



Radiofrequency Ablation for Recurrent Thyroid Cancers: 2025 Korean Society of Thyroid Radiology Guideline

Eun Ju Ha^{1*}, Min Kyoung Lee^{2*}, Jung Hwan Baek³, Hyun Kyung Lim⁴, Hye Shin Ahn⁵, Seon Mi Baek⁶, Yoon Jung Choi⁷, Sae Rom Chung³, Ji-hoon Kim⁸, Jae Ho Shin⁹, Ji Ye Lee⁸, Min Ji Hong¹⁰, Hyun Jin Kim¹¹, Leehi Joo³, Soo Yeon Hahn¹², So Lyung Jung¹³, Chang Yoon Lee¹⁴, Jeong Hyun Lee³, Young Hen Lee¹⁵, Jeong Seon Park¹⁶, Jung Hee Shin¹², Jin Yong Sung¹⁷, Miyoung Choi¹⁸, Dong Gyu Na¹⁹; Guideline Committee for the Korean Society of Thyroid Radiology (KSThR) and Korean Society of Radiology

¹Department of Radiology, Ajou University School of Medicine, Suwon, Republic of Korea

²Department of Radiology, Yeouido St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Republic of Korea

³Department of Radiology and Research Institute of Radiology, University of Ulsan College of Medicine, Asan Medical Center, Seoul, Republic of Korea

⁴Department of Radiology, Soonchunhyang University Seoul Hospital, Seoul, Republic of Korea

⁵Department of Radiology, Chung-Ang University Hospital, Chung-Ang University College of Medicine, Seoul, Republic of Korea

⁶Department of Radiology, Haeundae Sharing and Happiness Hospital, Busan, Republic of Korea

⁷Department of Radiology, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea

⁸Department of Radiology, Seoul National University Hospital, Seoul National University College of Medicine, Seoul, Republic of Korea

⁹Department of Radiology, Anam Hospital, Korea University College of Medicine, Seoul, Republic of Korea

¹⁰Department of Korea, CHA Gangnam Medical Center, CHA University, Seoul, Republic of Korea

¹¹Department of Korea, Daejin Medical Center, Bundang Jesaeng General Hospital, Seongnam, Republic of Korea

¹²Department of Korea and Center for Imaging Science, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea

¹³Department of Radiology, St. Vincent's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Republic of Korea

¹⁴Department of Radiology, National Cancer Center, Goyang, Republic of Korea

¹⁵Department of Radiology, Ansan Hospital, Korea University College of Medicine, Ansan, Republic of Korea

¹⁶Department of Radiology, Hanyang University College of Medicine, Hanyang University Hospital, Seoul, Republic of Korea

¹⁷Department of Radiology and Thyroid Center, Daerim St. Mary's Hospital, Seoul, Republic of Korea

¹⁸Division for Healthcare Technology Assessment Research, National Evidence-based Healthcare Collaborating Agency, Seoul, Republic of Korea

¹⁹Department of Radiology, Gangneung Asan Hospital, University of Ulsan College of Medicine, Gangneung, Republic of Korea

Radiofrequency ablation (RFA) is a minimally invasive treatment modality used as an alternative to surgery in patients with benign thyroid nodules, recurrent thyroid cancers (RTCs), and primary thyroid microcarcinomas. The Korean Society of Thyroid Radiology (KSThR) initially developed recommendations for the optimal use of RFA for thyroid tumors in 2009 and revised them in 2012 and 2017. As new meaningful evidence has accumulated since 2017 and in response to a growing global interest in the use of RFA for treating malignant thyroid lesions, the task force committee members of the KSThR decided to update the guidelines on the use of RFA for the management of RTCs based on a comprehensive analysis of current literature and expert consensus.

Keywords: Thyroid; Ultrasound; Radiofrequency ablation; Thyroid recurrent cancers; Thyroid intervention

Received: September 25, 2024 **Revised:** October 14, 2024 **Accepted:** October 16, 2024

*These authors contributed equally to this work.

Corresponding author: Jung Hwan Baek, MD, PhD, Department of Radiology and Research Institute of Radiology, University of Ulsan College of Medicine, Asan Medical Center, 88 Olympic-ro 43-gil, Songpa-gu, Seoul 05505, Republic of Korea

• E-mail: radbaek@naver.com

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INTRODUCTION

Image-guided minimally invasive ablation therapy (MIT) has been established as an effective and safe modality for the treatment of benign and malignant tumors in various organs [1-4]. Ultrasound (US)-guided radiofrequency ablation (RFA) is one of the MITs widely used as an alternative to surgery in patients with benign thyroid nodules and recurrent thyroid cancers (RTCs) [3]. The Korean Society of Thyroid Radiology (KSThR), an organization of thyroid radiologists in Korea primarily involved in the diagnosis and management of thyroid nodules, first proposed its recommendations for RFA in patients with benign thyroid nodules in 2009 and revised the recommendations for both benign thyroid nodules and RTCs in 2012 and 2017 [3,5].

Since 2017, several clinical studies on RFA for RTCs have provided additional meaningful evidence on its use for treating this condition; accordingly, the need to revise the earlier KSThR recommendations for the management of RTCs has been recognized. This guideline aimed to review the available scientific evidence and provide a consensus-based expert opinion on the use of RFA for RTCs in clinical practice.

Methodology

The KSThR task force members reviewed relevant articles on thyroid RFA and submitted suggestions for the clarification of prior recommendations; the task force reviewed new information from studies published since June 1, 2017, with relevant literature continuing to be reviewed through January 11, 2024. For this purpose, a systematic literature search of international and domestic databases (specifically, MEDLINE, Embase, and KoreaMed) was performed using the keywords ("thyroid cancer" AND "recurrence" AND ["radiofrequency ablation" OR "RF ablation" OR "RFA" OR "sclerotherapy" OR "ethanol ablation" OR "microwave ablation" OR "MWA" OR "laser ablation" OR "LA" OR "minimally invasive" OR "non-surgical"]). We held one offline and three online meetings to initiate the process of formulating the guidelines, and it was decided that the recommendations would cover standard terminology and reporting criteria, indications, pre-procedural evaluations, procedures, post-procedural monitoring, efficacy, and safety. The scope of the revised guidelines, methodology, information identification, and availability are described in

Supplementary Tables 1-3.

