Comparison of the Efficacy and Safety of Thyroid Microwave Ablation and Radiofrequency Ablation versus Open Surgery for the Treatment of Benign Thyroid Nodules: A Propensity Score Matching Study

Ann. Ital. Chir., 2024 95, 6: 1108–1117
https://doi.org/10.62713/aic.3531

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AIM: With the advantage of preserving thyroid function while minimizing intervention-related morbidity, minimally invasive thermal ablation techniques such as microwave ablation (MWA) and radiofrequency ablation (RFA) have emerged as alternatives to traditional open surgery. This study compares the efficacy and safety of MWA and RFA with that of open surgery for the treatment of benign thyroid nodules by utilizing a propensity score matching study design to improve comparability.

METHODS: This retrospective study included patients with benign thyroid nodules treated at the North China Electric Power University (Baoding) School Hospital between May 2020 and May 2023. Following propensity score matching, the patients were equally divided into three treatment groups: MWA, RFA, and open surgery. Data on demographic characteristics, thyroid function, treatment outcomes (including nodule size reduction, postoperative pain, cosmetics, hospital stay, and quality of life (QoL)), and postoperative complications were analyzed.

RESULTS: A total of 160 patients, including 55 patients who received MWA, 58 patients treated with RFA and 47 patients operated with open surgery, were initially included. Propensity score matching, aimed at minimizing baseline differences among the groups, was conducted, leaving behind 105 patients, who were equally distributed with 35 persons per group. Compared to open surgery, both MWA and RFA significantly reduced intraoperative blood loss, operation time, length of hospital stay, and pain scores ($p < 0.05$). The incidence of complications, such as hypothyroidism, hematoma, wound pain, and incision adhesion, was also significantly lower ($p < 0.05$). In addition, the MWA and RFA were superior to open surgery in terms of cosmetic satisfaction and overall QoL scores ($p < 0.05$). No significant differences were observed between the MWA and RFA groups in terms of treatment efficacy, complication rates, cosmetic satisfaction, and QoL scores ($p > 0.05$). At the 6-month follow-up, no significant differences in thyroid function were observed among the three treatment modalities ($p > 0.05$).

CONCLUSIONS: MWA and RFA exhibit comparable outcomes, in terms of efficacy and safety, for the treatment of benign thyroid nodules, with advantages over open surgery including shorter hospital stays, lower level of postoperative pain, better cosmetic outcomes, higher QoL scores, and lower rates of certain complications.

Keywords: thyroid microwave ablation; thyroid radiofrequency ablation; thyroid open surgery; benign thyroid nodules; propensity score matching; efficacy; safety

Introduction

Benign thyroid nodules are a common endocrinological condition affecting a substantial portion of the global population, with a prevalence rate of up to 67% [1] based on ultrasonographic assessment. While many of these nodules warrant no intervention, owing to their asymptomatic nature and benign pathology, a subset presents with cosmetic issues, local compressive symptoms, or the potential for the regrowth of thyroid tissue necessitating therapeutic intervention [2, 3]. Traditionally, open surgical resection has served as the cornerstone of definitive treatment for nodules that meet criteria for intervention, enabling immediate and unequivocal removal of the offending lesion [1]. However, the invasiveness of surgery, the need for general anesthesia, and the risk of postoperative complications, such as hypothyroidism, recurrent laryngeal nerve injury, and significant scarring, have driven the search for less invasive alternatives.

Over the past decade, thermal ablation techniques, including microwave ablation (MWA) and radiofrequency ablation (RFA), have emerged as innovative, minimally invasive options for treating benign thyroid nodules [4, 5]. These methods utilize thermal energy to induce coagulative necrosis within the nodule, resulting in a reduction of nodule size and amelioration of related symptoms [6]. The

Submitted: 26 June 2024 Revised: 30 October 2024 Accepted: 8 November 2024 Published: 20 December 2024
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appeal of these techniques lies in their outpatient nature, the use of local anesthesia, minimal scarring, and the retention of thyroid function, making them attractive options for patients and clinicians alike [7]. Despite their increasing adoption, the comparative efficacy and safety of MWA and RFA relative to traditional open surgery remain subjects of ongoing investigation [8].

The literature to date offers insights into these ablation techniques' capabilities to reduce nodule volume and improve patient symptoms while preserving thyroid function [9, 10, 11]. However, the evidence often arises from non-comparative, single-arm studies or retrospective analyses with inherent biases due to non-randomized treatment assignment and heterogeneous patient populations. Furthermore, comparisons between these minimally invasive techniques and open surgery frequently lack methodological rigor, such as the absence of propensity score matching to account for confounders that could influence treatment outcomes. These gaps underscre the critical need for well-designed comparative studies to elucidate the relative merits and drawbacks of MWA, RFA, and open surgery in managing benign thyroid nodules.

