International Journal of Hyperthermia

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ihyt20

Efficacy and safety of ultrasound-guided radiofrequency, microwave and laser ablation for the treatment of T1N0M0 papillary thyroid carcinoma on a large scale: a systematic review and meta-analysis

Xuemeng Gao, Yang Yang, Yitong Wang & Ying Huang

To cite this article: Xuemeng Gao, Yang Yang, Yitong Wang & Ying Huang (2023) Efficacy and safety of ultrasound-guided radiofrequency, microwave and laser ablation for the treatment of T1N0M0 papillary thyroid carcinoma on a large scale: a systematic review and meta-analysis, International Journal of Hyperthermia, 40:1, 2244713, DOI: 10.1080/02656736.2023.2244713

To link to this article: https://doi.org/10.1080/02656736.2023.2244713

INTERNATIONAL JOURNAL OF HYPERTHERMIA
2023, VOL. 40, NO. 1, 2244713
https://doi.org/10.1080/02656736.2023.2244713

Efficacy and safety of ultrasound-guided radiofrequency, microwave and laser ablation for the treatment of T1N0M0 papillary thyroid carcinoma on a large scale: a systematic review and meta-analysis

Xuemeng Gao, Yang Yang, Yitong Wang and Ying Huang

Department of Ultrasound, Shengjing Hospital of China Medical University, Shenyang, Liaoning, China

ABSTRACT

Background: To analyze the efficacy and safety of radiofrequency ablation (RFA), microwave ablation (MWA) and laser ablation (LA) in T1N0M0 papillary thyroid carcinoma (PTC) patients by evaluating data on several outcomes on a large scale.

Materials and methods: Literature searches were conducted in PUBMED, EMBASE and the Cochrane Library for studies of thermal ablation (TA) for treating T1N0M0 PTC. Data on the volume reduction rate (VRR) at the 12-month follow-up and final follow-up, complete disappearance rate, local recurrence rate, lymph node metastasis rate, and complication rate of RFA, MWA and LA were evaluated separately. RFA effects were compared between T1aN0M0 and T1bN0M0 patients.

Results: A total of 36 eligible studies were included. RFA presented superior efficacy than MWA in 12-month VRR. At the final follow-up, the difference was slight in subgroups, showing a significant reduction. The complete disappearance rate of LA (93.00%) was higher than that of RFA (81.00%) and MWA (71.00%). Additionally, the local recurrence rate pooled proportions of MWA and RFA were both 2.00%, lower than that of the LA group (3.00%). There was no event of distant metastasis. The lymph node metastasis rates were similar, as RFA (1.00%) had the lowest. For minor complication rates, the pooled proportions of RFA (3.00%) were smaller than those of LA (6.00%) and MWA (13.00%). T1aN0M0 lesions presented with better outcomes than T1bN0M0 lesions.

Conclusion: RFA, MWA and LA were reliable in curing PTC, and RFA presented advantages in most outcomes. T1aN0M0 patients may experience fewer side effects than T1bN0M0 patients.

ARTICLE HISTORY
Received 9 March 2023
Revised 31 July 2023
Accepted 31 July 2023

KEYWORDS
Thermal ablation; radiofrequency ablation; microwave ablation; laser ablation; papillary thyroid carcinoma; ultrasound

1. Introduction

Thyroid cancer incidence has risen since the early 1970s largely due to increased detection of small papillary thyroid cancer (PTC) [1]. The age-standardized incidence in China rose from $3.21/10^5$ in 2005 to $9.61/10^5$ in 2015 [2]. Recent research has revealed that overdiagnosis may contribute to an increase in cases of PTC, probably related to the developed sensitivity in detecting micro-sized tumors [3]. PTC is the most common subtype and carries the best overall prognosis [4]. According to the TNM stage classification, thyroid cancer with a diameter equal to or less than 2 cm is characterized as T1N0M0. The 7th edition of the American Joint Committee on Cancer (AJCC) staging system trialed a subdivision of T1 tumors into T1a (<1 cm) and T1b (1.0-2 cm) [5].

Surgical resection (SR) is widely performed according to several guidelines as the first-line treatment for PTC patients [6,7]. However, for low-risk PTC, controversies about surgery or less-invasive therapy exist across the phases of disease management [8]. A previous study found that surgical treatments had side effects and influenced patients' quality of life in terms of their health [9]. Thermal ablation (TA) is highly recommended as a proper treatment in low-risk PTC patients who are at surgical risk, have a short life expectancy and relevant comorbidities, or are unwilling to undergo surgery, according to the Europe 2021 Clinical Practice Guideline for the Use of Minimally Invasive Treatments in Malignant Thyroid Lesions [10]. In recent decades, a growing number of studies have confirmed the therapeutic effect of TA as a safe and effective minimally invasive treatment, including radiofrequency ablation (RFA), microwave ablation (MWA) and laser ablation (LA), each with their own benefits and drawbacks. For instance, a study presented that RFA was an effective and safe treatment alternative for T1N0M0 PTC, but that it could cause the risks of incompletely ablated tumors and LNM metastasis [11]. Other studies suggested that PTC patients under MWA therapy also experienced a low incidence of complications and good therapeutic effects [12,13]. Therefore, a comprehensive evaluation of the efficacy and safety of the three thermal techniques is required to provide patients with suitable treatment options. The efficacy of TA

CONTACT Ying Huang huangying712@163.com Department of Ultrasound, Shengjing Hospital of China Medical University, Shenyang, Liaoning, China.
Supplemental data for this article can be accessed online at https://doi.org/10.1080/02656736.2023.2244713.

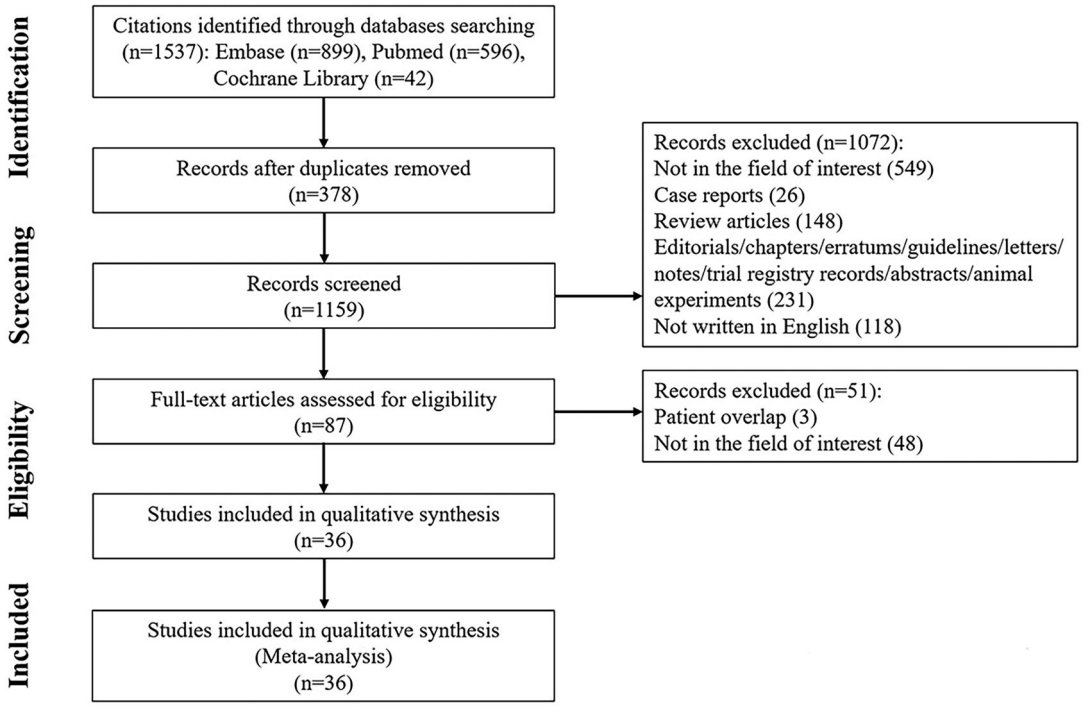

Figure 1. Flow diagram of article selection process.

Table 1. Characteristics of the studies included in this meta-analysis.

Authors	Year	Ablation modality	Study design	No. patients	Age mean ± SD	Male/female	Follow-up (m/d) mean ± SD	NOS-Gen
Yan et al. [18]	2022	RFA	Retrospective	55	42.67 ± 11.11	8/47	46.61 ± 12.34 m	8
Yan et al. [18]	2022	RFA	Retrospective	55	44.09 ± 9.89	11/44	47.93 ± 11.45 m	8
Zhang et al. [19]	2022	RFA	Retrospective	133	45.77 ± 9.88	36/97	6.45 ± 4.92 m	8
Yan et al. [20]	2022	RFA	Retrospective	91	43.0 ± 13.0	18/73	50.9 ± 15.9 m	7
He et al. [21]	2021	RFA	Retrospective	95	66 ± 4.4	71/24	36.6 ± 16.6 m	8
He et al. [22]	2021	RFA	Retrospective	71	43.94	23/48	NA	7
Song et al. [23]	2021	RFA	Retrospective	115	44.9 ± 10.4	18/97	26.97 ± 9.62 m	8
Xiao et al. [24]	2021	RFA	Retrospective	131	41.2 ± 10.9	27/104	26.2 ± 13.3 m	8
Xiao et al. [24]	2021	RFA	Retrospective	131	41.1 ± 10.3	28/103	25.1 ± 10.6 m	8
Xiao et al. [25]	2021	RFA	Retrospective	91	40.7 ± 9.3	19/72	26.0 ± 10.3 m	8
Yan et al. [26]	2021	RFA	Retrospective	414	43.56 ± 9.79	323/91	42.15 ± 11.88 m	8
Yan et al. [27]	2021	RFA	Retrospective	332	44.1 ± 9.5	82/250	47.0 ± 18.8 m	8
Yan et al. [28]	2021	RFA	Retrospective	47	43.39 ± 9.26	37/10	47.77 ± 11.54 m	8
Cho et al. [29]	2020	RFA	Retrospective	74	46 ± 12	8/66	72 ± 18 m	7
Song et al. [30]	2020	RFA	Retrospective	112	44.9 ± 10.6	94/18	30.2 ± 13.9 m	8
Wu et al. [31]	2020	RFA	Retrospective	198	42.5 ± 9.5	141/57	25.9 ± 4.5 m	7
Xiao et al. [16]	2020	RFA	Retrospective	66	41.0 ± 9.2	52/14	20.5 ± 7.4 m	8
Zhang et al. [32]	2020	RFA	Retrospective	94	45.4 ± 10.8	24/70	64.2 ± 2.8 m	8
Ding et al. [33]	2019	RFA	Retrospective	37	45.14 ± 12.96	8/29	6.7 ± 4.0 m	7
Lim et al. [34]	2019	RFA	Retrospective	133	46 ± 12	19/114	39 ± 25 m	8
Wei et al. [35]	2022	MWA	Retrospective	350	44 ± 12	82/268	25.31 ± 8.06 m	8
Zheng et al. [36]	2022	MWA	Retrospective	21	45.05 ± 9.17	12/9	36.1 ± 5.5 m	8
Lu et al. [37]	2021	MWA	Retrospective	73	38.71 ± 11.82	60/13	8.12 ± 4.54 m	7
Cao et al. [38]	2021	MWA	Retrospective	34	43 ± 11	8/26	17 ± 9 m	8
Wang et al. [39]	2021	MWA	Retrospective	63	43.56 ± 14.172	12/51	NA	7
Wu et al. [40]	2021	MWA	Retrospective	106	44.39 ± 11.13	19/87	24.95 ± 10.55 m	8
Zu et al. [12]	2021	MWA	Retrospective	320	44.99 ± 10.62	83/237	890.7 ± 532.9 d	7
Teng et al. [41]	2020	MWA	Retrospective	41	46.10 ± 8.85	13/28	NA	8
Yue et al. [42]	2020	MWA	Prospective	119	48.7 ± 11.8	27/92	37.2 ± 20.9 m	7
Lia et al. [43]	2019	MWA	Retrospective	168	47.36 ± 10.75	36/132	753 ± 520 d	8
Teng et al. [44]	2019	MWA	Retrospective	185	42.2 ± 11.7	40/145	20.7 ± 8.8 m	8
Teng et al. [45]	2018	MWA	Retrospective	15	48.0 ± 8.8	6/9	NA	8
Zhang et al. [46]	2022	LA	Retrospective	12	38.75 ± 6.80	3/9	19.75 ± 11.46 m	8
Zhang et al. [46]	2022	LA	Retrospective	60	39.33 ± 9.72	11/49	16.33 ± 10.01 m	8
Kim et al. [47]	2021	LA	Retrospective	90	48.7 ± 10.7	7/83	111.6 ± 20.7 m	7
Peng et al. [48]	2021	LA	Retrospective	105	44.1 ± 12.2	31/74	65.4 ± 6.3 m	8
Ji et al. [49]	2019	LA	Retrospective	37	43.9 ± 17.6	12/25	16.5 ± 6.9 m	8
Zhou et al. [50]	2019	LA	Retrospective	36	41.5 ± 11.3	14/22	49.2 ± 4.5 m	8
Zhang et al. [51]	2018	LA	Retrospective	64	42.5 ± 12.3	23/41	25.7 ± 8.2 m	8

SD, standard deviation; NA, data unavailable; m, month; d, day.

on PTC has been examined by several meta-analyses, though typically on a small scale, and the outcomes have occasionally been contradictory [14,15].