Study selection and quality appraisal of the selected studies were performed in pairs. The Risk of Bias Assessment Tool for Non-randomized Studies (RoBANS-2) was used to assess study quality [6]. The level of evidence and recommendation grading system were established based on a review of existing guidelines and other grading systems (Supplementary Tables 4, 5). The study design and quality (risk of bias) were the main factors affecting the level of evidence. The quality of evidence, clinical benefits and harms, costs, patient preferences, and values were considered for recommendation grading.

A consensus of nine panels, who are experts in thyroid radiology, was reached through the modified Delphi method, particularly in the contest of the benefit (median value ≥ 7 : significant net benefits) and harms (median value ≤ 3 : harms outweigh benefits). We structured the Key Questions (KQs) as survey questions with scores ranging from 1 to 9. If agreement (defined as scores of 7–9) was below 67%, the wording of the questions was revised based on the initial survey responses and additional feedback, and a second round of the survey was conducted. Nine panel members who participated in the modified Delphi process reviewed the evidence and discussed recommendations [7]. The evidence level and net benefits were the main factors underlying decisions regarding the recommendations. The strength of each recommendation was discussed in terms of its clinical applicability and impact on patient outcomes. Accordingly, although a high value was placed on the Delphi score, the strength of recommendation was downgraded if it was the consensus of the expert committee.

Standard Terminology

Establishing standardized terminology pertaining to RFA for the treatment of RTCs is crucial for treatment planning, evaluation of disease status and clinical outcomes, post-treatment follow-up, and appropriate communication. Several efforts have been made to standardize this terminology in the field of interventional radiology, including thyroid radiology [1,8,9]. Nevertheless, further endeavors to integrate standard RFA terminology for RTCs are necessary, considering the rapid advancements in devices and techniques and the expanding applications of RFA in clinical practice. Herein, we propose a standard RFA terminology in the context of RTC treatment.

General Terms

The term session refers to a singular procedure with a predetermined time frame during which an operator performs the RFA procedure. The term index tumor refers to an initially identified tumor for ablation [1]. A single RFA session may involve the treatment of multiple index tumors or a single index tumor for different purposes (i.e., curative or palliative intent, as discussed later). The use of the term per session (or per procedure) is recommended when reporting post-procedure results. The term per patient or per index tumor should be specified to avoid confusion when referring to time-specific events or post-procedure results.

Image-guided tumor ablation is a minimally invasive, non-surgical mode of treatment in which a target tumor is destroyed using chemical or energy-based ablations. Unlike percutaneous chemical ablation, energy-based ablation destroys tumor cells by the direct application of thermal (e.g., RFA) or nonthermal (e.g., irreversible electroporation) energy [1]. Since energy-based thermal ablation is a broad term that encompasses several different modalities (e.g., thermal and nonthermal), the term RFA should be specified and clearly denoted in medical records.

RFA generates heat and induces coagulation at the site of the target tumor by using radiofrequency (375–500 kHz) to create the “Joule effect” (ionic agitation or ionic friction) in the vicinity of an electrode [1,4,10,11]. Unless otherwise specified, it is understood that the term RFA has been used for image-guided (mostly, US-guided) percutaneous RFA.

Techniques and Procedures

While there is no size limit for treating RTCs with palliative intent, RFA with curative intent is usually indicated for index tumor with a size of ≤ 2 cm [12]. The RFA technique may differ depending on the size of the index tumor. Generally, the RFA electrode can be fixed at the center of the tumor (fixed-electrode technique) for the ablation of small tumors (size < 5 mm). If the index tumor is large, the moving-shot technique, which involves unit-by-unit ablation using a moving electrode within the tumor, can be used [3].

When the index tumor is ablated, there is an increase in index tumor echogenicity, signifying echogenic bubbles and various byproducts of coagulation necrosis. The term transient hyperechoic zone refers to the area in which this phenomenon occurs; this denotes the completion of RFA of the target index tumor, leading to coagulation necrosis [1,11]. The degree of hyperechogenicity depends on the

power (W) and duration of RFA as well as the impedance of the index tumor and its surrounding normal tissues. Tissue properties and treatment parameters such as the precise power and duration of RFA should be reported [13].

The term hydrodissection refers to the separation/dissection of normal tissue and/or critical structures from the index tumor using cold 5% dextrose water (DW) to facilitate effective and safe ablation [3,11,14]. The term hydrodissection should be used without hyphenation and should not be confused with lidocaine injections.

The term bolus injection of cold 5% DW refers to the rapid injection of the solution around the affected nerves to manage thermal damage [15,16].

Clinical Outcomes

The definitions of clinical outcomes, technical success, and technique efficacy depend on whether RFA is performed with a curative or palliative intent. Therefore, the purpose of RFA must be determined before evaluating technical success and technique efficacy. Technical success and technique efficacy are two terms that should not be used interchangeably. Achieving technical success is not equivalent to proving technique efficacy, although it may influence the technique efficacy to a certain degree. Unlike technical success, technique efficacy encompasses the time component (i.e., follow-up 1 year after RFA). Both terms can be used on either a per-index tumor or per-session basis.

Technical Success

Technical success refers to the completeness of the RFA procedure and adherence to the pre-RFA protocol. It is assessed immediately after RFA and its definition depends on the aim of RFA [1].

In the context of curative intent, technical success is defined as the complete ablation of the index tumor with fully achieved coagulation of the tumor and its safety margin as well as complete devascularization and disappearance of abnormal vasculature immediately after RFA on advanced Doppler imaging or contrast-enhanced US (CEUS) [5,17–19].

Recent technological advancements in US for the sensitive evaluation of small vessels with low velocity, advanced Doppler imaging techniques (e.g., microvascular flow imaging, Micro-Flow Imaging, superb microvascular imaging, and Slow Flow) [20,21], and CEUS have proven useful for detecting abnormal vasculatures at the target tumor and for evaluating technical success in terms of

ablation of viable tumors immediately after RFA [22]. In cases of incomplete ablation of the index tumor (e.g., if the tumor is large or in proximity to important anatomical structures), earlier follow-up (1–3 months) US with advanced Doppler imaging techniques and simultaneous thyroid protocol CT are recommended to assess the residual unablated tumor and for subsequent RFA planning [1,19,21].