Addressing this clinical imperative, our study harnesses a retrospective cohort design bolstered by propensity score matching—a statistical technique that simulates the conditions of a randomized controlled trial by balancing observable covariates across treatment groups—to provide a robust comparison of the efficacy and safety of MWA and RFA versus open surgery. The innovative aspect of this study lies in its exploration of the efficacy and safety comparison between MWA, RFA, and open surgery—an area that has been rarely investigated before. Currently, there is a lack of dedicated research focusing on the comparative analysis between MWA, RFA, and open surgery. This study aims to bridge this knowledge gap by elucidating the efficacy and safety profiles of MWA and RFA, offering unique insights to guide clinical decision-making regarding benign thyroid nodules. Specifically, it aims to compare the three treatment modalities in terms of their impact on thyroid function, treatment outcomes, including nodule size reduction, postoperative pain, hospital stay duration, cosmetic satisfaction, and quality of life, as well as the incidence of postoperative complications.

Materials and Methods

Study Design

This retrospective study included patients with benign thyroid nodules treated between May 2020 and May 2023 at the North China Electric Power University (Baoding) School Hospital. Patients were divided into three groups based on the type of surgery they underwent (MWA, RFA, and open surgery). Patient selection involved several steps to ensure that patient preferences, such as aesthetics and cost, were respected and considered. Initially, the physicians provided comprehensive information about the available treatment options, including their benefits and potential risks, to all patients in a clear and understandable manner, ensuring that the patients fully understood their choices. Subsequently, the patients and the physicians made decisions together through open and honest discussions, considering the patient's medical condition, personal values, and preferences. Importantly, all patient decisions were made within the framework of medical ethics, ensuring that patient autonomy and informed consent were rigorously maintained throughout the decision-making process.

Eligibility and Grouping Criteria

Individuals meeting the following criteria were included: (i) having clinically diagnosed benign thyroid nodules [12]; (ii) nodule diameter ranging from 0.5 to 4.2 cm; (iii) aged $\geq$18 years; (iv) requiring surgical treatment; (v) having normal mental and cognitive function; and (vi) having complete medical records.

The exclusion criteria employed in this study are as follows: (i) clinically confirmed with inflammatory or malignant nodules; (ii) comorbid with severe heart, liver, lung, or other important organ dysfunction; (iii) comorbid with severe coagulation disorders; (iv) having vocal cord dysfunction; (v) having retrosternal goiter; (vi) intolerant to surgery or unable to cooperate with treatment; and (vii) having received radiation therapy or similar treatments in the 3 months before surgery.

Treatment Approach

During open surgery, the patients were administered general anesthesia while assuming supine position, with their shoulders raised. A curved incision was made 2 cm above the sternal notch, sequentially dividing the skin, strap muscles, and the thyroid isthmus. The strap muscles were divided in the midline to fully expose the thyroid, and the surgery was performed directly at the lesion.

While performing MWA, the patients were placed in supine position with the neck in hyperextension. Their vital signs were monitored, and ultrasound was used to assess the nodules from different aspects, such as volume, shape, and location. After disinfection, local anesthesia was performed at the nodule site, followed by fluid isolation. The thyroid, carotid artery, tracheoesophageal cleft, and other areas were isolated to reduce thermal damage. A MWA device (METI, Nanjing Fuzhong Medical High tech Co., Ltd., Nanjing, China) was used to create an incision at the puncture point, and the output power was set to 30 W. Under ultrasound guidance, a microwave antenna of the same model was placed at the nodule site to perform ablation. After ablation, an ultrasound examination was conducted to assess the nodule tissue lesion and defect area, and to examine the status of ablation. If the ablation was not complete, supplementary ablation was performed. The puncture site was dressed with a dressing and pressure was applied for approximately 15 minutes post-procedure. Microwave

therapy instrument model METI-IVB (Nanjing Fuzhong Medical High tech Co., Ltd., Nanjing, China), with a microwave working section length of 10 mm and a diameter of 2 mm, was utilized. Ultrasonic diagnostic instrument model E-CUBE7 (Nanjing Fuzhong Medical High tech Co., Ltd., Nanjing, China), with a probe frequency of 10 MHz, was used during this procedure. S-5L radiofrequency ablation device Model specification (S-5L Registration certificate number: National Medical Device Registration No. 20203010442 Manufacturer, Maide Medical Technology Co., Ltd., Shanghai, China) was used while conducting RFA. Before performing the treatment, the patients assumed supine position, and after routine disinfection and draping were conducted, local anesthesia with 2% lidocaine was administered under ultrasound guidance from the skin puncture site to the thyroid capsule. Part of the thyroid and recurrent laryngeal nerve was injected with 2% lidocaine solution under ultrasound guidance to create a liquid isolation band of about 5 mm to protect the anterior neck muscles and carotid artery. An electrode needle was inserted into the nodule, avoiding the dangerous triangular area formed by the nasal root and the corners of both sides of the mouth to prevent injury to the recurrent laryngeal nerve and esophagus. The electrode needle was moved in the nodule using a moving-ablation technique to eliminate the nodules one by one. The electrode needle was inserted into the deepest part of the nodule for treatment to avoid changes in the ultrasound image due to near-to-far treatment that can result in ineffective nodule ablation. The power was initially adjusted to 35–75 W, and if a high echo area does not appear within 5–10 seconds, the power was adjusted, but not exceeding 120 W. For cystic-solid nodules, the internal fluid was first aspirated, followed by ablation.