In order to further explore the safety and efficacy of different thermal treatments of T1N0M0 PTC, as well as to compare the RFA effect between T1aN0M0 PTC and T1bN0M0 PTC, we thus conducted a large-scale meta-analysis and synthesized the results with previous meta-analyses.

2. Materials and methods

2.1. Literature search strategy

Two reviewers (blinded and blinded) independently performed the literature search. The search terms were ("Thyroid carcinoma" OR "Thyroid microcarcinoma" OR "Thyroid malignancy") AND ("radiofrequency ablation" OR "RFA" OR "laser ablation" OR "LA" OR "microwave ablation" OR "MWA" OR "thermal ablation") Data were collected based on PubMed, Embase, and Cochrane Library from the establishment of the database to November 18, 2022. The search terms were as follows: in PubMed, ((thyroid [Title/Abstract]) AND ((((Carcinoma[MeSH Terms]) OR (carcinoma [Title/Abstract])) OR (microcarcinoma [Title/Abstract])) OR (malignancy [Title/Abstract]))) AND ((((((((((Radiofrequency ablation [MeSH Terms]) OR (radiofrequency [Title/Abstract])) OR (radio frequency[Title/Abstract])) OR (radio-frequency[Title/Abstract])) OR (RFA[Title/Abstract])) OR (microwave [Title/Abstract])) OR (micro wave [Title/Abstract])) OR (microwave [Title/Abstract])) OR (MWA[Title/Abstract])) OR (laser[Title/Abstract])) OR (LA[Title/Abstract])) OR (thermal ablation [Title/Abstract])).

2.2. Inclusion criteria

Two reviewers selected relevant studies by screening the literature search results. Studies meeting all of the following criteria were included: 1) ultrasound-guided biopsy confirmed PTC [10]; 2 cm or less in maximum diameter; 2) absence of lymph node (LN) metastasis, distant metastasis, and extrathyroidal extension (ETE); 3) patients received RFA, MWA or LA treatment, independent outcomes reported for each TA technique; 4) retrospective and prospective observational studies were both included; and 5) reported details on outcomes (i.e. local recurrence, volume reduction rate, complete disappearance rate and major or minor complications).

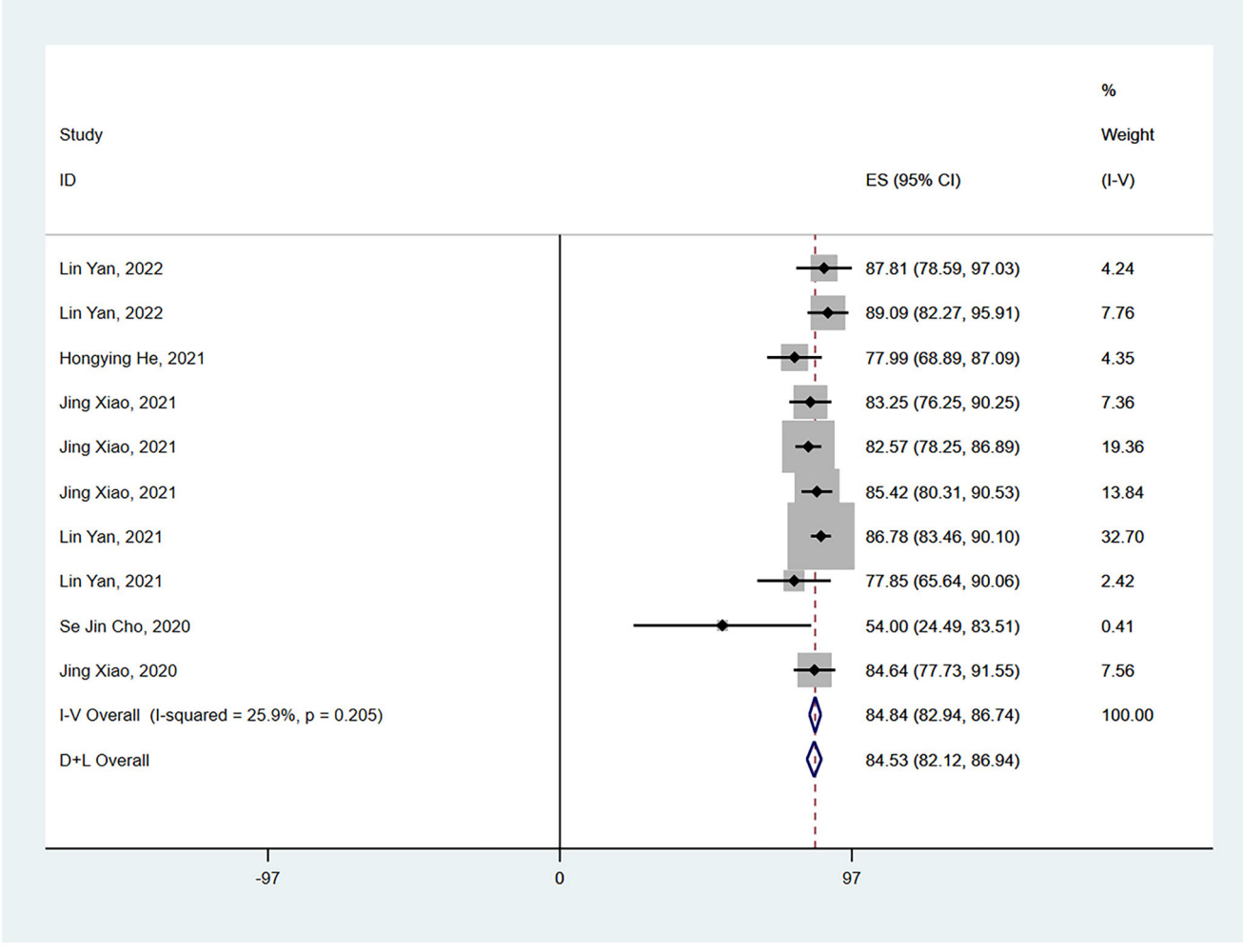

Figure 2. RFA's pooled estimates of VRR at the 12-month follow-up.

2.2.1. Exclusion criteria

Two reviewers selected relevant studies by screening the literature search results. Studies meeting any of the following criteria were excluded: 1) case reports or series with fewer than 5 patients; 2) abstracts, reviews, comments, letters, guidelines and editorials; 3) studies not written in English; 4) studies with overlapping cohorts; and 5) studies not focusing on therapeutic efficacy and safety.

2.3. Data extraction

The following characteristics were extracted from the included studies: 1) study characteristics: first author, publication year, affiliation, study period, study design style, treatment methods of TA and sample size; 2) patients' demographic and clinical characteristics: mean age, sex, ablation technique (RFA, MWA, or LA), and follow-up interval; 3) therapeutic efficacy characteristics: local recurrence, lymph node metastases, complete disappearance rate, 12-month follow-up volume reduction rate, final follow-up volume reduction rate; and 4) safety characteristics: major and minor complications.

Local recurrence was defined as the recurrence of PTC in the original surgical site or original ablation focus as well as the emergence of new PTC in other parts of the thyroid [12]. Complete disappearance was defined as any of the following descriptions: 'completely disappeared', 'completely absorbed' or 'completely resolved'. The volume reduction rate (%) was calculated as ([initial tumor volume − final tumor volume] × 100)/initial tumor volume) [16]. Complications were evaluated by the reporting standards of the Society of Interventional Radiology [17]. Major complications (such as transient (lasting >1 month) or permanent voice changes, postoperative hypothyroidism, hypoparathyroidism or hyperthyroidism, brachial plexus injury and dysphagia) and minor complications (such as voice changes less than 1 month, bleeding, vomiting, skin burn, fever, local infection and severe pain that needed medication) were included.

2.4. Quality assessment

Since the studies included were nonrandomized controlled, retrospective or prospective observational studies, two researchers independently conducted the Newcastle–Ottawa Scale (NOS) to evaluate the literature quality.

2.5. Data synthesis and statistical analysis

The standard mean difference (SMD) of the volume reduction rate at the 12-month follow-up and final follow-up was

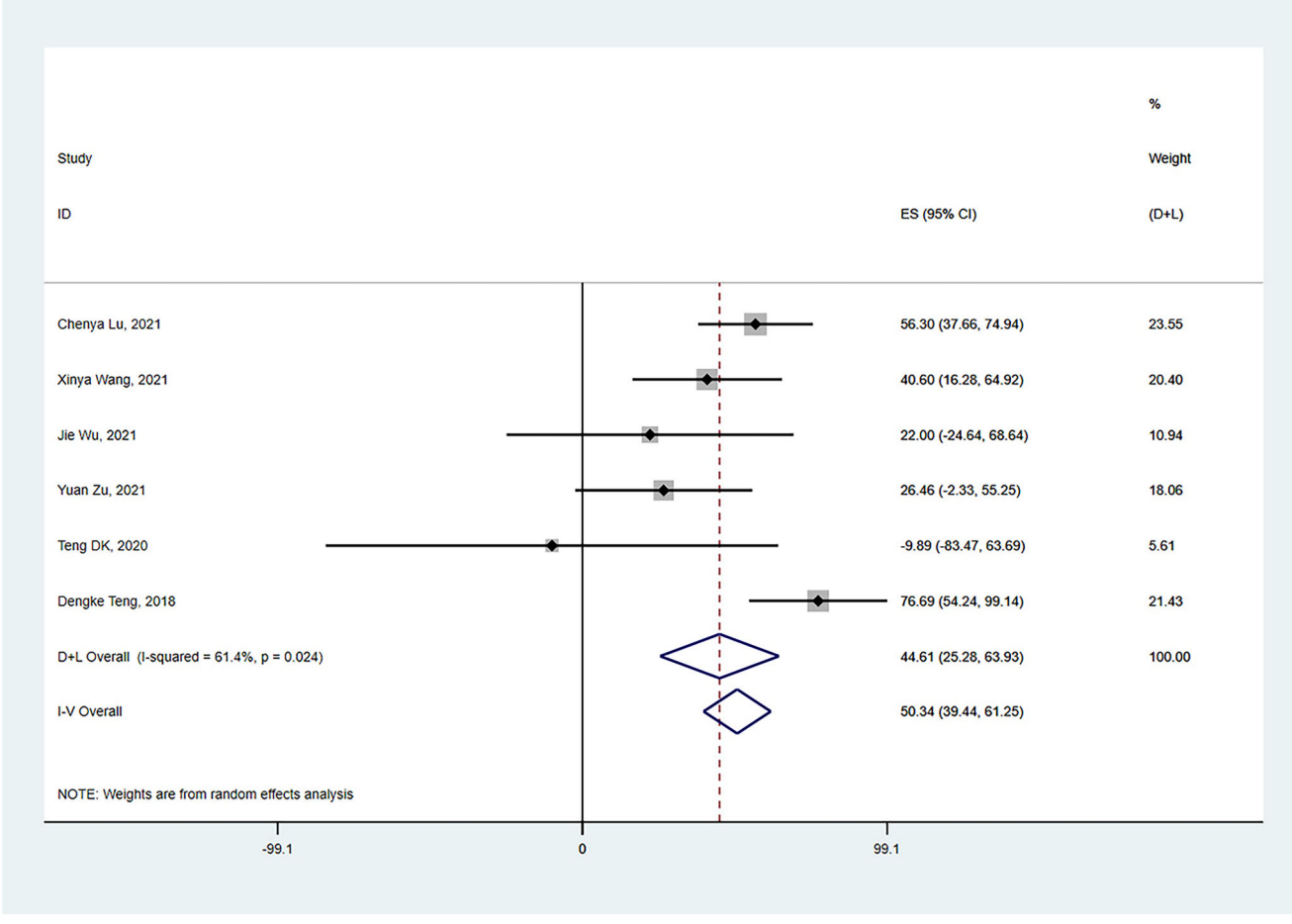

Figure 3. MWA's pooled estimates of VRR at the 12-month follow-up.

conducted as continuous data. We analyzed dichotomous data as odds ratios (ORs) or risk ratios (RRs) using the proportion of complete disappearance, local recurrence, lymph node metastasis, and major and minor complications. These data were used as the main outcomes for this meta-analysis.

Statistical analysis was conducted with Stata 15.0. All studies included were performed through both the fixed-effect model and the random-effects model. Then, I^2 and Q tests were used to evaluate heterogeneity. If the heterogeneity test result was $p \geq 0.1$ and $I^2 \leq 50\%$, the fixed-effect model was used; otherwise, if $p < 0.1$ and $I^2 > 50\%$, the data were analyzed using the DerSimonian–Laird random-effect model. For studies with heterogeneity, we conducted a sensitivity analysis to fully explore its source. Furthermore, publication bias was evaluated using funnel plots and Egger's test for studies whose sample size ≥ 10. A p value < 0.05 was considered to indicate significant publication bias.