With regard to palliative intent, technical success is tentative because of the nature of RTC. In such circumstances, the alleviation of patient symptoms and medical problems is of the utmost priority for technical success, instead of strictly adhering to the RFA protocol. For instance, reduction of the index tumor size and alleviation of tumor-related symptoms are considered technical successes, even in cases of incomplete RFA of the target tumor and its margin. Similarly, reduced bulging, pain, ulceration, and bleeding at the affected site could be considered a technical success in cases of RFA with palliative intent for RTCs involving the skin [3,19].

Technique Efficacy

Technique efficacy is based on the assessment of the ablated index tumor at specific follow-up time points and is determined according to the treatment plan, technical success, and RFA intention [1]. Presuming technical success, technique efficacy is determined using simultaneous conventional greyscale US with advanced Doppler imaging techniques and thyroid protocol CT at the 6–12 months follow-up after the first RFA session. Specifically, undetectable vasculature (or no enhancement)

and volume reduction (or disappearance) of the index tumor should be demonstrated on both US imaging and thyroid protocol CT [12,23]. If technique efficacy is achieved at the 6–12 months follow-up post-RFA, subsequent annual follow-ups using conventional greyscale US and advanced Doppler imaging techniques are recommended.

In the context of curative intent, technique efficacy can be assessed using the following parameters: 1) complete/incomplete disappearance of the index tumor (or undetectable vasculature in the ablated tumor), 2) volume reduction rate (VRR) of the index tumor, and 3) serum thyroglobulin (Tg) and anti-Tg antibody levels [24]. The pre- and post-RFA volume is calculated based on the longest diameter in the anteroposterior (A), transverse (B), and craniocaudal (C) directions using the following formula: $\text{volume} = A \times B \times C \times \pi/6$. The post-RFA VRR is calculated using the following formula: $(\text{initial volume} - \text{final volume})/\text{initial volume} \times 100$ [3]. Assessing serum Tg and anti-Tg antibody levels is also recommended to evaluate technique efficacy [24,25]. Standard units of RFA parameters should be used for better communication between physicians and for precise evaluation of RFA procedures and disease status (Table 1).

For palliative treatment, technique efficacy should focus on alleviating symptoms and improving quality of life. That is, debulking the index tumor and not necessarily the VRR or how well the operator complied with the RFA protocol.

Clinical Success

The term clinical success overlaps with the term technique efficacy. However, clinical success is a much broader term,

Table 1. Index of standard units and formula for radiofrequency ablation of recurrent thyroid cancer

Parameters	Standard units or formula
Length of exposed electrode	Centimeter (cm) or millimeter (mm)
Running time	Seconds (s) or minutes (min)
Power modulation	Watts (W)
Energy delivery	Joules (J) or kilojoules (kJ)
Volume of index tumor	Milliliter (mL) $\text{Anteroposterior length (cm)} \times \text{transverse length (cm)} \times \text{craniocaudal length (cm)} \times \pi/6$
Volume reduction rate	Percent (%) $(\text{initial volume} - \text{final volume})/\text{initial volume} \times 100$
Serum Tg level*	Nanogram per milliliter (ng/mL) or microgram per liter (μg/L)
Time frame for complication	Immediate (within a day) Periprocedure (within 30 days) Delayed (after 30 days)

*Although this parameter isn't used as the unit, it should be described together with the thyroid stimulating hormone level and anti-Tg antibody level for accuracy of washout Tg level.

Tg = thyroglobulin

and its definition should focus on the patient's quality of life and overall survivability. It reflects the ability of RFA to resolve the initial symptoms at the time of presentation and affects a patient's overall quality of life. For instance, compressive symptoms and pain caused by RTC can be alleviated by effective RFA, thereby improving the visual analog scale score and overall quality of life. Technique efficacy is evaluated based on changes in tumor volume reduction over time, whereas clinical success is evaluated based on improvements in the overall quality of life and survivability of the patient.

Various parameters reflect the clinical success of RFA for RTCs [1]. Overall survival (OS) is defined as the likelihood of patient survival for a certain period after RFA. If mortality occurs, disease-specific overall survival should be distinguished from other secondary causes of death such as non-thyroid malignancies. However, because thyroid cancer is associated with an extremely low mortality rate, time-to-progression or disease-free, recurrence-free, progression-free, or local tumor progression-free survival can be used to evaluate the clinical success after RFA for RTCs. Disease-free survival or recurrence-free survival can be defined as the length of time from the completion of RFA to the point at which a tumor reappears on imaging or when tumor-related symptoms recur. Progression-free survival refers to the length of time from the first RFA session to disease progression or death. In the context of RTCs, recurrence-free survival and progression-free survival may reflect the primary and secondary effectiveness of RFA. Finally, in the case of palliative treatment (debulking of the index tumor), the term symptom-free survival should be considered.

The term residual unablated tumor refers to the residual tumor visualized immediately after RFA or on the first follow-up imaging with vascularity on advanced Doppler imaging or enhancement on thyroid protocol CT. Local tumor progression refers to the absence of residual unablated tumor immediately after RFA on advanced Doppler imaging or CEUS but the detection of new tumor foci at the previously ablated index tumor site during the follow-up period [1]. Presuming the technical success of RFA (e.g., complete ablation with curative intent), local tumor progression is defined as the visualization of 1) a viable tumor within the ablated index tumor, seen as the reappearance of vascular flows on advanced Doppler imaging and/or enhancement of thyroid protocol CT images, and/or 2) newly developed tumor foci at the periphery of the previous ablated index tumor [1]. Although both modalities have some limitations in terms

of the evaluation of ablated tumor margins compared with histopathological evaluation, local tumor recurrence should not be used to describe local tumor progression. Local tumor recurrence refers to the detection of tumors outside the ablated index tumor near the surgical excision site and/or ipsilateral metastatic lymphadenopathy as confirmed by fine-needle aspiration (FNA) biopsy or core needle biopsy (CNB) assessment.

Complications

The incidence of complications should not be considered in terms of technique efficacy. The complication rate should be calculated based on the incidence per session (or per procedure) because a patient may have more than one index tumor and may require several sessions to achieve technical success. Based on the time frame of manifestations, complications can be categorized as 1) immediate (occurring within 24 h of an RFA session), 2) periprocedural (occurring 24 h to 30 days after an RFA session), and 3) delayed (occurring more than 30 days after an RFA session) [26,27].