Complications

Post-ablation complications for thyroid nodules typically include local infection, bleeding or hematoma formation, vocal cord paralysis resulting in hoarseness, thyroid function abnormalities such as hypothyroidism or hyperthyroidism, and persistent pain. These complications can impact patient's recovery and quality of life.

In this study, hoarseness, hypothyroidism, hematoma, wound pain, and adhesion of incision edges were considered as complications of thyroid ablation.

Data Collection

General patient information, including age, sex, body mass index (BMI), diabetes, hypertension, alcohol consumption, smoking history, multinodularity, nodule location, dominant nodule size, dominant nodule volume, and family history of thyroid nodules, was retrieved through the medical records system. At admission and 6 months post-operation, 5 mL of fasting venous blood from the elbow was collected from each patient using a fully automated chemiluminescence analyzer (DXI-800, Batch No: 20173406577, Beckman, Los Angeles, CA, USA) to measure the levels of total triiodothyronine (TT3), total thyroxine (TT4), and thyroid-stimulating hormone (TSH).

The length of hospitalization and postoperative complications for all patients were recorded. The level of postoperative pain was assessed using the Visual Analog Scale (VAS) measured in scores ranging from 0 to 10, which represent the degree of pain, with 0 indicating no pain and 10 the most severe pain. The Cronbach's α of the scale was 0.714 [13].

A department-developed questionnaire was used 6 months post-operation to evaluate patients' satisfaction with the cosmetic outcome. Based on the survey results, a patient could be categorized as "very satisfied", "somewhat satisfied", or "dissatisfied". The total satisfaction was calculated as follows: (number of very satisfied cases + number of somewhat satisfied cases)/total number of cases $\times$ 100%.

The European Organization for Research and Treatment of Cancer Quality of Life Questionnaire (EORTC QLQ-C30) was used to assess patients' quality of life, including five functional domains, namely physical functioning (PF), role functioning (RF), emotional functioning (EF), cognitive functioning (CF), and social functioning (SF). The scores range from 0 to 100, with higher scores indicating better quality of life and lower scores indicating the presence of more symptoms or problems. The Cronbach's α coefficient of this scale was 0.927 [14].

Nodule size changes after treatment were recorded, and volume reduction rate (VRR) of the thyroid nodules was calculated using the formula in the following:

VRR = [(Nodule volume before treatment – Nodule volume at follow-up)/Nodule volume before treatment] $\times$ 100%

In this study, recurrence was defined as regrowth of thyroid tissue after treatment.

Data Cleaning and Management

Before conducting data analysis, this study executed a standardized data cleaning process to identify and rectify any inconsistencies, errors, or missing values. This involved careful scrutiny of the dataset, removal of duplicate entries, correction of data input errors, and handling of missing values. Stochastic regression imputation was used in Python 3.6.0 (Python Software Foundation, Amsterdam, Netherlands) with pandas, numpy, seaborn, random, and missingno to fill in missing values. Missing data were kept below 5% to control potential selection bias, and sensitivity analysis was conducted by calculating the outcome of lost follow-up cases based on the worst and best outcomes. If the results showed no significant difference, the impact of lost follow-up on the conclusion was considered minimal, making the conclusion more reliable. The final results were then output after filling in the missing values.

Statistical Analysis

Using G*Power 3.1.9.7 software (University of Dusseldorf, Dusseldorf, NRW, Germany), the "analysis of vari-

Table 1. Baseline characteristics of study participants before propensity score matching.