A protocol was developed and published (PROSPERO CRD42023399526).

3. Results

3.1. Literature search

The article selection process is presented in detail in Figure 1. The initial literature search identified 1537 articles. After removing duplicates, 1159 articles were screened. Then, 1072 were excluded, including 549 unrelated studies, 26 case reports, 148 review articles, 231 in other formats and 118 not written in English. After 87 full-text articles were assessed for eligibility, 48 unrelated articles were removed, and three articles were excluded due to overlapping cohorts. In the case of patient overlap, studies with larger sample sizes were chosen. Finally, 36 studies were included in this meta-analysis.

3.2. Characteristics of the included studies

The detailed characteristics of the 36 included studies are presented in Table 1. Among these articles, 35 studies were retrospective, and 1 was prospective. Generally, 18 studies

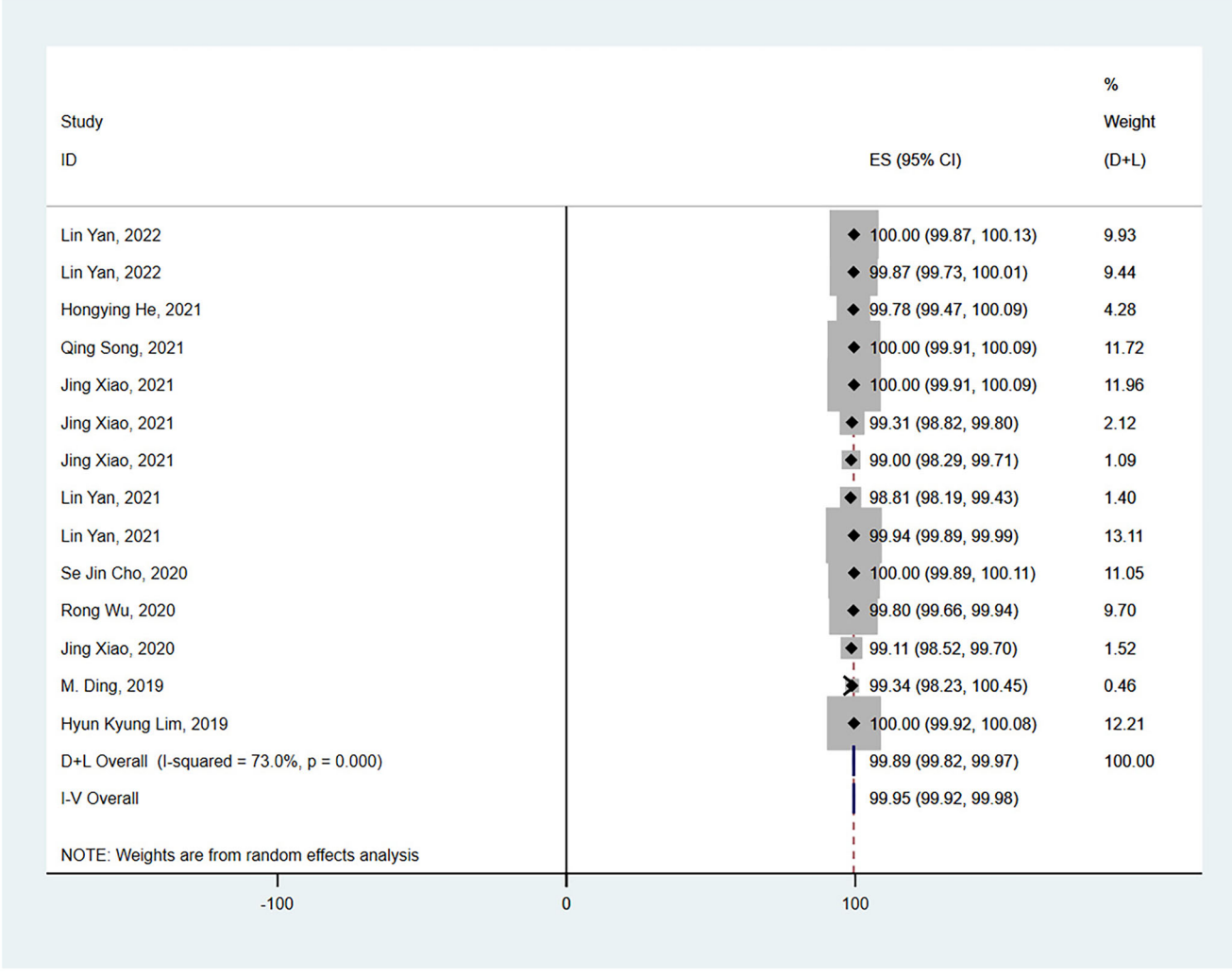

Figure 4. RFA's pooled estimates of VRR at the final follow-up.

Figure 5. MWA's pooled estimates of VRR at the final follow-up.

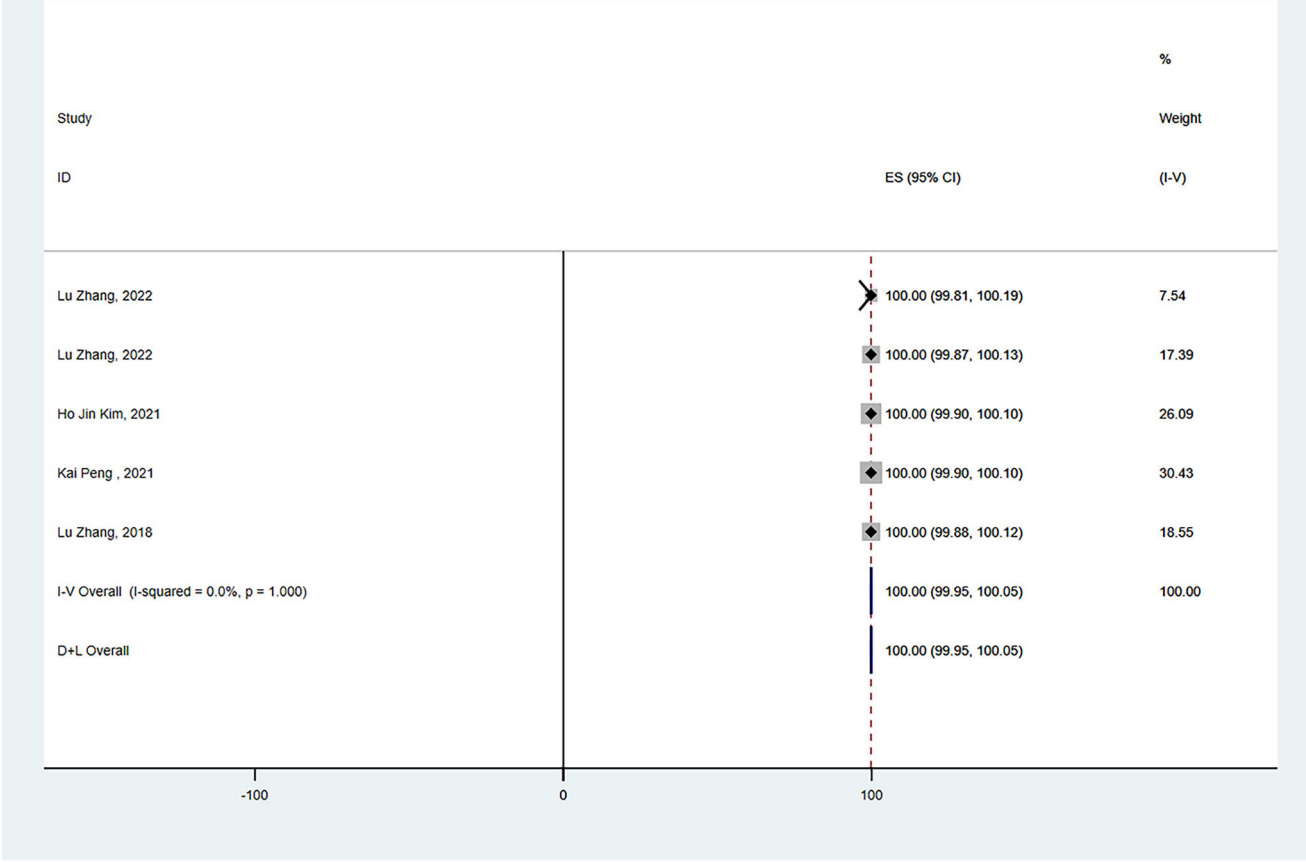

Figure 6. LA's pooled estimates of VRR at the final follow-up.

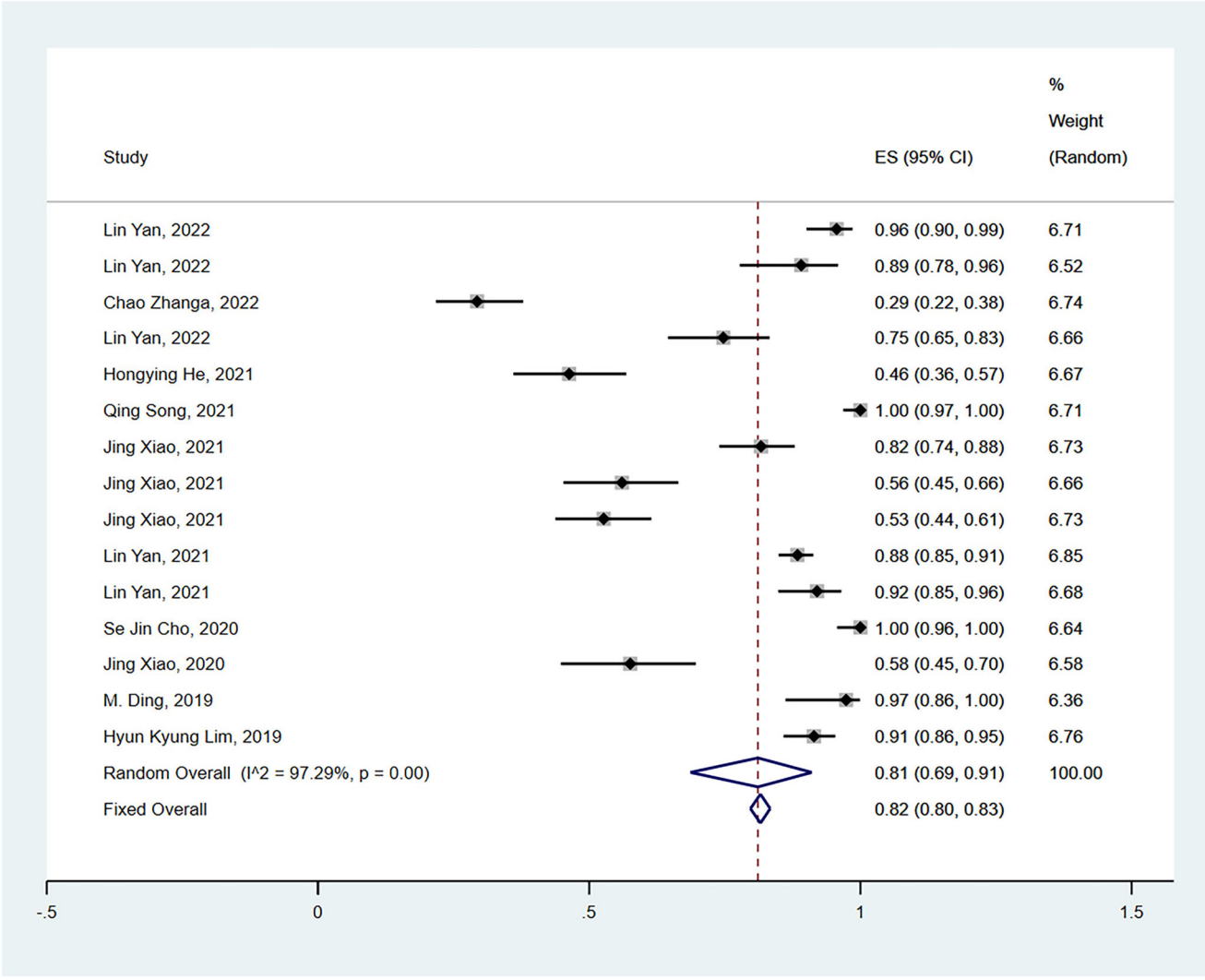

Figure 7. RFA's pooled proportions of complete disappearance rate.

were performed by RFA, 12 studies by MWA and 6 studies by LA.

3.2.1. Volume reduction rates at the 12-month follow-up

Initially, we collected 13 studies on RFA, 8 studies on MWA, and 4 studies on LA. The heterogeneity test of mean volume reduction rates at the 12-month follow-up were $I^2 = 95.0\%$ in RFA, $I^2 = 92.3\%$ in MWA and $I^2 = 98.1\%$ in LA. Significant heterogeneities were shown in all groups, so we conducted sensitivity analysis. Three articles on RFA, two articles on MWA and two articles on LA were found to have high interference with the results. The principles of statistics in the meta-analysis were as follows: sample sizes larger than three were enrolled. Thus, 10 studies in RFA, 6 studies in MWA, and no study in LA were included using random effect models: pooled estimates were 84.844% (95% CI: 82.944%∼86.743%, $I^2 = 25.9\%$; Figure 2) in RFA and 44.609% (95% CI: 25.283%∼63.935%, $I^2 = 61.4\%$; Figure 3) in MWA.