Based on the severity, complications can be further classified as minor or major. A major complication is defined as any procedure-related adverse effect requiring immediate intervention, surgery, or prolonged hospitalization. In contrast, a minor complication is defined as any procedure-related adverse effects that are transient and require conservative treatment that may include a brief hospitalization for observation only (e.g., voice change ≤ 1 month). The terms side-effect and minor complications are often used interchangeably, although they are not the same [26]. The side effects of RFA are defined as signs and symptoms, such as muscle twitching, pain, edema, vasovagal reactions, hypertension that resolved without medication, vomiting/nausea, and coughing, as well as any undesired situation during RFA. Transient voice changes due to lidocaine injection, minimal hematoma/bleeding/parenchymal edema without any related symptoms, and tolerable mild pain/discomfort that did not require medication are not considered as complications or side effects. On the other hand, examples of major complications during RFA for RTCs include persistent nerve injuries (e.g., persistent voice change [period >1 month], Horner syndrome), vascular injuries (e.g., dissection or pseudoaneurysm), tracheal injuries, and esophageal perforation requiring intervention, surgery, or prolonged hospitalization.

Recommendations

The Recommendations of the 2025 Thyroid RFA Guideline by the KSThR are summarized in Table 2.

Indications

Key Question 1. What are the Treatment Options for RTCs?

[Recommendations]

- 1-1: Treatment options for RTCs include surgical removal, ¹³¹I therapy, minimally invasive treatment (MIT), external beam radiation (EBRT), thyroid stimulating hormone (TSH)-suppressive therapy, and systemic chemotherapy
- 1-2: Consider MIT as an alternative to surgery for patients who refuse to undergo reoperation, have radioactive iodine/radioiodine (RAI) refractoriness, or are at high risk for surgery
- 1-3: Consider MIT in a multimodal approach with a multidisciplinary team that includes members with specific expertise in MIT
- 1-4: Select the MIT modality based on disease status, patient characteristics and preferences, and specific institutional resources

Patients with differentiated thyroid cancer generally undergo life-long follow-up, and the estimated recurrence rate during postoperative surveillance is 30% [28]. The preferred treatment for locoregional RTCs is surgical removal of the recurrent tumor (when resectable) [29,30], ¹³¹I therapy (when responsive to RAI), MIT (ethanol ablation [EA], RFA, laser ablation, or microwave ablation [MWA]), and EBRT. Therefore, TSH suppressive therapy can be considered for patients with stable asymptomatic diseases. Systemic therapy with kinase inhibitors can be considered for patients with progressive macroscopic disease when all other treatment options have been exhausted [29,30].

Although surgical removal is considered the standard treatment for locoregional RTCs, reoperation can be challenging because of normal tissue plane distortions and severe fibrosis in the surgical bed [29,31,32]. These factors result in high rates of complications such as voice changes and hypoparathyroidism in patients undergoing surgery for RTCs [29,31,32]. In addition, postsurgical biochemical and structural remission has only been reported in some

patients [33]. With the increase in the population of older adults, the number of older patients with RTCs who are at high risk of surgery is also increasing [3,12,34]. Moreover, some patients refuse to undergo reoperation or experience refractory RAI. Therefore, MIT or active surveillance must be considered as an alternative to surgery in certain circumstances [3,29,35]. Several observational studies suggest that low-volume recurrent nodal disease can be indolent and manageable using active surveillance [29,36,37]. However, RTCs in the neck, especially in the central compartment, have a relatively high likelihood of invading critical adjacent structures, which can compromise the functionality of the organs and the quality of life of patients [38]. MIT may be beneficial for patients with oligometastatic neck disease as it can help avoid local complications and delay the need for initiating systemic treatment [3,12,29,35,38].

MITs for the treatment of RTCs should be selected with due appreciation of the disease status, patient characteristics and preferences, and specific resources available at the institution [35]. In patients with distant metastases and progression, MIT can be used for palliative purposes or to prevent aerodigestive tract obstruction [3,29,35]. The final decision regarding the use of MIT should be made carefully using a multimodal approach that involves not only a multidisciplinary team of experts in both traditional and image-guided interventional treatment modalities, but also the patient, if possible [29,35,39].

Key Question 2. What are the Indications of RFA for RTCs?

[Recommendations]

- 2-1: RFA can be performed with a curative or palliative intent for RTCs at the thyroidectomy bed, neck dissection site, and metastatic cervical lymph nodes for patients who refuse surgery or at high surgical risk
- 2-2: Curative-intent RFA should be considered when complete removal of the tumor is possible in patients with RTC and a limited number (≤ 3) of small tumors (size ≤ 2 cm)
- 2-3: For palliative intent, RFA can be used when the resulting volume reduction can reduce symptoms and improve the quality of life of the patient

RFA can be performed with either curative or palliative intent in patients with RTCs who refuse surgery or are at

Table 2. Summary of recommendations and evidences

KQs	Recommendations	Evidence level	Strength of recommendations
KQ 1. What are the treatment options for RTCs?	1-1: Treatment options for RTCs include surgical removal, ¹³¹ I therapy, MIT, EBRT, TSH-suppressive therapy, and systemic chemotherapy	High	Strong recommendation
	1-2: Consider MIT as an alternative to surgery for patients who refuse to undergo reoperation, have RAI refractoriness, or are at high risk for surgery	High	Strong recommendation
	1-3: Consider MIT in a multimodal approach with a multidisciplinary team that includes members with specific expertise in MIT	Low	Weak recommendation
	1-4: Select the MIT modality based on disease status, patient characteristics and preferences, and specific institutional resources	Low	Weak recommendation
KQ 2. What are the indications of RFA for RTCs?	2-1: RFA can be performed with a curative or palliative intent for RTCs at the thyroidectomy bed, neck dissection site, and metastatic cervical lymph nodes for patients who refuse surgery or at high surgical risk	High	Strong recommendation
	2-2: Curative-intent RFA should be considered when complete removal of the tumor is possible in patients with RTC and a limited number (≤ 3) of small tumors (size ≤ 2 cm)	Moderate	Strong recommendation
	2-3: For palliative intent, RFA can be used when the resulting volume reduction can reduce symptoms and improve the quality of life of the patient	Low	Weak recommendation
KQ 3. What are the appropriate laboratory and imaging evaluations for patients with RTCs before RFA?	3-1: Clinical, imaging, and laboratory checklists should be evaluated before RFA	High	Strong recommendation
	3-2: Thyroid protocol CT is recommended to be included in treatment planning before RFA	Low	Weak recommendation
KQ 4. What is the recommendation for patients undergoing anticoagulant or anti-platelet drug therapy before RFA?	4-1: Patients at risk of excessive bleeding, such as those on anticoagulation medications or those with disorders affecting the coagulation cascade, should be thoroughly evaluated before RFA, and steps should be taken to appropriately manage this risk	Low	Weak recommendation
KQ 5. What are the appropriate techniques for RFA of RTCs?	5-1: Local anesthesia, i.e., perilesional lidocaine injection, is enough for pain control	High	Strong recommendation
	5-2: Hydrodissection using a cold 5% dextrose water is recommended for separating the tumor from critical structures	High	Strong recommendation
	5-3: The moving-shot technique is the standard RFA technique for RTCs; however, the fixed-electrode technique can be used for RFA of small cancers (size < 5 mm)	High	Strong recommendation
	5-4: Stent-assisted RFA can be considered for RTCs with intraluminal tracheal invasion	Low	Weak recommendation
	5-5: Combination therapy with EBRT can be considered for tumors invading the trachea and esophagus or nerves	Low	Weak recommendation
	5-6: Bolus injection of cold 5% dextrose water is effective for managing nerve damage during RFA	Moderate	Strong recommendation