Parameters	MWA (n = 55)	RFA (n = 58)	Open surgery (n = 47)	p (A vs C)	p (B vs C)	p (A vs B)	Total	
							F/χ^2	p
Age (years)	43.15 ± 5.43	42.81 ± 6.58	45.66 ± 6.59	0.043	0.020	0.772	2.795	0.045
Gender (male/female)	18/37	16/42	10 /37	0.196	0.456	0.551	1.667	0.435
Body mass index (kg/m²)	26.73 ± 4.25	26.85 ± 4.79	24.51 ± 3.15	0.008	0.005	0.877	4.979	0.008
Diabetes	9 (16.36%)	10 (17.24%)	13 (27.66%)	0.167	0.199	0.901	2.454	0.293
Hypertension	13 (23.64%)	16 (27.59%)	8 (17.02%)	0.410	0.200	0.631	1.642	0.440
Drinking history (%)	21 (38.18%)	24 (41.38%)	14 (29.79%)	0.373	0.219	0.729	1.560	0.458
Smoking history (%)	16 (29.09%)	9 (15.52%)	15 (31.91%)	0.757	0.047	0.082	4.471	0.107
Multinodularity (%)	25 (45.45%)	20 (34.48%)	29 (61.70%)	0.129	0.008	0.234	7.759	0.028
Nodule location (%)				0.036	0.153	0.234	7.569	0.109
- Right lobe	28 (50.91%)	25 (43.10%)	16 (34.04%)					
- Left lobe	22 (40.00%)	25 (43.10%)	18 (38.30%)					
- Isthmus	5 (9.09%)	8 (13.79%)	13 (27.66%)					
Family history of thyroid nodules	9 (16.36%)	9 (15.52%)	11 (23.40%)	0.372	0.306	0.902	1.263	0.532

A, MWA; B, RFA; C, open surgery; RFA, radiofrequency ablation; MWA, microwave ablation.

Table 2. Baseline characteristics of study participants after propensity score matching.

Parameters	MWA (n = 35)	RFA (n = 35)	Open surgery (n = 35)	p (A vs C)	p (B vs C)	p (A vs B)	Total	
							F/χ^2	p
Age (years)	42.55 ± 5.21	43.12 ± 6.45	44.76 ± 7.32	0.151	0.285	0.710	1.128	0.328
Gender (male/female)	12/23	13/22	10/25	0.607	0.445	0.803	0.600	0.741
Body mass index (kg/m²)	25.64 ± 3.21	26.12 ± 3.56	24.89 ± 4.28	0.403	0.169	0.586	0.975	0.381
Diabetes	5 (14.29%)	5 (14.29%)	3 (8.57%)	0.710*	0.707*	1.000	—	0.809**
Hypertension	7 (20.00%)	9 (25.71%)	5 (14.29%)	0.526	0.232	0.569	1.429	0.490
Drinking history (%)	12 (34.29%)	11 (31.43%)	14 (40%)	0.621	0.454	0.799	0.584	0.747
Smoking history (%)	9 (25.71%)	9 (25.71%)	11 (31.43%)	0.597	0.597	1.000	0.381	0.826
Multinodularity (%)	14 (40.00%)	16 (45.71%)	19 (54.29%)	0.231	0.473	0.629	1.454	0.483
Nodule location (%)				0.967	0.788	0.818	0.657	0.957
- Right lobe	14 (40.00%)	13 (37.14%)	15 (42.86%)					
- Left lobe	16 (45.71%)	15 (42.86%)	15 (42.86%)					
- Isthmus	5 (14.29%)	7 (20%)	5 (14.29%)					
Family history of thyroid nodules	8 (22.86%)	8 (22.86%)	6 (17.14%)	0.550	0.550	1.000	0.460	0.795

A, MWA; B, RFA; C, open surgery; *Continuous correction for chi-squared test; **Fisher's exact test.

ance (ANOVA): Fixed effects, omnibus, one-way" option based on F tests was employed for a priori analysis. The parameters were configured as follows: two-tailed mode, effect size (f) = 0.4, and probability of type I error (α) = 0.05. Subsequently, sample sizes for three groups were input to calculate power (1-β err prob), yielding a result of power = 0.955. To compare the efficacy of MWA, RFA, and open surgery in the treatment of benign thyroid nodules, we used multinomial logistic regression in R to calculate propensity scores and performed 1:1:1 matching across the three groups using a caliper of 0.02. The confounding factors included in the propensity score matching analysis were gender, BMI, diabetes, hypertension, drinking history, smoking history, multinodularity, nodule location, and family history of thyroid nodules. After matching, we assessed the balance of characteristics and analyzed the treatment effects within the matched sample.

Statistical analysis was conducted using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Normally distributed data are expressed as mean ± standard error, whereas non-normally distributed data are expressed as median (P25, P75). Data of continuous variables were compared using either ANOVA or the Kruskal-Wallis H test, depending on data normality, which was determined using Shapiro-Wilk test. Categorical variables are presented as count and percentage. Data of categorical variables were compared using the chi-squared test or Fisher's exact test. Bonferroni test was utilized as post-hoc analysis in multi-group comparisons. The threshold for statistical significance was set at $p < 0.05$.