3.2.2. Volume reduction rates at the final follow-up

Fourteen RFA related, 10 MWA related, and 5 LA related researches were initially included. The heterogeneity test demonstrated $I^2 = 73.0\%$ (RFA), $I^2 = 98.1\%$ (MWA) and $I^2 = 0.0\%$ (LA). The RFA and MWA groups presented significant heterogeneities, so sensitivity analysis was performed. Two articles on MWA were found to have high interference with the results. Finally, we included 8 studies in MWA in the analysis. RFA and MWA were performed by a random effect model, and LA was performed by a fixed effect model. The mean volume reduction rates at the final follow-up after RFA, MWA and LA therapy, achieved pooled estimates of 99.892% (95% CI: 99.815%∼99.969%, $I^2 = 73.0\%$; Figure 4), 99.191% (95% CI: 98.970%∼99.413%, $I^2 = 38.7\%$; Figure 5)

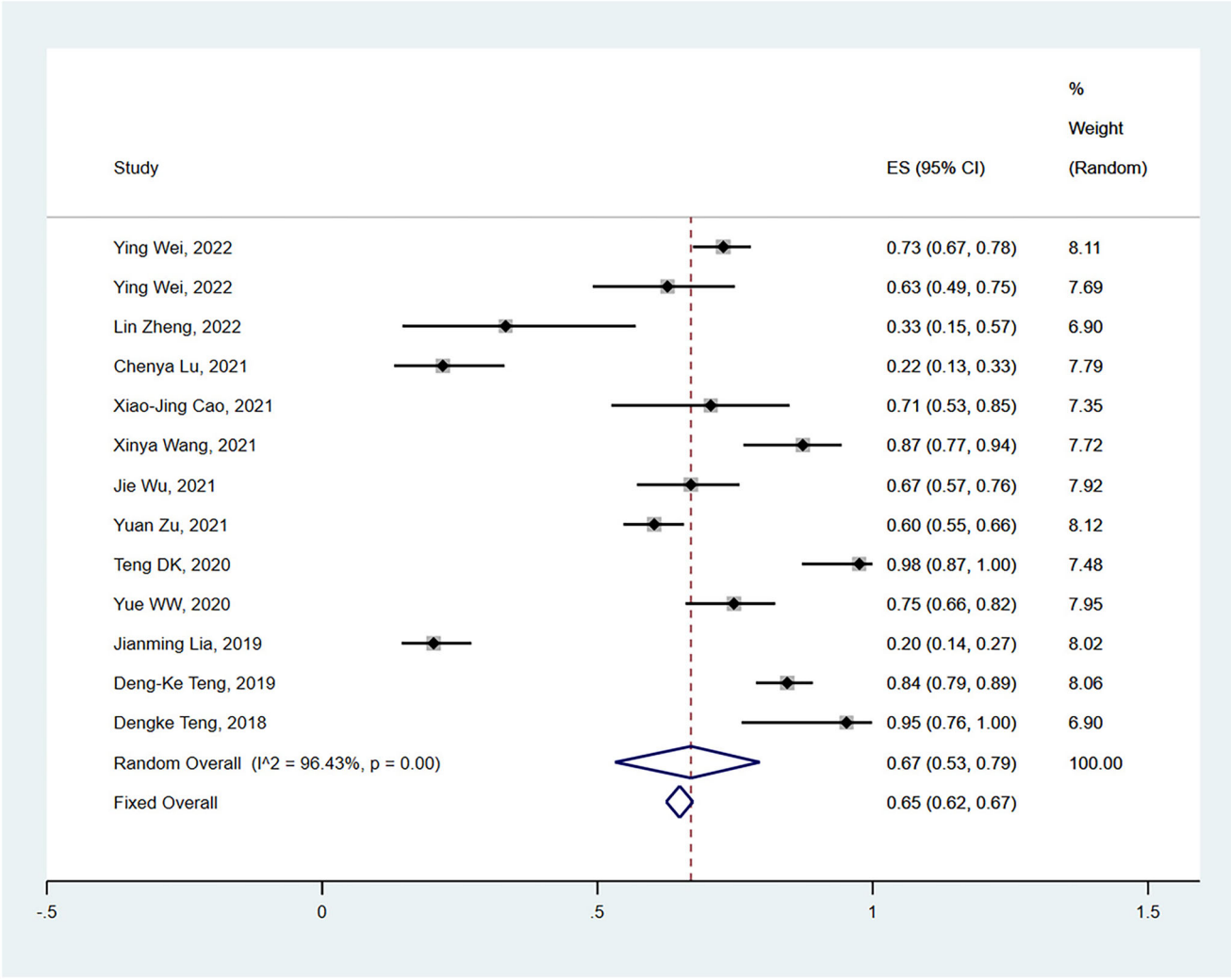

Figure 8. MWA's pooled proportions of complete disappearance rate.

and 100.00% (95% CI: 99.947%∼100.00%, I^2 = 0.00%; Figure 6).

3.2.3. Complete disappearance rate

The heterogeneity test presented I^2 = 97.29% in RFA, I^2 = 96.43% in MWA and I^2 = 94.89% in LA, with 15 studies from RFA, 13 studies from MWA, and 7 studies from LA. After sensitivity analysis, one article in MWA was found to have high interference with the results, so we performed an analysis based on the remaining 12 articles. A random effect model was used in all groups. Results achieved pooled proportions of 81.00% (95% CI: 69.00%∼91.00%, I^2 = 97.29%; Figure 7) in RFA, 71.00% (95% CI: 60.00%∼81.00%, I^2 = 93.62%; Figure 8) in MWA and 93.00% (95% CI: 77.00%-100.00%, I^2 = 94.89%; Figure 9) in LA.

Specifically, in the RFA subgroup, the heterogeneity test result was I^2 = 97.45% in T1aN0M0 PTC and I^2 = 75.90% in T1bN0M0 PTC. Significant heterogeneities were found in T1aN0M0, and after sensitivity analysis, one article was excluded. Therefore, the final outcomes of the pooled proportion were 91.00% (95% CI, 83.00%∼97.00%, I^2 = 94.76%; Figure 10) in T1aN0M0 PTC and 60.00% (95% CI, 50.00%∼70.00%, I^2 = 75.90%; Figure 11) in T1bN0M0 PTC.

3.2.4. Local recurrence

Fifteen studies with RFA, seven studies with MWA, and 5 studies with LA were included after screening. Local recurrence demonstrated a pooled proportion of 2.00% (95% CI: 2.00%∼3.00%, I^2 = 0.00%; Figure 12) in RFA, 2.00% (95% CI: 1.00%∼2.00%, I^2 = 37.75%; Figure 13) in MWA and 3.00% (95% CI: 1.00%∼6.00%, I^2 = 22.03%; Figure 14) in LA using a fixed effect model.

The results in RFA were 2.00% (95% CI, 1.00%∼3.00%, I^2 = 17.22%; Figure 15) in T1aN0M0 PTC and 3.00% (95% CI, 1.00%∼5.00%, I^2 = 0.00%; Figure 16) in T1bN0M0 PTC through a fixed effect model.

3.2.5. Lymph node metastases

The pooled proportions for lymph node metastases were 1.00% (95% CI: 0.00%∼1.00%, I^2 = 0.00%; Supplementary Figure S1), 2.00% (95% CI: 1.00%∼3.00%, I^2 = 0.00%; Supplementary Figure S2) and 2.00% (95% CI: 0.00%∼4.00%,

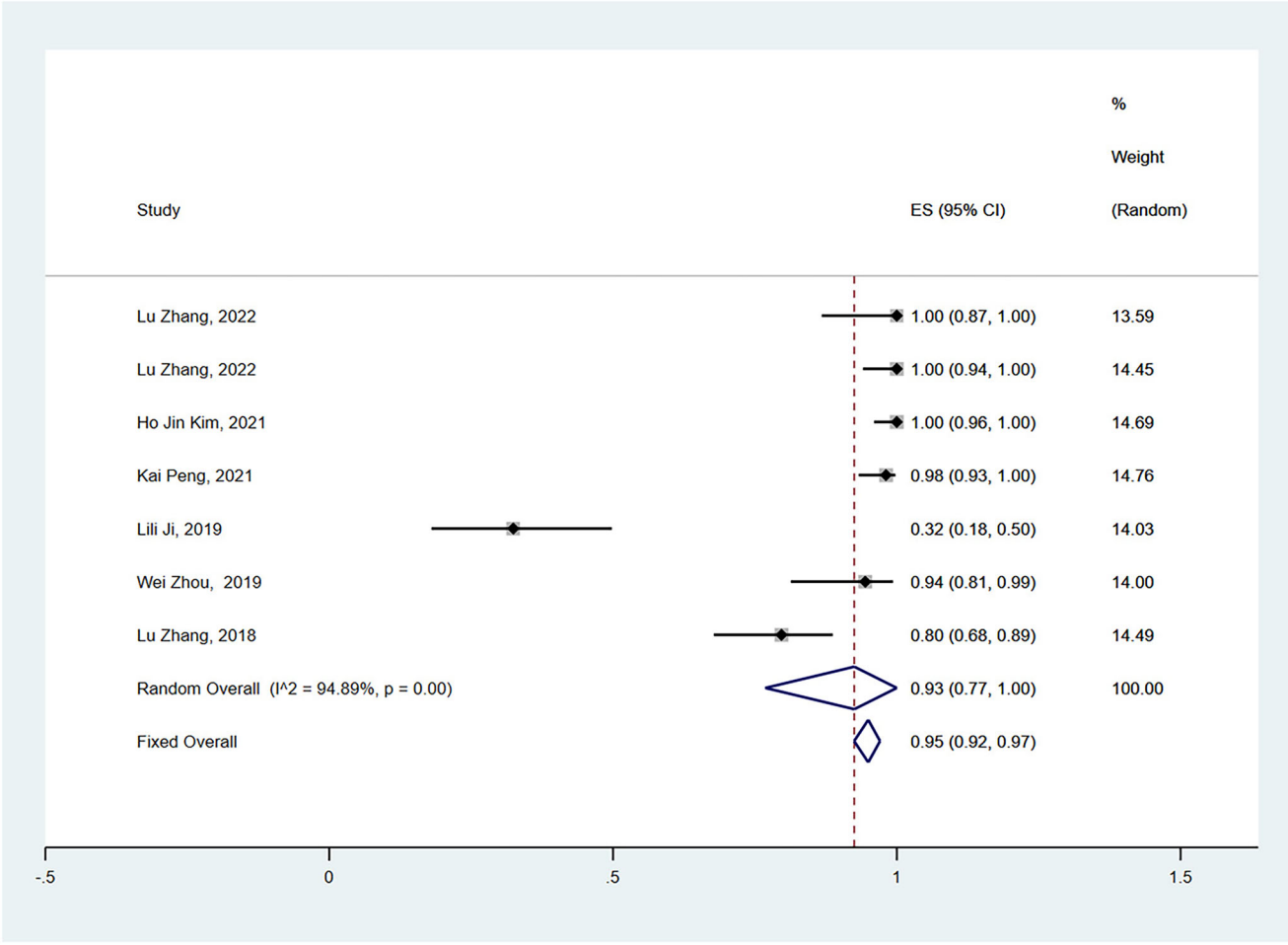

Figure 9. LA's pooled proportions of complete disappearance rate.

I^2 = 0.00%; Supplementary Figure S3) with a fixed effect model, among nine studies in RFA, six studies in MWA, and five studies in LA, respectively.

The RFA subgroup presented a pooled proportion of 1.00% (95% CI: 0.00%∼1.00%, I^2 = 0.00%; Supplementary Figure S4) in T1aN0M0 PTC and 1.00% (95% CI: 0.00%∼2.00%, I^2 = 0.00%; Supplementary Figure S5) in T1bN0M0 PTC through the fixed effect model.

3.2.6. Complication rates

After screening the studies, three studies in RFA, four studies in MWA and no study in LA were found to have major complications. Since sample sizes that were larger than three were considered significant, the major complication rate was not available for meta-analysis. Thus, we focused mainly on the minor complication rate.

We considered 11 related researches from RFA, 8 related researches from MWA, and 5 related researches from LA in the final analysis. For the minor complication rates, the pooled proportions were 3.00% (95% CI: 2.00%∼4.00%, I^2 = 0.00%; Supplementary Figure S6) in RFA, 13.00% (95% CI: 5.00%∼25.00%, I^2 = 95.33%; Supplementary Figure S7) in MWA and 6.00% (95% CI: 0.00%∼17.00%, I^2 = 88.17%; Supplementary Figure S8) in LA. Significant heterogeneities were shown in the MWA and LA groups, so we conducted sensitivity analysis. No articles in both were found with high interference with the results. Therefore, a fixed effect model was conducted in the RFA group, and a random effect model was conducted in both the MWA and LA groups.