Table 2. Summary of recommendations and evidences (continued)

KQs	Recommendations	Evidence level	Strength of recommendations
KQ 6. What are the appropriate clinical, laboratory, and imaging evaluations for RTCs after RFA?	6-1: Clinical, laboratory, and imaging checklists should be evaluated after RFA for RTCs	High	Strong recommendation
	6-2: Thyroid US is recommended at 6–12 months after ablation; after that, we recommend annual follow-up US	High	Strong recommendation
	6-3: Thyroid protocol CT is recommended at 6–12 months after ablation, but earlier follow-up (1–3 months) is recommended when there is concern regarding an unablated residual tumor or a large tumor	Low	Weak recommendation
KQ 7. Is RFA an effective treatment for the management of RTCs?	7-1: RFA is an effective treatment for the management of RTCs	High	Strong recommendation
KQ 8. Is RFA a safe and tolerable procedure?	8-1: RFA is safe and well-tolerated and is associated with a low rate of complications when performed by experienced operators	High	Strong recommendation

All items achieve median Delphi score ≥ 7 .

KQ = key question, RTC = recurrent thyroid cancer, MIT = minimally invasive treatment, EBRT = external beam radiation, TSH = thyroid stimulating hormone, RAI = radioactive iodine/radioiodine, RFA = radiofrequency ablation, US = ultrasound

a high surgical risk [3,19]. MIT for RTC should involve a multimodal approach by a multidisciplinary team to determine possible successful treatment strategies [3,4,40]. Treatment options, whether MIT alone or in combination with other therapies such as ^{131}I therapy, EBRT, or systemic chemotherapy, should also be selected through a multidisciplinary decision-making process.

For curative intent, RFA should be performed when complete tumor removal is possible, without evidence of metastasis beyond the neck. If the RTC is confined to the unoperated lateral neck and the patient is not at a high surgical risk or has not undergone surgery, surgical compartmental neck dissection rather than MIT should be considered as the primary treatment.

Several studies have demonstrated that RFA is an effective treatment for patients with RTC in the central compartment and lateral neck after total thyroidectomy, with or without neck dissection, as indicated by a mean VRR range of 81.2% to 98.4% and a complete disappearance rate range of 61.1% to 100% at a mean follow-up of 21.4–47.9 months [12,23,38,41–45]; the reported incidence of >50% VRR of the index tumor varies from 97.5% to 100% [42]. In a comparative study by Kim et al. [12], the recurrence-free survival after RFA was comparable to that after repeat surgery, but the complication rate was lower. In a long-term follow-up study by Chung et al. [46], the mean VRR was 99.5% and the complete disappearance rate was 91.3% at

a mean follow-up of 80 months, indicating that the effects of RFA were maintained long after the procedure. However, in most studies, the indications for RFA for RTCs included a high risk of surgery and patients refusing surgery, even if surgery was clinically required. Factors determining a high risk for surgery include repeated surgery, poor lung function, poor systemic condition, severe cardiovascular disease, and advanced age.

For curative intent, most studies with favorable results included patients with maximum three or four recurrent cancers [12,23,38,41–43,45,47–49] and mean tumor diameters of 0.79–2.4 cm [12,23,38,41–45,47,50–52]. However, few studies have examined the effects of RFA on the size of recurrent tumors. Only one study compared the efficacy of RFA according to the tumor size (<2.0 cm vs. >2.0 cm) and reported no difference between the two groups [42]. Recent ATA guidelines recommend observation alone for recurrent tumors with central neck nodes <8 mm in size [29]. International guidelines on RFA for RTCs also recommend curative intent in case of RTCs when the number of tumors detected using US is low (≤ 3) and their size is small (≤ 2 cm) [3,35,40]. However, long-standing RTCs in the central compartment are more likely to invade the trachea, and the efficacy of RFA is inversely associated with the extent of contact between the tumor and airways [38,53]. Most studies on the use of RFA for RTCs enrolled patients with papillary thyroid cancer, although some reports have demonstrated that

RFA is a safe and effective option for patients with recurrent medullary thyroid carcinoma [42-44,49] or follicular thyroid carcinoma [49,51]. However, available data are limited and require further validation.

For palliative intent, RFA can be used when the resulting volume reduction alleviates symptoms and improves the quality of life of patients. In a study by Chung et al. [38], RFA was found to be a viable alternative for local control of RTCs in the central compartment, even in cases of airway invasion. For patients undergoing palliative RFA, a combined treatment with adjuvant EBRT or systemic therapy may be necessary. In one prospective study, RFA was found to be feasible and safe, and improved symptoms in patients who were considered inoperable [34].

Pre-Procedure Evaluation

Key Question 3. What are the Appropriate Laboratory and Imaging Evaluations for Patients with RTCs before RFA?

[Recommendations]

- 3-1: Clinical, imaging, and laboratory checklists should be evaluated before RFA
- 3-2: Thyroid protocol CT is recommended to be included in treatment planning before RFA

Table 3 lists the recommended pre-procedural checklists for RFA. RTC should be confirmed based on US-guided FNA assessment, with or without the measurement of Tg levels in the washout fluid or CNB samples [3,5]. Tg immunostaining of CNB specimens may be helpful for diagnosis. In patients with medullary thyroid cancer, calcitonin levels in aspirates or CNB specimens should be assessed instead of Tg levels [3].