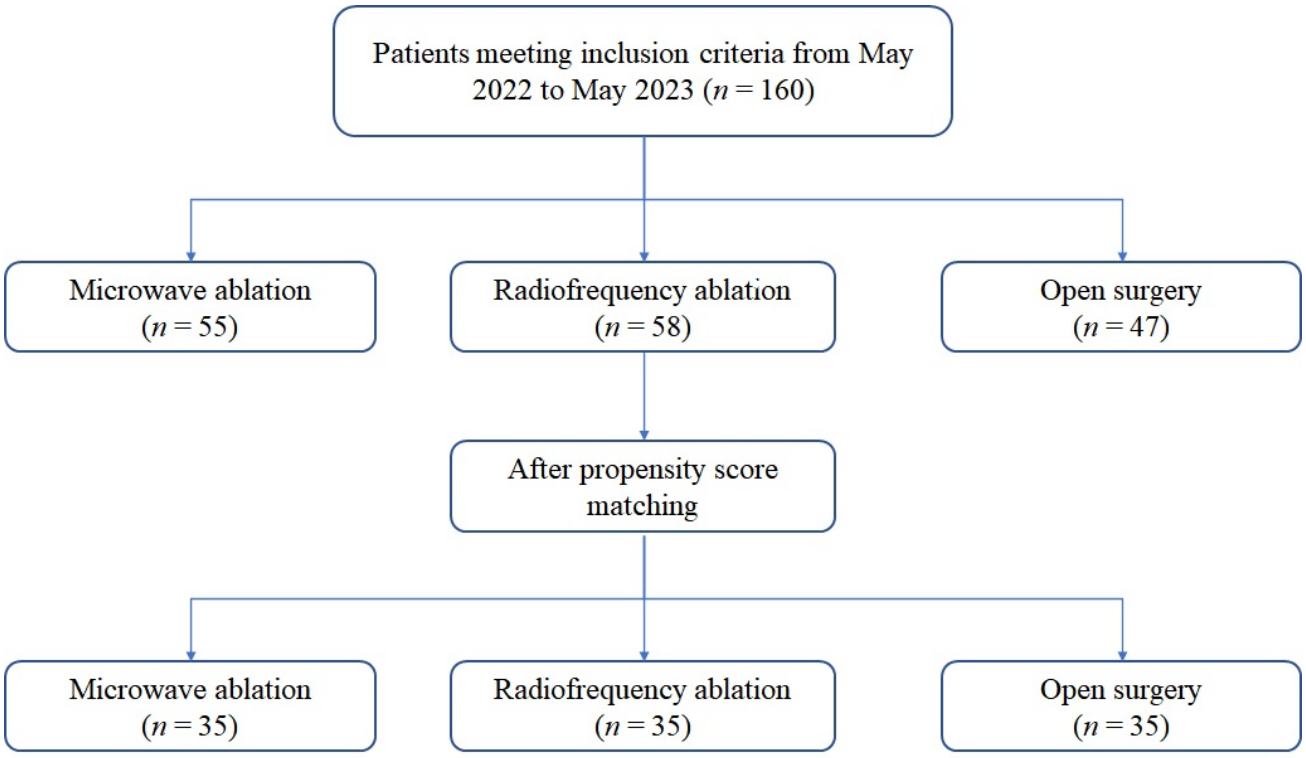

Fig. 1. Patient enrollment flowchart.

Results

Demographic Data and Propensity Score Matching

Initially, the present study included 160 patients, of which 55 underwent MWA, 58 RFA, and 47 open surgery. Before matching, there were significant differences in age, Multinodularity and BMI among the groups (Table 1). To address these differences, propensity score matching was used to create a sample bearing comparable baseline characteristics, with a total of 105 patients, which is evenly divided across the three treatment types (Fig. 1). After matching, there were no significant differences in the baseline characteristics between the groups. This matching process balanced the groups, allowing for a fair comparison of the treatments' effectiveness and safety. Post-matching analysis showed *p*-values well above 0.05 for all parameters, indicating that the initial differences were successfully adjusted for, and any subsequent outcome differences can be regarded, with more confidence, as attributed to the treatment methods rather than patient characteristics (Table 2).

Thyroid Function

Analysis of baseline thyroid function among patients undergoing MWA, RFA, and open surgery for the treatment of benign thyroid nodules revealed no significant differences in levels of TSH, TT3, and TT4 ($p > 0.05$ for all comparisons) (Table 3). Following treatment, no statistically significant differences were detected in thyroid function at the 6-month follow-up among the different treatment modalities. These findings indicate that all three treatment modalities preserve thyroid function equally well up to 6 months post-treatment, with no therapy showing superiority in thyroid function preservation.

