger triangle[16]. In this study, the ablation power was maintained within the range of 30–40 W, and the ablation time was strictly controlled. Ablation time is a critical factor. In this study, the procedures were performed precisely and efficiently, with short operative times consistently achieved. Furthermore, hydrodissection serves as a diagnostic tool to evaluate potential tracheal invasion by assessing tumor-trachea separability during fluid injection. Although tumors located in the lower pole may present challenges in achieving clear separation from the trachea, the absence of recurrence or metastasis during extended follow-up periods ultimately confirms both the non-invasive nature and favorable outcomes. In this study, all lesions located at the lower pole were successfully separated from the trachea using the hydrodissection technique, thereby confirming the absence of tracheal invasion.

In this study, 10 lesions (11.1%) exhibited extensive contact with the trachea but did not develop complications. Comparative analysis revealed that lesions in the left lower lobe were more frequent in the complication group. In contrast, lesions in the isthmus and the upper lobe were more frequent in the non-complication group. This is because lesions located in the upper pole and isthmus can be more easily separated from the trachea via hydrodissection, thereby reducing the risk of damage to the trachea and adjacent nerves. Among these 10 lesions without complications, 8 underwent RFA after 2023, when radiologist proficiency had improved, indicating a potential role of experience in reducing complications. Therefore, this study confirms the precisely preoperative evaluation, operative techniques (including operative time, ablation power, puncture and the hydrodissection technique) and assessment are essential, RFA is a safe and effective treatment for trachea-adjacent cT1N0M0 PTC in patients without capsular invasion proved by ultrasound, distant metastasis, or previous history of thyroid surgery or RFA .

Among the trachea-distant cT1N0M0 PTC cases, complications occurred in 4 patients. This may be attributed to: (1) insufficient protective effect from the relatively thin cervical adipose layer in some patients,

potentially leading to thermal injury of the RLN; (2) anatomical variations in the RLN course; (3) patient-related factors, such as lifestyle habits predisposing to RLN injury or inflammation.

This study has several limitations that should be acknowledged. First, as a retrospective analysis, it may be subject to potential recall bias. Second, being a single-center investigation, the sample source lacks diversity and the follow-up duration was relatively short. A prospective study is warranted. Based on existing research outcomes, we have already developed a protocol for a prospective trial and are currently in the process of collecting patient data.

5 Conclusion

With precise preoperative evaluation, operative techniques and assessment, RFA is an effective and safe treatment for cT1N0M0 PTC located adjacent to the trachea, providing patients with an additional therapeutic option.

Abbreviations

Abbreviation	Full Trem
RFA	Radiofrequency Ablation
PTC	Papillary Thyroid Carcinoma
DFS	Disease-free Survival
LNM	Lymph Node Metastasis
CEUS	Contrast-enhanced Ultrasound
VRR	Volume Reduction Rate

Declarations

Human Ethics and Consent to Participate Declarations

This cohort study was approved by the Ethics Committee of Xuanwu Hospital, Capital Medical University.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Authors' contributions

Zimeng Lv: Methodology, Formal analysis, Data Curation, Writing - Original Draft,