3.3. Publication bias

The funnel plots were presented in the Supplementary Figures S1–S17. The funnel plot of RFA's VRR at the final follow-up (Supplementary Figure S10) showed low symmetry and the *p* values of Egger's tests (0.001) was less than 0.05, which is the obvious publication bias in this study. Other studies were symmetrical with the p values of Egger's tests more than 0.05, demonstrated no obvious publication bias.

4. Discussion

This meta-analysis analyzed the efficacy and safety of RFA, MWA and LA on PTC patients by evaluating data on several outcomes. Our findings showed that RFA demonstrated significantly superior efficacy than MWA in 12-month VRR. This

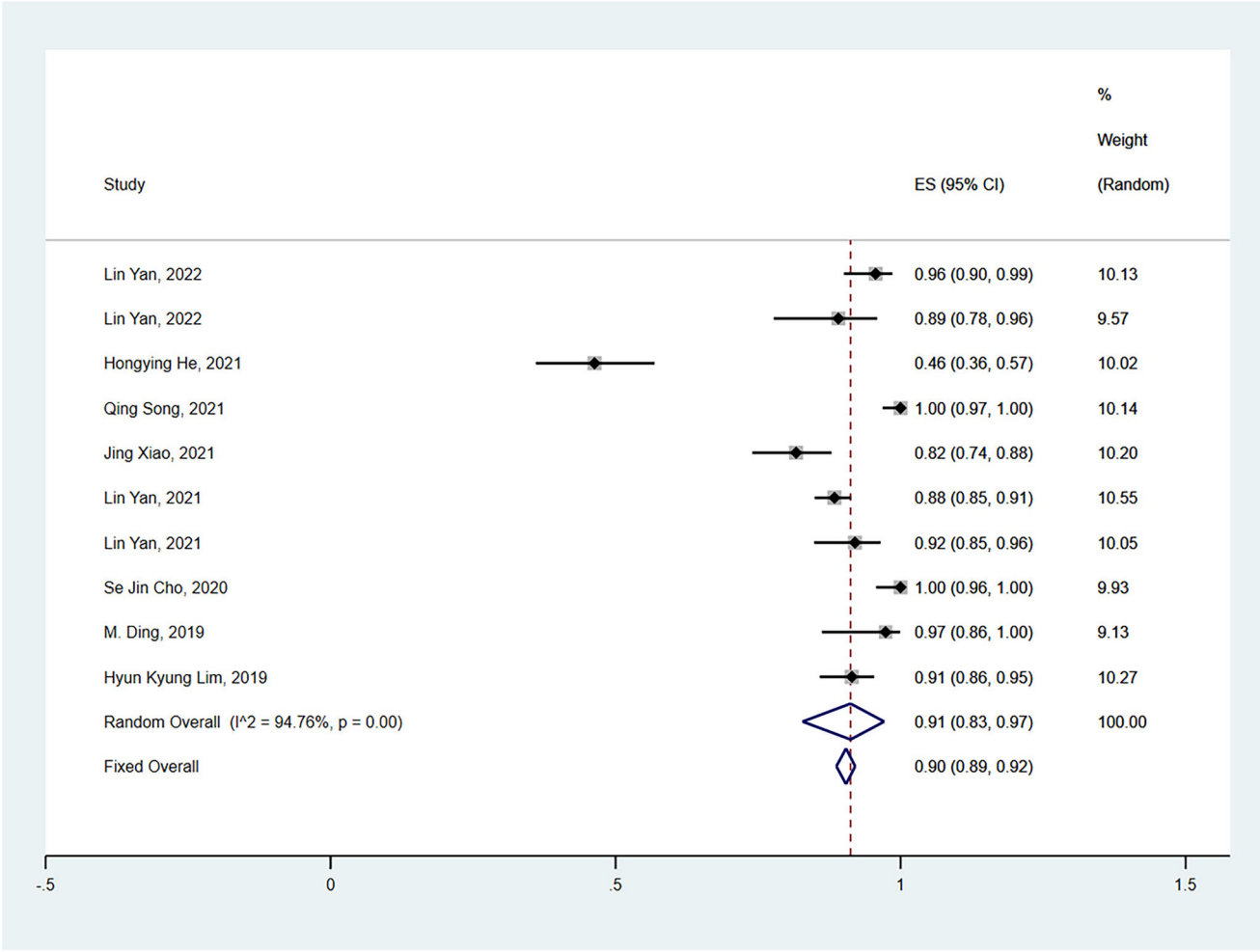

Figure 10. RFA's pooled proportions of complete disappearance rate in T1aN0M0 PTC.

finding is consistent with the previous study conducted by Li et al. [52], which also indicated that RFA achieved much better outcomes than MWA and LA. The three subgroups differed slightly for VRR in the final follow-up with LA showing the most variation, followed by RFA, and MWA showing the least variation, which was conformable with a previous meta-analysis by Choi et al. [53].

Furthermore, the complete disappearance rate of LA was higher than that of RFA and MWA. This result differed from the findings of two previous meta-analyses [15,52]. However, all studies insisted that RFA had a strong impact on CDR than MWA. The fact that the LA group size was almost half that of the other groups may have contributed to the difference in outcomes of LA data. Overall, all thermal techniques achieved the pooled estimates of more than 99%, suggesting that TA was an effective invasive treatment for PTC patients to inactivate tumors. In addition, we focused on the local recurrence rate. The pooled proportions of MWA and RFA were both 2.00%, lower than that of the LA group. The newly discovered lesions underwent secondary TA and received full deactivation. When the cancer was adjacent to the trachea, capsule, recurrent laryngeal nerve, common carotid artery or other sensitive areas, the safety margin of ablation was limited, which would relatively reduce the ablation power and time, resulting in incomplete ablation and residual primary cancer [52]. Moreover, extracapsular invasion was difficult to diagnose by ultrasound and affected by operators' experiences and machines. Therefore, TA was less satisfying on treating PTC under these circumstances. The recurrence rate also may be related to the genetic factors. The previous study has suggested that PTC patients with BRAF(V600E) or TERT promoter mutation had a higher likelihood for recurrence [54,55]. Thus, indolent PTCs without aggressive genetic alterations were characterized by recurrence rate. Taken together, we could take gene expression into consideration in future research. Besides, some studies reported that local ablation could release immune-associated antigens and enhance host adaptive immune responses, thus suppressing the growth of primary lesions and metastasis [56,57]. More studies could be explored on this field.

The lymph node metastasis rates were similar. RFA was the lowest, and MWA and LA were both slightly higher. No distant metastases were found. The reason could be as follows: on the one hand, the LNM detection was dependent on the sonographer's experience. On the other hand, only nodules with clearly diagnosed PTC were recruited, and

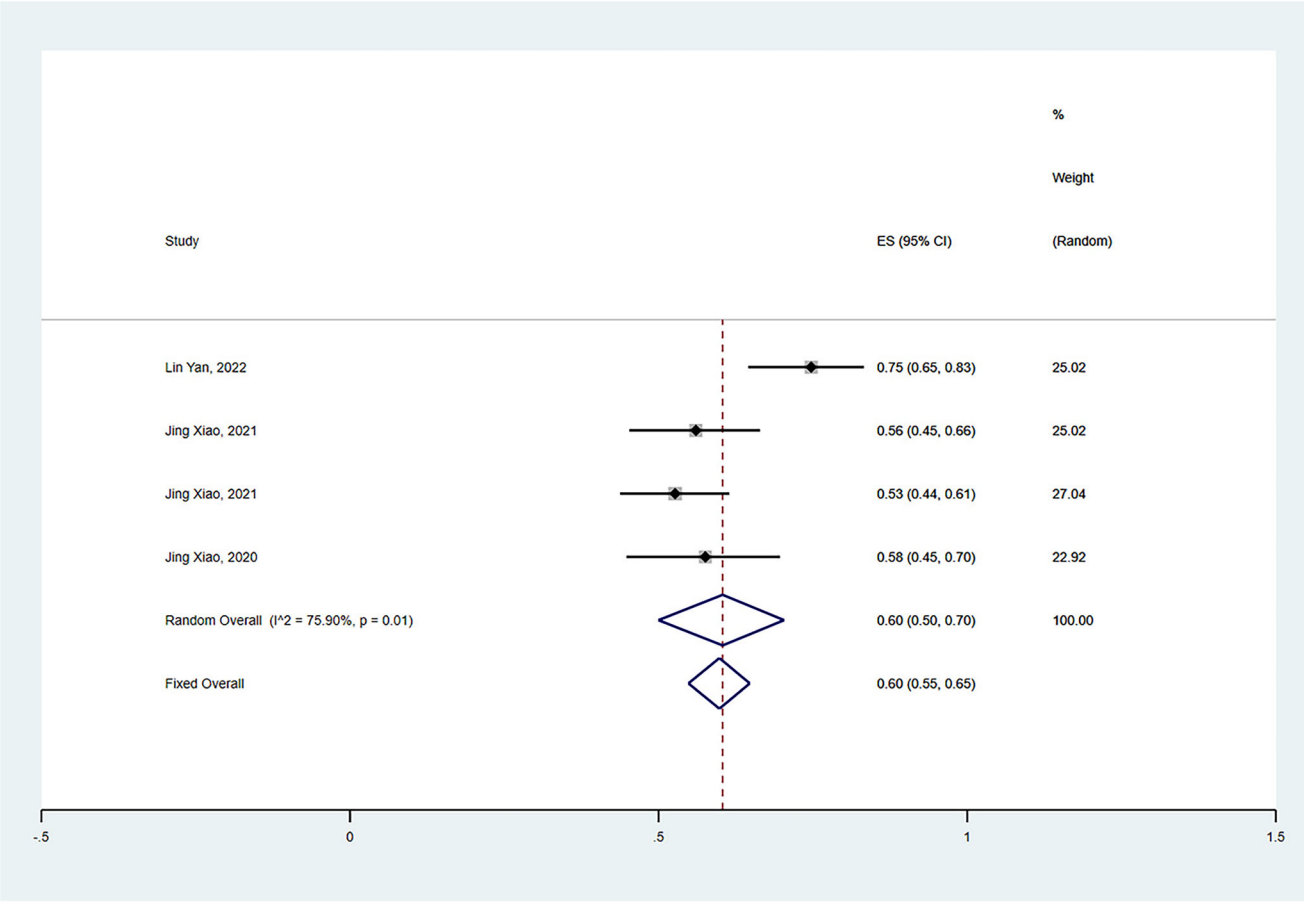

Figure 11. RFA's pooled proportions of complete disappearance rate in T1bN0M0 PTC.

nodules that FNA or CNB could not identify were excluded [44]. Due to X-ray exposition, CT scan, as an invasive and expensive treatment, is not recommended for the diagnose of LNM in PTC. Since metastasis of PTC was found to occur in the central compartment first and then in the lateral compartment of neck, lymph node scans by sonographers with experience more than five years is a valid, cost-effective and highly sensitive diagnostic approach [58]. Generally, these data suggested that TA gained stable and safe effects in treating PTC patients. In terms of safety, the minor complication rates were analyzed. No life-threatening complications were found during follow-up. Common complications were transient hoarseness and burning sensation. When the lesions were close to the region where the recurrent laryngeal nerve traverses, there was a relatively high risk of injury to the recurrent laryngeal nerve during the ablation. Besides, variation in operators' experience may contribute to complication occurrence [59]. Hypo/hyperthyroidism was not reported in major complications, since TA was effective to avoid post-operative hypothyroidism. Thus, TA was unlikely to cause significant thyroid function change as minimally invasive treatment. The pooled proportions of RFA were much smaller than those of LA and MWA, suggesting that RFA may be superior in causing fewer side effects. The reason could be explained by the heat production rates. In MWA, when multiple antennae are used together to propagate the current, the result is an exponential increase in heating. MWA offers the ability to deliver more thermal energy in a shorter time, resulting in a higher final tissue temperature than RFA [60]. Therefore, the coagulation zone size of RFA is limited [61]. For small-sized tumors such as PTCs, MWA is not easy to manipulate and may produce a larger zone of active heating than necessary, making it more likely to cause injury to the adjacent nerves.