Unlike benign nodules, the safety margin around RTCs is generally quite small, and procedure-related complications, especially in cases of central neck recurrence, are more frequent [52]. US assessment is important for characterizing RTCs and evaluating critical adjacent anatomical structures such as the nerves, trachea, esophagus, and blood vessels. The sonographic features, volume, and vascularity of tumors should be assessed [3,5], and their number and size should be carefully evaluated for curative intent [12,41,48], although RFA can be an alternative treatment option for palliative intent even for RTCs invading the airways [38]. For accurate planning, thyroid protocol CT of the neck is recommended to identify additional RTCs that are not detected using US before RFA. In this context, CT can provide added value over US; it can also provide more detailed anatomical information on the RTC [54]. The 2021 KSThR guidelines recommend performing thyroid protocol CT before RFA (https://www.thyroidimaging.kr/guidelines/file/ct_2021_final.pdf) [18]. The protocol includes unenhanced axial, early arterial-phase CE (25–40

Table 3. Pre-procedural checklist before radiofrequency ablation for recurrent thyroid cancer

Examination	Characteristics
Pathologic and/or serologic diagnosis	Cancer recurrence at US-guided FNA or CNB Increased washout Tg level in aspirate or Tg immunostain of CNB specimen Increased washout calcitonin level in aspirate or calcitonin immunostaining of CNB specimen in patients with medullary cancer
US	Features of nodule and surrounding critical structures Tumor volume Number and size of recurrent lesions
Laboratory tests	Complete blood count Blood coagulation battery Thyroid function test (serum TSH, T3, fT4) Serum Tg, anti-Tg antibody
CT	Suspicious cervical lymph node
MRI	Selectively indicated
Laryngeal/vocal cord assessment	Subjective voice assessment Laryngeal evaluation (laryngoscopy or US)*

*Indicated for patients with voice impairment or relevant prior surgical or procedural history.

US = ultrasound, FNA = fine-needle aspiration, CNB = core-needle biopsy, Tg = thyroglobulin, TSH = thyrotropin, T3 = triiodothyronine, fT4 = free thyroxine

seconds scan delay), axial, coronal, and sagittal reformatted imaging. The reconstructed images should have thin sections (2–2.5 mm). MRI can be considered for the assessment of possible invasive recurrent disease, wherein the possibility of aerodigestive tract (trachea and esophagus) invasion necessitates complete assessment. PET-CT or PET-MRI are not routinely recommended prior to ablation [3].

The recommended laboratory tests include a complete blood count, coagulation battery, thyroid function tests (measurement of TSH, triiodothyronine [T3], and free thyroxine [fT4] levels), and assessment of serum Tg and anti-Tg antibody levels. A reduced or negative serologic conversion of serum Tg levels can be a surrogate marker for successful ablation [12].

Subjective voice assessment should be performed prior to RFA because voice change is the most common major complication of RFA [55]. Due to the relatively higher rate of voice change after RFA for RTCs (especially for centrally located cancers) than after RFA for benign thyroid nodules [52], patients with voice impairment or relevant surgical history warrant laryngeal evaluation and assessment of vocal fold mobility using endoscopy or US. In addition, a laryngeal examination should be performed prior to ablation on the contralateral side [3,5,52,55]. The factors listed in Table 4 should be considered when obtaining informed consent.

Key Question 4. What is the Recommendation for Patients Undergoing Anticoagulant or Anti-Platelet Drug Therapy before RFA?

[Recommendations]

4-1: Patients at risk of excessive bleeding, such as those on anticoagulation medications or those with disorders affecting the coagulation cascade, should be thoroughly evaluated before RFA, and steps should be taken to appropriately manage this risk

Two multicenter studies investigated procedure-related complications of thyroid RFA in a retrospective study in Korea; hematoma occurred in approximately 1.0% of the included patients (n = 1459), although spontaneous regression was observed within 1 week of RFA in all cases [56]. In another prospective study in the United States, none of the 233 patients developed hematoma [57]. Considering the relatively low rates of postprocedural bleeding, thyroid RFA can be regarded as a safe procedure based on current evidence. However, because thyroid RFA manipulates the highly vascularized parenchymal structure of the thyroid gland, as with the kidneys, liver, and spleen [58], sufficient pre-procedural preparation should be emphasized [40].

For patients with a bleeding tendency, such as those taking anticoagulant/antiplatelet drugs or those with diseases affecting coagulation (e.g., liver cirrhosis and end-stage renal disease), coagulation function should be thoroughly evaluated and the underlying issues should be appropriately managed [3,40,59]. Specifically, fresh frozen plasma or human prothrombin complex can be used for patients with liver cirrhosis, and anticoagulant/antiplatelet drug use should be discontinued to improve coagulation function before the procedure [3,40,58,59]. In general, the reported duration of withdrawal was 7–10 days for aspirin or clopidogrel, 3–5 days for warfarin, 1–4 days for direct oral anticoagulant (DOAC) drugs currently on the Korean market (dabigatran, apixaban, rivaroxaban, and edoxaban) depending on the patient's creatinine clearance, and 4–6 h for heparin [3,40,58,60]. With careful consideration given to post-procedural hemostasis, physicians should advise patients to resume heparin 2–6 hours after RFA, warfarin the night after RFA, DOACs 1–2 days after RFA, and aspirin or clopidogrel the next day to prevent thromboembolic events [3,40]. However, heparin-based bridging therapy is not generally recommended for high-risk patients because of

Table 4. Checklist for recurrent thyroid cancer RFA informed consent

- 1) Ablated recurrent thyroid cancer lesions decrease gradually in size over several months to years
- 2) Number of expected treatment sessions
- 3) Possibility of regrowth of treated recurrent thyroid cancer lesion and need for additional treatment
- 4) Patients may experience various degrees of pain during ablation. For that reason, local and possibly systemic anesthetic agents may be used during and after the procedure
- 5) Complications and side effects
- 6) Patients should inform physician about their history of thyroid surgery, medication, and side effects of any drugs they are taking
- 7) Further observation or admission may be required after RFA, depending on patient's condition after ablation

Adapted from Kim et al. *Korean J Radiol* 2018;19:632-655 [3].

RFA = radiofrequency ablation

the periprocedural interruption of warfarin or DOAC therapy [60]. In cases where discontinuation of anticoagulation medication is difficult, RFA can be performed with caution and after thorough discussion with the patient and consideration of their specific conditions.