Thyroid Nodule Volume

At baseline, the thyroid nodule volumes were similar among the three treatment groups ($p > 0.05$). At 6-month follow-up, the reduction in nodule volume was slightly greater in the RFA group compared to the MWA group, although the difference was not statistically significant ($p > 0.05$). Since the nodules were completely removed in the open surgery group, no post-treatment nodule volume data were reported for this group. Although the volume reduction rate in the RFA group was slightly higher than that of the MWA group, but the difference was not statistically significant ($p > 0.05$). During the 6-month follow-up period, no recurrence of nodules was observed (Table 4).

Evaluation of Efficacy and Safety

The comparison of the efficacy and safety of MWA, RFA, and open surgery for treating benign thyroid nodules revealed significant differences in several areas (Table 5). Both MWA and RFA resulted in less intraoperative blood loss, shorter operation times, shorter hospital stays, and lower pain scores compared to open surgery, with all these differences being statistically significant ($p < 0.05$). However, there were no significant differences in blood loss, operation time, length of hospital stay, or pain scores between the MWA and RFA groups ($p > 0.05$).

Table 3. Comparison of baseline and post-treatment levels of thyroid function indicators among the three treatment modalities.

Parameter	MWA (n = 35)	RFA (n = 35)	Open surgery (n = 35)	p (A vs C)	p (B vs C)	p (A vs B)	Total	
							F	p
Baseline TSH (mIU/L)	1.35 ± 0.29	1.36 ± 0.31	1.27 ± 0.35	0.334	0.257	0.866	0.758	0.471
Baseline TT3 (nmol/L)	2.12 ± 0.34	2.11 ± 0.35	2.05 ± 0.31	0.350	0.472	0.830	0.483	0.618
Baseline TT4 (nmol/L)	131.21 ± 16.31	132.31 ± 17.4	134.41 ± 18.21	0.441	0.613	0.790	0.309	0.735
TSH at 6-month post-treatment (mIU/L)	1.21 ± 0.25	1.21 ± 0.21	1.11 ± 0.33	0.104	0.108	0.986	1.770	0.176
TT3 at 6-month post-treatment (nmol/L)	1.92 ± 0.35	1.91 ± 0.34	1.81 ± 0.25	0.147	0.185	0.898	1.311	0.274
TT4 at 6-month post-treatment (nmol/L)	130.01 ± 15.41	128.01 ± 16.51	129.01 ± 14.31	0.787	0.787	0.589	0.147	0.864

A, MWA; B, RFA; C, open surgery; TT3, total triiodothyronine; TT4, total thyroxine; TSH, thyroid-stimulating hormone.

Table 4. Comparison of thyroid nodule volume among the three treatment modalities.

Parameter	Time	MWA (n = 35)	RFA (n = 35)	Open surgery (n = 35)	p (A vs C)	p (B vs C)	p (A vs B)	Total	
								H/Z	p
Mean volume (mL)	Baseline	4.10 (1.70, 8.40)	4.20 (2.40, 9.60)	3.20 (0.10, 11.80)	0.667	0.915	0.746	0.523	0.770
	At 6-month post-treatment	1.30 (0.10, 2.40)	0.10 (0.10, 2.90)	—	—	—	—	0.652	0.514
VRR (%)	—	0.74 (0.30, 0.92)	0.81 (0.62, 0.96)	—	—	—	—	1.775	0.076

VRR, volume reduction rate.

Table 5. Evaluation of efficacy and safety of the three treatment modalities.

Parameters	MWA (n = 35)	RFA (n = 35)	Open surgery (n = 35)	p (A vs C)	p (B vs C)	p (A vs B)	Total	
							F	p
Intraoperative blood loss (mL)	10.57 ± 3.14	11.07 ± 2.89	30.28 ± 3.57	$p < 0.001$	$p < 0.001$	0.509	429.082	<0.001
Time of operation (min)	28.26 ± 6.19	29.13 ± 5.76.21	78.59 ± 13.24	$p < 0.001$	$p < 0.001$	0.691	353.225	<0.001
Length of hospital stay (hours)	23.56 ± 3.21	24.32 ± 2.87	52.76 ± 4.32	$p < 0.001$	$p < 0.001$	0.369	782.621	<0.001
Pain score (0–10)	2.34 ± 0.87	2.11 ± 0.76	2.82 ± 1.09	0.031	0.002	0.287	5.505	0.005

Regarding cosmesis and quality of life (QoL), both cosmetic satisfaction and overall QoL scores were significantly higher in the MWA (p = 0.001 and p = 0.013, respectively) and RFA groups (p = 0.003 and p = 0.021, respectively) when compared to the open surgery group (Table 6). These findings indicate superior cosmetic results and higher quality of life scores for patients treated with the ablation techniques compared to the traditional open surgery. No significant differences were observed between the MWA and RFA groups in terms of cosmetic satisfaction (p = 0.666) and overall QoL scores (p = 0.843), suggesting similar patient satisfaction levels with both ablation treatments (Table 6).