We also explored the separate effect of RFA on T1aN0M0 and T1bN0M0 patients. In the present data, T1aN0M0 lesions presented with superior results over T1bN0M0 lesions in terms of the complete disappearance rate. According to the results of the local recurrence rate, RFA also achieved better outcomes in T1aN0M0 than in T1bN0M0. This conclusion was consistent with that in a meta-analysis by Wang et al. [14]. Both groups had a pooled proportion of 1.00% in lymph node metastases. All these data imply that RFA had a satisfying effect on treating T1N0M0 papillary carcinoma with a more desirable influence. For low-risk PTC, the optimal management was controversial. Surgery may remove small indolent lesions that likely would not have caused significant morbidity. Several trials have shown no increase in mortality of patients under active surveillance (AS) compared to immediate surgery [62]. In a previous study, all patients agreed to be treated with TA over surgery or AS. The study speculated that the lower invasiveness and higher cosmetic results of TA

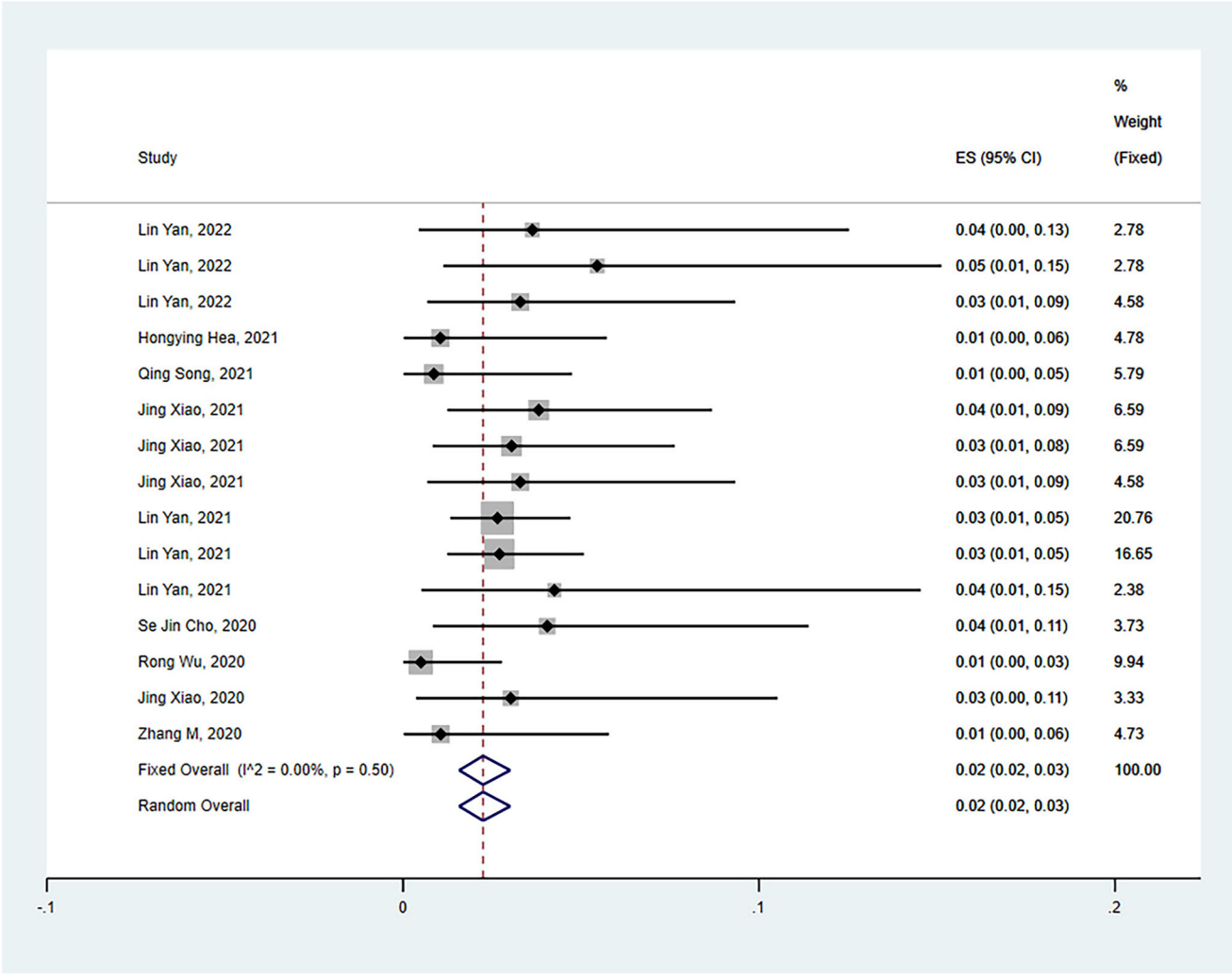

Figure 12. RFA's pooled proportions of local recurrence rate.

might be the reasons. Simultaneously, ablation could be preferred over AS because of anxiety and negative emotion related with receiving a cancer diagnosis without receiving active treatment [63]. Combining with our results, TA may bridge the gap in treatment options for patients wishing to have their PTMC managed in a minimally invasive way [64].

Although we only included patients in our analysis who had no lymph node metastases before TA, accumulating studies have confirmed that TA could also be effective in the treatment of LNM from PTC [65]. A meta-analysis based on this topic demonstrated that all TAs were safe and effective for the treatment of cervical metastatic lymph nodes (CMLNs) of PTC, which suggested that TA could be applied more under this circumstance. The quality of life (QoL) of patients after treatment has also become an essential part. A previous study showed that the main risk factors affecting QoL in PTC after RFA were female gender, psychological burden, inattention, and neuromuscular system and pharyngeal/oral symptoms [66]. Therefore, preoperative examinations are necessary to assess related symptoms, and psychological intervention should be provided to improve the QoL [67].

There are a few limitations to our study. First, the majority of the studies that were included were regionally concentrated from the same country. Second, the sample size of the studies was limited, which could cause substantial biases. Third, the studies included in this meta-analysis were all non-randomized controlled studies due to the limitations of the current research. Moreover, there were several outcomes such as QoL we did not list in the data analysis, which could be explored more in further studies.

5. Conclusion

In general, our meta-analysis evaluated the safety and efficacy of RFA, MWA and LA in treating T1N0M0 PTC and made extensive comparisons between the RFA efficacy of T1aN0M0 and T1bN0M0 patients. We discovered that all three TA techniques were reliable and satisfying in curing PTC lesions, with RFA showing superior advantages over MWA and LA in the majority of outcomes. Moreover, the results suggested that T1aN0M0 patients experienced fewer side effects than those with T1bN0M0. Based on the results of our analysis,

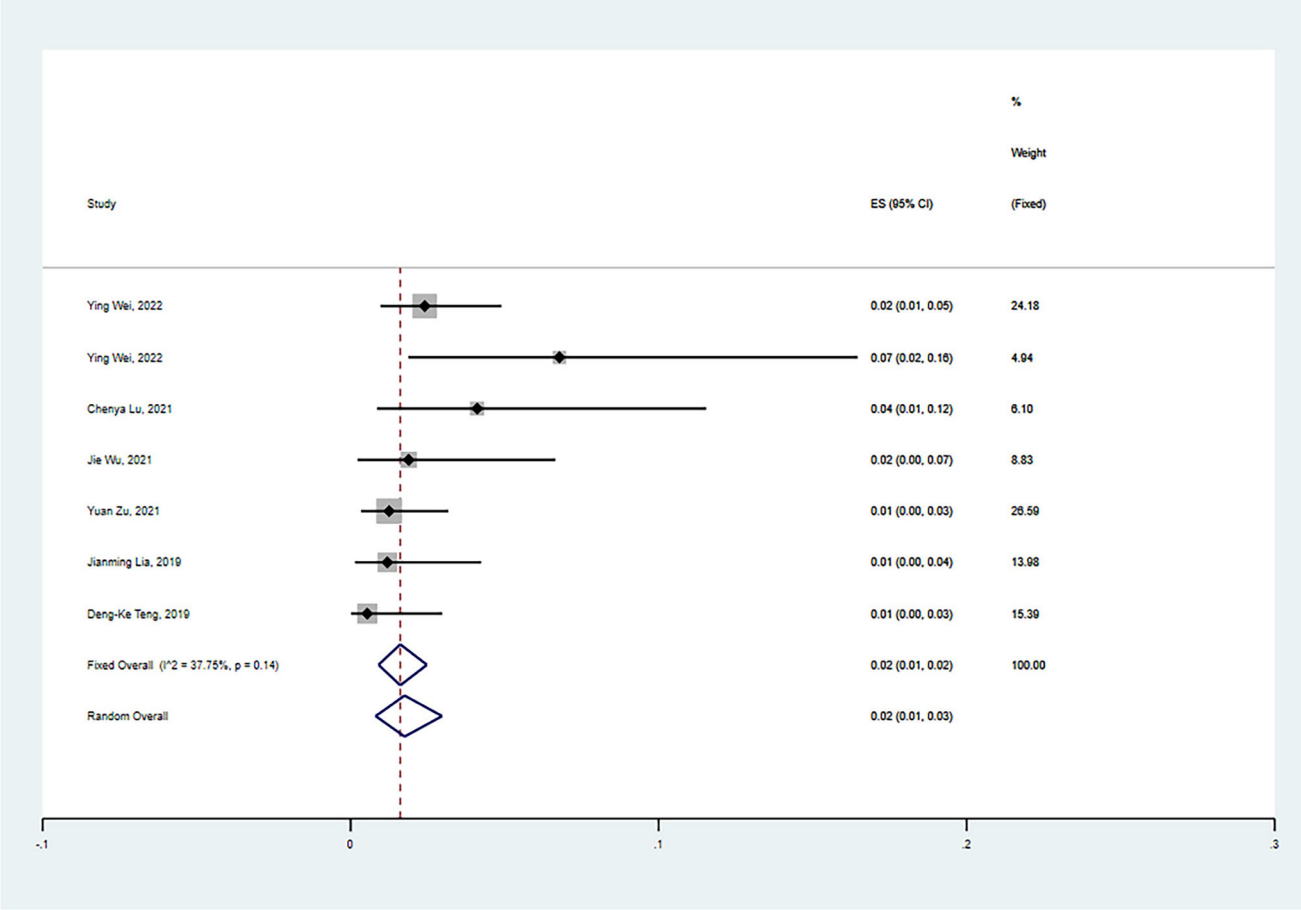

Figure 13. MWA's pooled proportions of local recurrence rate.

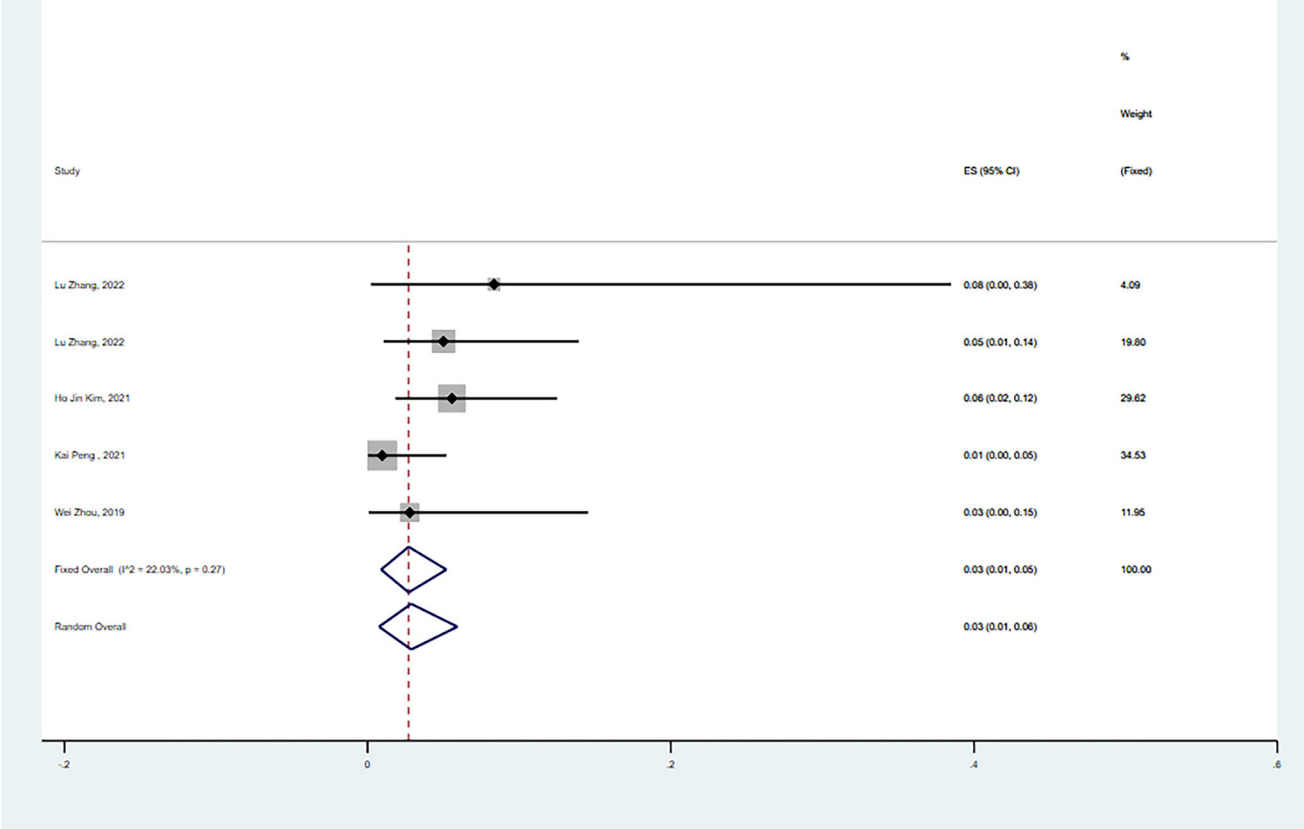

Figure 14. LA's pooled proportions of local recurrence rate.