Standard Techniques

Key Question 5. What are the Appropriate Techniques for RFA of RTCs?

[Recommendations]

- 5-1: Local anesthesia, i.e., perilesional lidocaine injection, is enough for pain control
- 5-2: Hydrodissection using a cold 5% dextrose water is recommended for separating the tumor from critical structures
- 5-3: The moving-shot technique is the standard RFA technique for RTCs; however, the fixed-electrode technique can be used for RFA of small cancers (size <5 mm)
- 5-4: Stent-assisted RFA can be considered for RTCs with intraluminal tracheal invasion
- 5-5: Combination therapy with EBRT can be considered for tumors invading the trachea and esophagus or nerves
- 5-6: Bolus injection of cold 5% dextrose water is effective for managing nerve damage during RFA

The 2017 KSThR guidelines recommend the following three standard techniques for RTCs: perilesional lidocaine injection, hydrodissection, and moving shot technique [3]. Local anesthesia with 1%–2% lidocaine was injected at the puncture site and periphery of the RTCs for pain control. If the tumor is located close to critical structures, hydrodissection should be used to separate them from the critical structures [11,48]. Cold 5% DW is recommended as the injection material because normal saline is an ionic fluid and can conduct electricity [61]. To achieve a sufficient safety margin during hydrodissection, continuous fluid injection is recommended when the injection needle remains in place [48]. Hydrodissection using cold (0°C–4°C) 5% DW with an iso-osmolar and nonionic composition has also been shown to provide a proper thermal barrier and protect critical structures from heat injury [11,43].

The moving-shot technique, which was first used to treat

benign thyroid nodules, has also been suggested as suitable for treating RTCs [41,48,62]. Before initiating ablation, the targeted tumor is conceptually divided into multiple ablation units, and RFA is performed unit-by-unit using a moving electrode. These conceptual units are smaller at the periphery of the tumor and portions adjacent to critical structures but larger in the central, safe portion of the tumor. Initially, the electrode tip is positioned in the deepest, most remote conceptual unit of the tumor to facilitate proper monitoring of the electrode tip without any disturbance due to microbubbles. The electrode is then moved backwards and superficially. However, if the RTC is small (size <5 mm), the electrode can be fixed at the center of the lesion throughout the ablation [48]. If possible, RFA should be performed on both the metastatic tumor and surrounding normal tissue with a safety margin of approximately 1–2 mm to prevent marginal recurrence [19,62]. The ablation is terminated when all portions of the target ablation area have been converted to transient hyperechoic zones [12,43,62].

Straight, modified, internally cooled electrodes that are shorter (7 cm) and thinner (18–19 G) than conventional electrodes are routinely used for RFA of RTCs [11,41]. A thin electrode of 19 G can easily approach a small RTC and reduce thermal injury to nearby critical structures [19,48]. Active tips are of various sizes (0.38, 0.5, 0.7, or 1.0 cm), and operators can choose the electrode tip size according to the tumor size and its relationship with the surrounding critical structures. Electrodes with smaller active tips (i.e., 0.38 cm or 0.5 cm) have been found to be effective and safe for treating small recurrent tumors or tumors that are close to critical structures [11].

Tracheal involvement in the operation bed is common and can play a role in higher mortality rates due to airway obstruction [63]; thus, anatomical considerations should be given the highest priority when treating RTCs involving the trachea. Tumors with perichondral involvement can be easily separated from the trachea by hydrodissection; however, this technique may have limited applicability in cases with annular ligament involvement [19]. Intratracheal involvement is another key factor in determining the ablation plan: RTCs with only extratracheal involvement can be easily treated using RFA, but stent-assisted ablation is necessary for intratracheal tumors, and a tracheal stent is needed to push the tumor out of the intratracheal space [38]. If the RTC invades the trachea, esophagus, or certain nerves simultaneously, combination therapy (RFA + EBRT) is recommended. Previous studies have recommended the

management of RTCs using EBRT alone (or tyrosine kinase inhibitor treatment alone); however, this can induce fistula formation. In contrast, combination therapy can prevent this complication because RFA performed before EBRT induces fibrosis in the treated recurrent tumor and reduces the tumor burden. Thus, combination therapy may be an effective and safe treatment for RTCs that invade the trachea, esophagus, and nerves.

Treatment of RTC with skin involvement is challenging. Although skin involvement in RTC is uncommon, tumors can induce skin necrosis and bleeding, resulting in a reduced quality of life. The hypodermis, which is affected by tumor involvement, can be easily separated from the dermis because it is mainly composed of loose fat lobules. However, if RTC involves the epidermis, hydrodissection is less effective because of its keratin-rich and compact nature. Therefore, early detection and management of skin involvement in RTC are necessary to prevent skin necrosis. Hydrodissection is effective in preventing skin burns [19], and applying an ice pack to the ablation site can reduce this complication.

Lee et al. [16] demonstrated that symptoms of nerve damage (voice change or shoulder weakness) during RFA can be managed successfully with a bolus injection of cold 5% DW [15,16]. The immediate symptomatic relief resulting from the cold 5% DW injection may have been due to the initial cooling of the damaged nerve and its reduction in additional conductive heat transfer to the nerve. Lee et al. [16] found that the early detection of symptoms and skilled injection of cold 5% DW can be effective in the management of nerve damage during RFA. Dexamethasone injections around damaged nerves may be used to resolve nerve damage.

Post-Procedural Evaluations

Key Question 6. What are the Appropriate Clinical, Laboratory, and Imaging Evaluations for RTCs after RFA?