Complications

The analysis of complications associated with MWA, RFA, and open surgery for benign thyroid nodules showed that MWA and RFA were associated with significantly lower rates of hypothyroidism, hematoma formation, wound pain, and adhesion of incision edges compared to open surgery. Specifically, the incidence of hypothyroidism was significantly lower for both MWA and RFA (p = 0.024). Similarly, hematoma formation was less frequent with MWA and RFA compared to open surgery (p = 0.006). Wound pain was also reduced in both MWA and RFA groups (p = 0.010), and the rate of adhesion of incision edges were lower in the MWA and RFA groups (p = 0.003). There was no significant difference in hoarseness among the groups, with both MWA and RFA showing 2.86% of cases and open surgery showing 11.43% (p = 0.361). Additionally, there were no significant differences in complication rates between MWA and RFA groups (p = 1.000) (Table 7).

Discussion

The management of benign thyroid nodules represents a significant clinical quandary, necessitating intervention against the risks associated with traditional open surgery [15, 16]. In this context, we offer a comprehensive comparative analysis of the efficacy and safety profiles of thyroid MWA, RFA, and classical open surgery, employing a rigorous propensity score matching methodology to ensure comparability among the treatment cohorts. The findings from this study contribute critical insights into optimizing therapeutic strategies for benign thyroid nodules, emphasizing the efficacy of MWA and RFA as viable alternatives to open surgery.

MWA and RFA were minimally invasive, often performed under local anesthesia, significantly shortening the recovery time and allowing for same-day discharge in many cases [17]. The comparative short-term outcomes of our study

Table 6. Comparison of cosmetic satisfaction and quality of life score among the three treatment modalities.

Parameters	MWA (n = 35)	RFA (n = 35)	Open surgery (n = 35)	p (A vs C)	p (B vs C)	p (A vs B)	Total	
							F	p
Cosmetic satisfaction (%)	92.12 ± 3.25	91.76 ± 3.01	89.21 ± 4.12	0.001	0.003	0.666	7.245	0.001
Overall QoL score (0–100)	89.25 ± 5.76	88.98 ± 5.32	85.67 ± 6.54	0.013	0.021	0.843	3.995	0.021

QoL, quality of life.

Table 7. Comparison of complication rates among the three treatment modalities.

Parameters	MWA (n = 35)	RFA (n = 35)	Open surgery (n = 35)	p (A vs C)	p (B vs C)	p (A vs B)	Total
							p
Hoarseness	1 (2.86%)	1 (2.86%)	4 (11.43%)	0.356*	0.353*	1.000	0.361**
Hypothyroidism	2 (5.71%)	2 (5.71%)	9 (25.71%)	0.022*	0.022	1.000	0.024**
Hematoma	1 (2.86%)	1 (2.86%)	8 (22.86%)	0.032*	0.032*	1.000	0.006**
Wound pain	2 (5.71%)	1 (2.86%)	9 (25.71%)	0.022	0.006	1.000	0.010**
Adhesion of incision edges	0 (0.00%)	0 (0.00%)	6 (17.14%)	0.025	0.033*	—	0.003**

A, MWA; B, RFA; C, open Surgery; *Continuous correction for chi-squared test; **Fisher's exact test.

elucidate the relative benefits of MWA and RFA over open surgery in select efficacy and safety parameters. The significantly shorter hospital stays and lower postoperative pain scores reported in the MWA and RFA groups highlight the minimally invasive nature of these treatments. Patients undergoing MWA and RFA experienced not only expedited discharge protocols but also reported substantially less discomfort, a testament to the less invasive procedural footprint and the localized therapeutic impact of these ablation techniques. MWA and RFA have emerged as minimally invasive, ultrasound-guided techniques that utilize thermal energy to induce coagulation necrosis in thyroid nodules, with the promise of reduced invasiveness and shorter recovery periods [18, 19]. This aspect was crucial in an era where healthcare systems were increasingly under pressure to optimize inpatient capacities and reduce costs. The shorter hospital stays and lower pain profiles not only benefit the healthcare system at large but also align with patients' preferences for less disruptive and more comfortable recovery processes. Although the two techniques differ in their heating mechanisms, they resulted in comparable clinical outcomes, in terms of efficacy, such as tumor ablation rates and local control rates, in this study. In terms of safety, both techniques are associated with similar rates of complication, including but not limited to local pain, infection, and risk of bleeding. The choice to use MWA or RFA may depend more on the specific clinical context and device availability, but overall, both offer effective treatment.