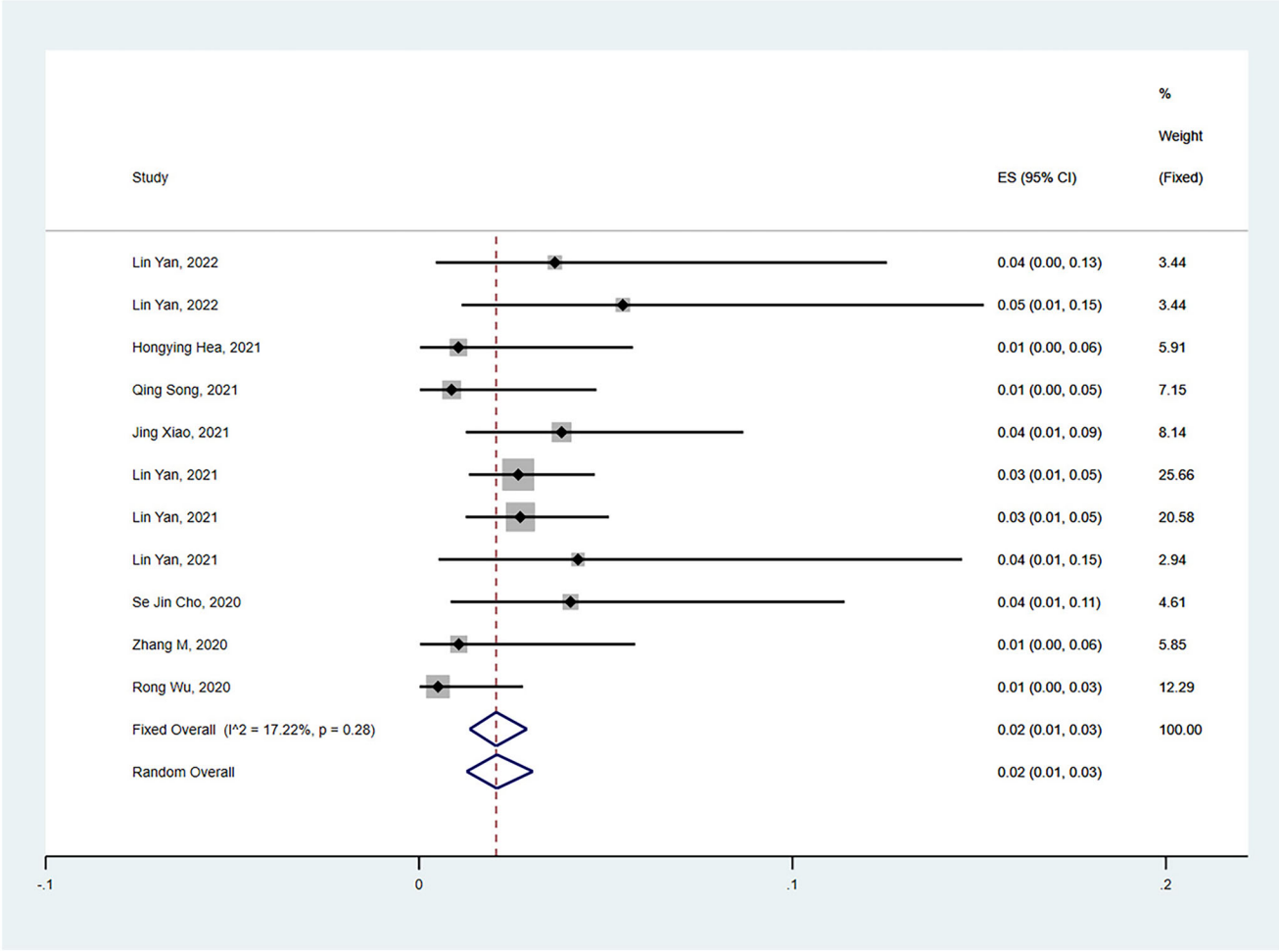

Figure 15. RFA's pooled proportions of local recurrence rate in T1aN0M0 PTC.

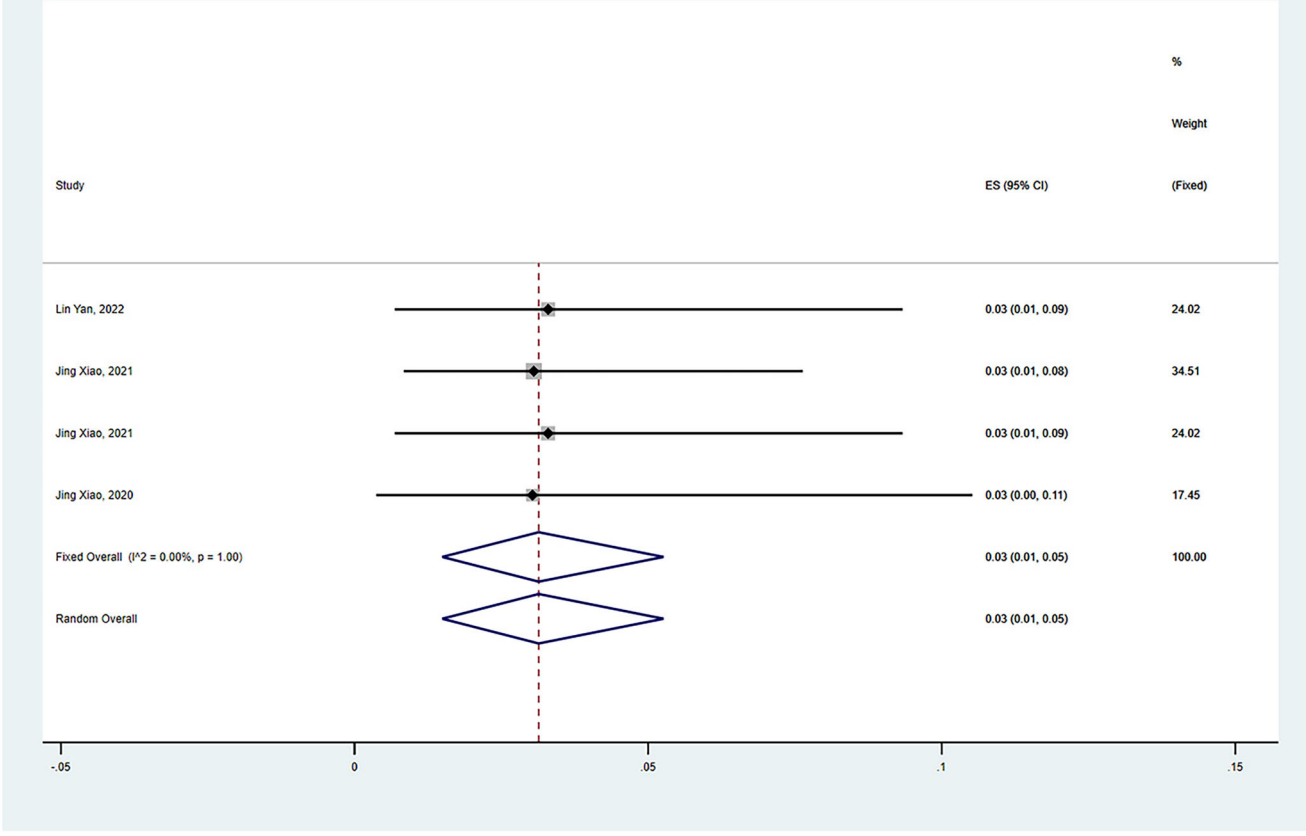

Figure 16. RFA's pooled proportions of local recurrence rate in T1bN0M0 PTC.

ultrasound-guided TA can be considered a safe and effective treatment approach for patients with T1N0M0 PTC.

Acknowledgements

Thanks to Xiaoxi Liu, Die Hu and Chenyang Kang for their clinical operational contributions in our study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was supported by grants from the 345 Talent Project and Planting Project of Shengjing Hospital and Liaoning BaiQianWan Talents Program.

Data availability statement

We confirmed that the data supporting the findings of this study are available within the article and our supplementary materials.

Reference

[1] Nabhan F, Dedhia PH, Ringel MD. Thyroid cancer, recent advances in diagnosis and therapy. Int J Cancer. 2021;149(5):984–992. doi: 10.1002/ijc.33690.

[2] Wang J, Yu F, Shang Y, et al. Thyroid cancer: incidence and mortality trends in China, 2005–2015. Endocrine. 2020;68(1):163–173. doi: 10.1007/s12020-020-02207-6.

[3] Davies L, Welch HG. Current thyroid cancer trends in the United States. JAMA Otolaryngol Head Neck Surg. 2014;140(4):317–322. doi: 10.1001/jamaoto.2014.1.

[4] Cabanillas ME, McFadden DG, Durante C. Thyroid cancer. Lancet. 2016;388(10061):2783–2795. doi: 10.1016/S0140-6736(16)30172-6.

[5] Anderson KL, Youngwirth LM, Scheri RP, et al. T1a versus T1b differentiated thyroid cancers: do we need to make the distinction? Thyroid. 2016;26(8):1046–1052. doi: 10.1089/thy.2016.0073.

[6] Haugen BR, Alexander EK, Bible KC, et al. 2015 American thyroid association management guidelines for adult patients with thyroid nodules and differentiated thyroid cancer: the American thyroid association guidelines task force on thyroid nodules and differentiated thyroid cancer. Thyroid. 2016;26(1):1–133. doi: 10.1089/thy.2015.0020.

[7] Kanona H, Virk JS, Offiah C, et al. Ultrasound-guided assessment of thyroid nodules based on the 2014 british thyroid association guidelines for the management of thyroid cancer—how we do it. Clin Otolaryngol. 2017;42(3):723–727. doi: 10.1111/coa.12621.

[8] Haymart MR, Esfandiari NH, Stang MT, et al. Controversies in the management of low-risk differentiated thyroid cancer. Endocr Rev. 2017;38(4):351–378. doi: 10.1210/er.2017-00067.

[9] Lan Y, Luo Y, Zhang M, et al. Quality of life in papillary thyroid microcarcinoma patients undergoing radiofrequency ablation or surgery: a comparative study. Front Endocrinol (Lausanne). 2020;11:249. doi: 10.3389/fendo.2020.00249.

[10] Mauri G, Hegedüs L, Bandula S, et al. European thyroid association and cardiovascular and interventional radiological society of Europe 2021 clinical practice guideline for the use of minimally invasive treatments in malignant thyroid lesions. Eur Thyroid J. 2021;10(3):185–197. doi: 10.1159/000516469.

[11] Yi Z, Siyu L, Lijun F, et al. Efficacy, safety, and controversy of ultrasound-guided radiofrequency ablation in the treatment of T1N0M0 papillary thyroid carcinoma. Front Oncol. 2022;12:1068210. doi: 10.3389/fonc.2022.1068210.

[12] Zu Y, Liu Y, Zhao J, et al. A cohort study of microwave ablation and surgery for low-risk papillary thyroid microcarcinoma. Int J Hyperthermia. 2021;38(1):1548–1557. doi: 10.1080/02656736.2021.1996643.

[13] Li J, Liu Y, Liu J, et al. Ultrasound-guided percutaneous microwave ablation versus surgery for papillary thyroid microcarcinoma. Int J Hyperthermia. 2018;34(5):653–659. doi: 10.1080/02656736.2018.1453092.

[14] Wang MH, Liu X, Wang Q, et al. Safety and efficacy of ultrasound-guided thermal ablation in treating T1aN0M0 and T1bN0M0 papillary thyroid carcinoma: a meta-analysis. Front Endocrinol (Lausanne). 2022;13:952113. doi: 10.3389/fendo.2022.952113.

[15] Tong M, Li S, Li Y, et al. Efficacy and safety of radiofrequency, microwave and laser ablation for treating papillary thyroid microcarcinoma: a systematic review and meta-analysis. Int J Hyperthermia. 2019;36(1):1278–1286.

[16] Xiao J, Zhang M, Zhang Y, et al. Efficacy and safety of ultrasonography-guided radiofrequency ablation for the treatment of T1bN0M0 papillary thyroid carcinoma: a retrospective study. Int J Hyperthermia. 2020;37(1):392–398. doi: 10.1080/02656736.2020.1752945.

[17] Mauri G, Pacella CM, Papini E, et al. Image-guided thyroid ablation: proposal for standardization of terminology and reporting criteria. Thyroid. 2019;29(5):611–618. doi: 10.1089/thy.2018.0604.

[18] Yan L, Zhang M, Song Q, et al. Clinical outcomes of radiofrequency ablation for multifocal papillary thyroid microcarcinoma versus unifocal papillary thyroid microcarcinoma: a propensity-matched cohort study. Eur Radiol. 2022;32(2):1216–1226. doi: 10.1007/s00330-021-08133-z.

[19] Zhang C, Yin J, Hu C, et al. Comparison of ultrasound guided percutaneous radiofrequency ablation and open thyroidectomy in the treatment of low-risk papillary thyroid microcarcinoma: a propensity score matching study. CH. 2022;80(2):73–81. doi: 10.3233/CH-201087.

[20] Yan L, Li X, Li Y, et al. Comparison of ultrasound-guided radiofrequency ablation versus thyroid lobectomy for T1bN0M0 papillary thyroid carcinoma. Eur Radiol. 2022;33(1):730–740. doi: 10.1007/s00330-022-08963-5.