Jingchun Yang: Conceptualization, Methodology, Writing - Review & Editing

Yifan Wang: Data Curation

Ying Chang: Methodology

Zhenpeng Leng: Methodology

Xufen Yang: Data Curation

Xiaoxia Jia: Data Curation

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Figures

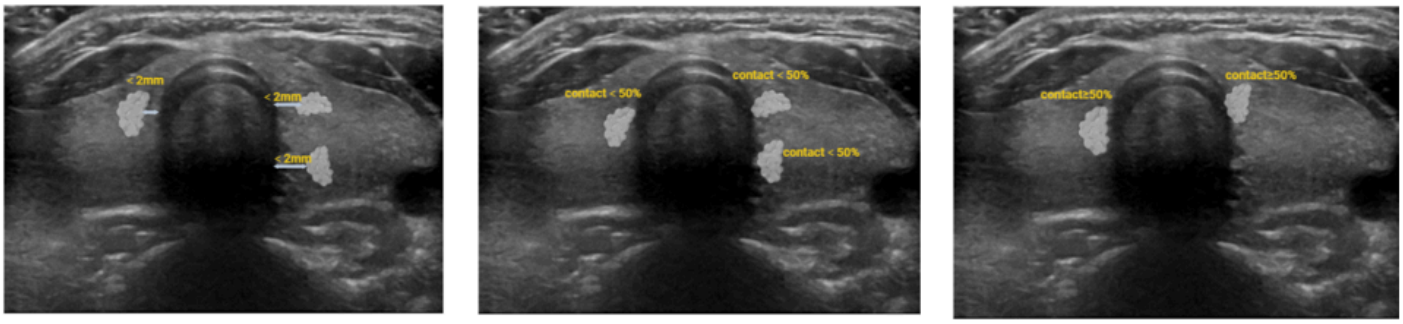


Figure 1

Schematic Diagram of Lesion-Trachea Contact Zones: (a) No contact (distance >2 mm between tumor and trachea); (b) Partial contact (the extent of tracheal contact <50%); (c) Extensive contact (the extent of tracheal contact ≥50%).

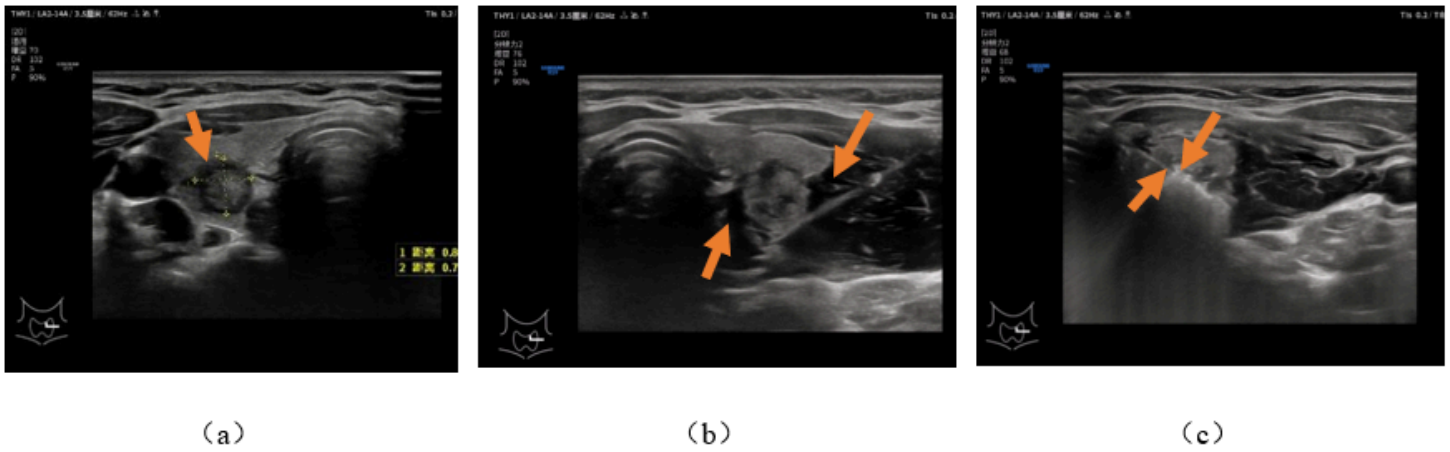


Figure 2

This study included ultrasound images of a 29-year-old male with PTC adjacent to the trachea undergoing RFA. (a) Two-dimensional ultrasound image of the tumor (yellow arrow) before ablation; (b) The 'fluid isolation method' (arrows) was used, with saline injected into the space between the tumor and surrounding soft tissue; (c) The ablation needle (arrow) was inserted into the target tumor via a lateral lobe approach.