The external incision made during MWA and RFA was markedly smaller than that required for open surgery, often resulting in minimal to no visible scarring. Our study underscores the superior cosmetic outcomes and enhanced QoL scores in the MWA and RFA groups relative to the open surgery group. These findings were pivotal, considering the psychosocial implications of neck scarring and the increasingly aesthetic considerations influencing patient treatment preferences. Especially considering the anatomical location of the thyroid gland, surgical scars can be visually prominent and psychologically distressing for patients [20, 21]. In contrast, the minimally invasive nature of MWA and RFA minimizes this concern, offering an approach that was not only therapeutically effective but also cosmetically preferable. The negligible scarring and preservation of neck aesthetics following the procedures of MWA and RFA offer additional arguments in favor of these methods, especially in patients for whom cosmetic outcomes were a significant concern.

In terms of complications, our findings revealed a markedly lower incidence of hypothyroidism and hematoma formation in the MWA and RFA groups compared to the open surgery group. This discrepancy underscores a fundamental advantage of thermal ablation techniques: their capacity to target nodular tissue with precision, minimizing collateral damage to surrounding thyroid tissue and consequential hypothyroidism [22, 23]. Furthermore, the significantly reduced rate of hematoma formation emphasizes the lesser degree of invasiveness and tissue disruption with MWA and RFA, which translates into safer profiles of these procedures.

No significant difference was noted between the microwave and RFA groups. This indicates that there are no significant differences in efficacy and safety between the MWA and RFA methods. Both thyroid RFA and MWA procedures involve inactivating thyroid nodules using a thermal ablation approach, although they employ different thermal mechanisms—one using microwave and the other radiofrequency. Both methods utilize energy to deactivate the tumors through thermal ablation, yielding almost identical outcomes.

It is imperative to contextualize our study within the broader spectrum of existing literature. Consistent with our findings, previous studies have also reported favorable safety

and efficacy profiles for thermal ablation methods [24, 25]. However, our study advances the discourse by leveraging a propensity score matching design, which mitigates the impact of confounding variables and enhances the robustness of our comparative analysis. This methodological rigor ensures that the observed outcomes were more reliably attributable to the treatment modalities themselves, rather than the underlying patient heterogeneity.

Despite these promising results, this study is not without limitations. The retrospective nature and the relatively short follow-up period underscore the need for cautious interpretation of our findings and call for further longitudinal studies to comprehensively understand the long-term implications of these treatment modalities. Additionally, while our study meticulously matched participants across treatment cohorts, residual confounding cannot be entirely ruled out; therefore, future prospective randomized controlled trials are warranted to validate our findings. Future investigations should aim to extend these findings through larger-scale, multicenter studies with longer follow-up periods to definitively examine the long-term outcomes and advantages of MWA, RFA, and open surgery. Additionally, exploration into the patient-specific factors that may predict optimal outcomes of each treatment modality is crucial for further personalizing thyroid nodule management [26, 27].

This study highlights the significant advantages of MWA and RFA over traditional open surgery in the management of benign thyroid nodules. Both MWA and RFA demonstrated comparable effectiveness in preserving thyroid function, shortened hospital stays, minimized postoperative pain, and improved cosmetic outcomes with fewer complications. These findings suggest that MWA and RFA should be considered as viable treatment options, particularly for patients seeking minimally invasive approaches. Future research should focus on long-term outcomes, large-scale trials, cost-effectiveness analyses, and technological advancements to further validate and enhance these techniques.

Conclusions

In conclusion, the current study makes a significant stride in the treatment landscape of benign thyroid nodules, identifying MWA and RFA as effective and safe alternatives to open surgery. By offering comparable preservation of thyroid function, noteworthy reductions in hospital stay and postoperative pain, superior cosmetic outcomes, and a favorable profile of complications, MWA and RFA warrant consideration in the tailored management strategy for patients with benign thyroid nodules. Given the increasing prevalence of thyroid nodular disease, our findings serve as a reference for clinicians navigating the complex treatment landscape for benign thyroid nodules, featuring the nuanced spectrum of therapeutic objectives encompassing efficacy, safety, aesthetics, and quality of life.

Availability of Data and Materials

The datasets used or analysed during the current study were available from the corresponding author on reasonable request.

Author Contributions

JC, JLB and XWG designed the study; XWG and HW collected and analyzed the data, JC and JLB participated in drafting the manuscript, all authors conducted the study, and all authors contributed to critical revision of the manuscript for important intellectual content. All authors gave final approval of the version to be published. All authors participated fully in the work, took public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or completeness of any part of the work were appropriately investigated and resolved.

Ethics Approval and Consent to Participate

This study was reviewed by the Ethical Review Committee of North China Electric Power University (Baoding) School Hospital (Ethical Review No. L2024-01). This study was performed in accordance with the principles of the Declaration of Helsinki. All participants included in this study gave informed consent.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

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