[21] He H, Song Q, Lan Y, et al. Efficacy and safety of ultrasound-guided radiofrequency ablation for low-risk papillary thyroid microcarcinoma in patients aged 55 years or older: a retrospective study. Int J Hyperthermia. 2021;38(1):604–610. doi: 10.1080/02656736.2021.1912416.

[22] He H, Wu R, Zhao J, et al. Ultrasound-guided radiofrequency ablation versus surgical resection for the treatment of T1bN0M0 papillary thyroid carcinoma in different age groups. Front Endocrinol. 2021;12:734432. doi: 10.3389/fendo.2021.734432.

[23] Song Q, Gao H, Ren L, et al. Radiofrequency ablation versus total thyroidectomy in patients with papillary thyroid microcarcinoma located in the isthmus: a retrospective cohort study. Int J Hyperthermia. 2021;38(1):708–714. doi: 10.1080/02656736.2021.1916625.

[24] Xiao J, Zhang Y, Yan L, et al. Ultrasonography-guided radiofrequency ablation for solitary T1aN0M0 and T1bN0M0 papillary thyroid carcinoma: a retrospective comparative study. Eur J Endocrinol. 2022;186(1):105–113. doi: 10.1530/EJE-21-0580.

[25] Xiao J, Zhang Y, Zhang M, et al. Ultrasonography-guided radiofrequency ablation vs. surgery for the treatment of solitary T1bN0M0 papillary thyroid carcinoma: a comparative study. Clin Endocrinol. 2021;94(4):684–691. doi: 10.1111/cen.14361.

[26] Yan L, Lan Y, Xiao J, et al. Long-term outcomes of radiofrequency ablation for unifocal low-risk papillary thyroid microcarcinoma: a large cohort study of 414 patients. Eur Radiol. 2021;31(2):685–694. doi: 10.1007/s00330-020-07128-6.

[27] Yan L, Zhang M, Song Q, et al. Ultrasound-Guided radiofrequency ablation versus thyroid lobectomy for low-risk papillary thyroid microcarcinoma: a propensity-matched cohort study of 884 patients. Thyroid. 2021;31(11):1662–1672. doi: 10.1089/thy.2021.0100.

[28] Yan L, Zhang M, Song Q, et al. The efficacy and safety of radiofrequency ablation for bilateral papillary thyroid microcarcinoma. Front Endocrinol. 2021;12:663636. doi: 10.3389/fendo.2021.663636.
[29] Cho SJ, Baek SM, Lim HK, et al. Long-term follow-up results of ultrasound-guided radiofrequency ablation for low-risk papillary thyroid microcarcinoma: more than 5-year follow-up for 84 tumors. Thyroid. 2020;30(12):1745–1751. doi: 10.1089/thy.2020.0106.
[30] Song Q, Gao H, Tian X, et al. Evaluation of ultrasound-guided radiofrequency ablation as a treatment option for papillary thyroid microcarcinoma in the isthmus: a retrospective study. Front Endocrinol. 2021;11:599471. doi: 10.3389/fendo.2020.599471.
[31] Wu R, Luo Y, Tang J, et al. Ultrasound-guided radiofrequency ablation for papillary thyroid microcarcinoma: a retrospective analysis of 198 patients. Int J Hyperthermia. 2020;37(1):168–174. doi: 10.1080/02656736.2019.1708480.
[32] Zhang M, Tufano RP, Russell JO, et al. Ultrasound-guided radiofrequency ablation versus surgery for low-risk papillary thyroid microcarcinoma: results of over 5 years' follow-up. Thyroid. 2020;30(3):408–417. doi: 10.1089/thy.2019.0147.
[33] Ding M, Tang X, Cui D, et al. Clinical outcomes of ultrasound-guided radiofrequency ablation for the treatment of primary papillary thyroid microcarcinoma. Clin Radiol. 2019;74(9):712–717. doi: 10.1016/j.crad.2019.05.012.
[34] Lim HK, Cho SJ, Baek JH, et al. US-Guided radiofrequency ablation for low-risk papillary thyroid microcarcinoma: efficacy and safety in a large population. Korean J Radiol. 2019;20(12):1653–1661. doi: 10.3348/kjr.2019.0192.
[35] Wei Y, Niu WQ, Zhao ZL, et al. Microwave ablation versus surgical resection for solitary T1N0M0 papillary thyroid carcinoma. Radiology. 2022;304(3):704–713. doi: 10.1148/radiol.212313.
[36] Zheng L, Liu FY, Yu J, et al. Thermal ablation for papillary thyroid microcarcinoma located in the isthmus: a study with 3 years of follow-up. Future Oncol (London, England). 2022;18(4):471–480. doi: 10.2217/fon-2021-0463.
[37] Lu C, Li X, Chu X, et al. Clinical effects of microwave ablation in the treatment of low-risk papillary thyroid microcarcinomas and related histopathological changes. Front Endocrinol. 2021;12:751213. doi: 10.3389/fendo.2021.751213.
[38] Cao XJ, Zhao ZL, Wei Y, et al. Microwave ablation for papillary thyroid cancer located in the thyroid isthmus: a preliminary study. Int J Hyperthermia. 2021;38(1):114–119. doi: 10.1080/02656736.2021.1880028.
[39] Wang X, Niu X, Mu S, et al. Analysis and evaluation of the efficacy of ultrasound-guided microwave ablation for papillary thyroid microcarcinoma. Int J Hyperthermia. 2021;38(1):1476–1485. doi: 10.1080/02656736.2021.1988152.
[40] Wu J, Zhao ZL, Cao XJ, et al. A feasibility study of microwave ablation for papillary thyroid cancer close to the thyroid capsule. Int J Hyperthermia. 2021;38(1):1217–1224. doi: 10.1080/02656736.2021.1962549.
[41] Teng DK, Li WH, Du JR, et al. Effects of microwave ablation on papillary thyroid microcarcinoma: a five-year follow-up report. Thyroid. 2020;30(12):1752–1758. doi: 10.1089/thy.2020.0049.
[42] Yue WW, Qi L, Wang DD, et al. US-guided microwave ablation of low-risk papillary thyroid microcarcinoma: longer-term results of a prospective study. J Clin Endocrinol Metab. 2020;105(6):1791–1800. doi: 10.1210/clinem/dgaa128.
[43] Li J, Liu Y, Liu J, et al. A comparative study of short-term efficacy and safety for thyroid micropapillary carcinoma patients after microwave ablation or surgery. Int J Hyperthermia. 2019;36(1):640–646.
[44] 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(1):109–117. doi: 10.1007/s12020-019-01868-2.
[45] Teng D, Sui G, Liu C, et al. Long-term efficacy of ultrasound-guided low power microwave ablation for the treatment of primary papillary thyroid microcarcinoma: a 3-year follow-up study. J Cancer Res Clin Oncol. 2018;144(4):771–779. doi: 10.1007/s00432-018-2607-7.
[46] Zhang L, Zhang GP, Zhan WW, et al. The feasibility and efficacy of ultrasound-guided percutaneous laser ablation for multifocal papillary thyroid microcarcinoma. Front Endocrinol. 2022;13:921812. doi: 10.3389/fendo.2022.921812.
[47] Kim HJ, Chung SM, Kim H, et al. Long-term efficacy of ultrasound-guided laser ablation for papillary thyroid microcarcinoma: results of a 10-year retrospective study. Thyroid. 2021;31(11):1723–1729. doi: 10.1089/thy.2021.0151.
[48] Peng K, Zhou P, Liu W. Long-term efficacy of ultrasound-guided percutaneous laser ablation for low-risk papillary thyroid microcarcinoma: a 5-year follow-up study. Biomed Res Int. 2021;2021:1–8. doi: 10.1155/2021/6616826.
[49] Ji L, Wu Q, Gu J, et al. Ultrasound-guided percutaneous laser ablation for papillary thyroid microcarcinoma: a retrospective analysis of 37 patients. Cancer Imaging. 2019;19(1):16. doi: 10.1186/s40644-019-0204-x.
[50] Zhou W, Ni X, Xu S, et al. Ultrasound-guided laser ablation versus surgery for solitary papillary thyroid microcarcinoma: a retrospective study. Int J Hyperthermia. 2019;36(1):897–904.
[51] Zhang L, Zhou W, Zhan W, et al. Percutaneous laser ablation of unifocal papillary thyroid microcarcinoma: utility of conventional ultrasound and contrast-enhanced ultrasound in assessing local therapeutic response. World J Surg. 2018;42(8):2476–2484. doi: 10.1007/s00268-018-4500-6.
[52] Li T, Lu B, Zhang Y, et al. Meta-analysis of the application effect of different modalities of thermal ablation and surgical treatment in papillary thyroid microcarcinoma. Dis Markers. 2022;2022:9714140. doi: 10.1155/2022/9714140.
[53] Choi Y, Jung SL. Efficacy and safety of thermal ablation techniques for the treatment of primary papillary thyroid microcarcinoma: a systematic review and meta-analysis. Thyroid. 2020;30(5):720–731. doi: 10.1089/thy.2019.0707.
[54] Chen Y, Sadow PM, Suh H, et al. BRAF(V600E) is correlated with recurrence of papillary thyroid microcarcinoma: a systematic review, multi-institutional primary data analysis, and meta-analysis. Thyroid. 2016;26(2):248–255. doi: 10.1089/thy.2015.0391.
[55] Xing M, Liu R, Liu X, et al. BRAF V600E and TERT promoter mutations cooperatively identify the most aggressive papillary thyroid cancer with highest recurrence. J Clin Oncol. 2014;32(25):2718–2726. doi: 10.1200/JCO.2014.55.5094.
[56] Yue W, Chen L, Yu L, et al. Checkpoint blockade and nanosonosensitizer-augmented noninvasive sonodynamic therapy combination reduces tumour growth and metastases in mice. Nat Commun. 2019;10(1):2025. doi: 10.1038/s41467-019-09760-3.
[57] Chu KF, Dupuy DE. Thermal ablation of tumours: biological mechanisms and advances in therapy. Nat Rev Cancer. 2014;14(3):199–208. doi: 10.1038/nrc3672.
[58] Lan X, Sun W, Zhang H, et al. A meta-analysis of central lymph node metastasis for predicting lateral involvement in papillary thyroid carcinoma. Otolaryngol Head Neck Surg. 2015;153(5):731–738. doi: 10.1177/0194599815601412.
[59] Min Y, Wang X, Chen H, et al. Thermal ablation for papillary thyroid microcarcinoma: how far we have come? Cancer Manag Res. 2020;12:13369–13379. doi: 10.2147/CMAR.S287473.
[60] Orloff LA, Noel JE, Stack BC, Jr., et al. Radiofrequency ablation and related ultrasound-guided ablation technologies for treatment of benign and malignant thyroid disease: an international multidisciplinary consensus statement of the American Head and Neck Society Endocrine Surgery Section with the Asia Pacific Society of Thyroid Surgery, Associazione Medici Endocrinologi, British Association of Endocrine and Thyroid Surgeons, European Thyroid Association, Italian Society of Endocrine Surgery Units, Korean Society of Thyroid Radiology, Latin American Thyroid Society, and Thyroid Nodules Therapies Association. Head Neck. 2022;44(3):633–660. doi: 10.1002/hed.26960.
[61] Yekuo L, Shasha W, Feng H. Multipolar radiofrequency ablation in controlling hemorrhage from blunt liver trauma. Am J Emerg Med. 2009;27(2):197–201. doi: 10.1016/j.ajem.2008.01.060.

[62] Oda H, Miyauchi A, Ito Y, et al. Incidences of unfavorable events in the management of low-risk papillary microcarcinoma of the thyroid by active surveillance versus immediate surgery. Thyroid. 2016;26(1):150–155. doi: 10.1089/thy.2015.0313.

[63] Mauri G, Orsi F, Carriero S, et al. Image-Guided thermal ablation as an alternative to surgery for papillary thyroid microcarcinoma: preliminary results of an Italian experience. Front Endocrinol (Lausanne). 2020;11:575152. doi: 10.3389/fendo.2020.575152.

[64] Tufano RP, Pace-Asciak P, Russell JO, et al. Update of radiofrequency ablation for treating benign and malignant thyroid nodules. The future is now. Front Endocrinol (Lausanne). 2021;12:698689. doi: 10.3389/fendo.2021.698689.

[65] Yan L, Zhang Y, Jiang B, et al. Radiofrequency ablation for cervical metastatic lymph nodes in children and adolescents with papillary thyroid carcinoma: a preliminary study. Front Endocrinol (Lausanne). 2021;12:624054. doi: 10.3389/fendo.2021.624054.

[66] Lan Y, Jin Z, Zhang M[, et al. Factors affecting quality of life of patients undergoing radiofrequency ablation for papillary thyroid microcarcinoma]. Zhongguo yi Xue ke Xue Yuan Xue Bao (Acta Acad Med Sin). 2020;42(5):632–639.

[67] Ou D, Chen C, Jiang T, et al. Research review of thermal ablation in the treatment of papillary thyroid carcinoma. Front Oncol. 2022;12:859396. doi: 10.3389/fonc.2022.859396.