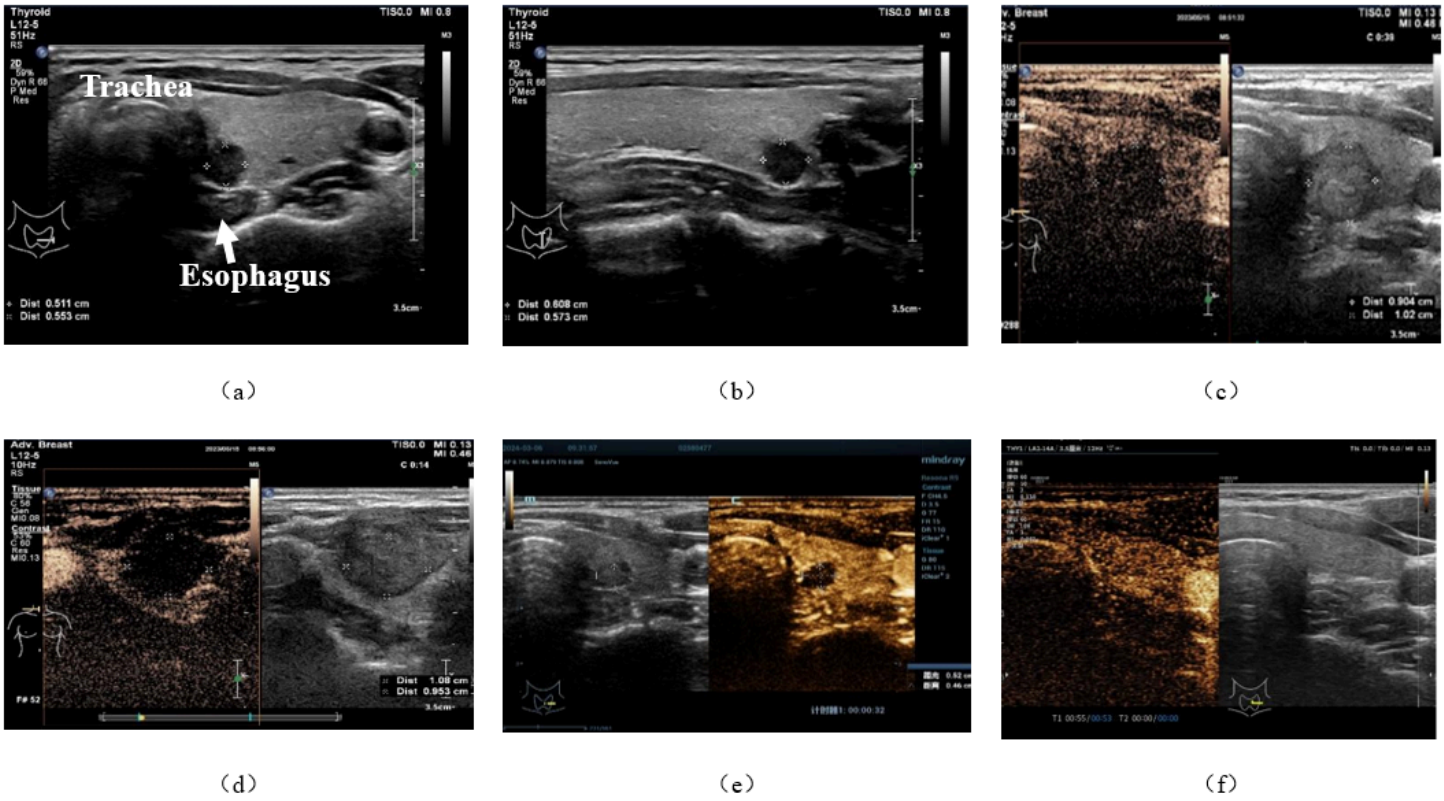


Figure 3

This study included ultrasound images of a 40-year-old female with PTC adjacent to the trachea undergoing RFA. (a, b) Longitudinal and transverse sections of the tumor on two-dimensional ultrasound before RFA; (c) Contrast-enhanced ultrasound showing no enhancement in the ablation zone post-RFA; (d) One-month follow-up contrast-enhanced ultrasound of the ablation zone; (e) Twelve-month follow-up contrast-enhanced ultrasound of the ablation zone; (f) Complete disappearance of the ablation zone at the 18-month follow-up.