[Recommendations]

- 6-1: Clinical, laboratory, and imaging checklists should be evaluated after RFA for RTCs
- 6-2: Thyroid US is recommended at 6–12 months after ablation; after that, we recommend annual follow-up US
- 6-3: Thyroid protocol CT is recommended at 6–12 months after ablation, but earlier follow-up (1–3 months) is recommended when there is concern regarding an unablated residual tumor or a large tumor

Table 5 shows the checklist of clinical, laboratory, and imaging findings to be evaluated after RFA for RTC. The intervals of follow-up US and clinical evaluation are not currently clearly defined but should be decided based on the treatment status and future treatment plan. Follow-up US is recommended at 6–12 months, after which an annual follow-up is recommended [3,42]. However, we recommend earlier follow-up US (1–3 months) if there is a concern about repeated ablation or the need to evaluate the ablation status. We also recommend a follow-up thyroid protocol CT 6–12 months after ablation; however, earlier CT evaluation is recommended when there is concern regarding a residual tumor or a large tumor based on 1–3 months follow-up US. Technique efficacy can be evaluated by changes in tumor volume, complete disappearance rate of the index tumor, and reduction of serum Tg levels with curative intent, whereas the alleviation of symptoms and improvement in quality of life should be evaluated with palliative intent. The largest tumor diameter, tumor volume, intratumoral vascularity, and presence or absence of new recurrent tumors should be assessed on follow-up US images [3,42,46]. The volume of the ablated tumor may increase immediately after RFA owing to edematous changes and a large ablated zone over the tumor size, including the safety margin. Subsequently, the volume gradually decreases and shows a large decline over 1–3 months. Well-ablated tumors decrease in size and volume (and eventually disappear), lose intratumoral vascularity, and have increased echogenicity within the tumor and surrounding soft tissue on US [48]. Some studies have reported that the ablation zone is clearer on CEUS rather than on US with color or power Doppler [64,65]. Moreover, a recent study showed the efficacy of advanced Doppler imaging techniques and Slow Flow for evaluating intratumoral vascularity and demonstrated

Table 5. Post-procedural checklist after radiofrequency ablation for recurrent thyroid cancer

US
• Features of ablated zone to detect under-ablated portion with vascularity on color-Doppler US • Tumor volume
Laboratory tests
• Thyroid function test (seum TSH, T3, fT4) • Serum Tg, anti-Tg antibody
CT or MRI*

*Selectively indicated.

US = ultrasound, TSH = thyrotropin, T3 = triiodothyronine, fT4 = free thyroxine, Tg = thyroglobulin

the better diagnostic performance of advanced Doppler imaging techniques for evaluating viable tumor portions compared with power Doppler imaging [20-22]. Therefore, we recommend evaluating the intratumoral vascularity using advanced Doppler imaging and a thyroid protocol CT. The viable tumor portion is indicated by the presence of intratumoral vascularity on advanced Doppler imaging and enhancement on thyroid protocol CT or by an increased size of the ablated tumor. Biopsy and FNA with washout Tg (or CNB) can be performed if a viable tumor portion is still identified at the site of the ablated recurrent tumor on US or thyroid protocol CT [43].

Evaluation of TSH, serum Tg, and anti-Tg antibody levels is necessary after ablation, because serum Tg level (half-life, 3-4 days) falls rapidly after treatment [43,66]. Serum anti-Tg antibody levels can be assessed along with a serum Tg test because the presence of the anti-Tg antibody commonly causes false low serum Tg levels in immunometric assays [25]. Anti-Tg antibody levels may increase transiently postoperatively as an apparent immune reaction to surgery and may also increase after RAI therapy [25].

Clinical Outcomes

Key Question 7. Is RFA an Effective Treatment for the Management of RTCs?

[Recommendations]

7-1: RFA is an effective treatment for the management of RTCs

Various image-guided tumor ablation techniques are used for the treatment of RTCs, and percutaneous chemical ablation (e.g., EA) and thermal ablation (e.g., RFA) are commonly recommended by various international societies [3,35,40]. Technique efficacy can be described according to the purpose of treatment (curative or palliative intent). For curative intent, technique efficacy should be evaluated based on VRR, complete disappearance rate of the index tumor, and serum Tg and anti-Tg antibody levels. Technique efficacy for palliative intent should focus on alleviating symptoms and improving the quality of life by debulking the index tumor. With regard to clinical success, the time-to-progression, disease-free, recurrence-free, progression-free, or local tumor progression-free survival reflects the effectiveness of RFA in RTCs.

Supplementary Table 6 summarizes the clinical outcomes of MIT for RTCs in 33 studies [2,12,23,34,38,41-43,46-50,52,64,65,67-83]. These studies included 1022 patients and 1484 RTCs, primarily papillary thyroid carcinoma, with a mean follow-up period of 31.2 months. Among the included studies, RFA was performed in 18 studies [12,23,34,38,41-43,46-50,52,67-70,81], EA in eight studies [2,71-76,83], LA in four studies [64,65,77,82], and MWA in three studies [78-80]. The treatment efficacy was evaluated based on the mean VRR, complete disappearance rate, and recurrence rate (Supplementary Table 7). The pooled mean VRR in 17 studies was 92% [12,23,38,41,42,46,48,64,65,67-69,73,77,79-81], and the pooled complete disappearance rate in 22 studies was 65% [2,12,23,34,41-43,46,48,65,67-73,75,79-82]. The pooled recurrence rate in 19 studies was 14% [2,12,23,34,43,46,47,50,64,69-73,75,76,78,80,83].

Supplementary Table 7 lists the clinical outcomes of the five ablation tools used for RTCs. RFA is the most commonly used ablation technique for treating RTCs, followed by EA. Among the ablation techniques used for RTCs, RFA has shown better efficacy than EA. The other three thermal ablation techniques also showed good efficacy in treating RTCs, although these studies involved fewer than 100 patients. Direct comparison of ablation techniques is difficult because of mixed data regarding curative and palliative treatment intents.

Currently, only three studies have compared surgery and ablation therapy for the management of RTCs using propensity methods: two studies on RFA and one on WMA (Supplementary Table 8) [12,47,80]. At the 3-year follow-up, RFA and MWA showed a higher recurrence-free survival rate than surgery (88.2%-100% vs. 76.5%-97.9%). Moreover, the 1-year and 6-year follow-up results of the ablation techniques also showed better recurrence-free survival rates than those of surgery (1-year, 96.0% vs. 92.2%; 6-year, 100% vs. 97.8%).

Additionally, RFA has shown similar or superior efficacy to other thermal ablation techniques, and its efficacy for large tumors is superior to that of other ablation techniques. Although the number of studies on ablation for the palliative treatment of RTCs is limited, the results for large tumors suggest that RFA can be an effective choice for palliative treatment.

Complications

Key Question 8. Is RFA a Safe and Tolerable Procedure?

[Recommendations]

8-1: RFA is safe and well-tolerated and is associated with a low rate of complications when performed by experienced operators

RFA is safe, well-tolerated, and associated with a low rate of complications [23,41,42,48,52]. The overall complication rate was 7%–11%, the major complication rate was 5%–7% [48,52], and the sequelae rate was 0%–0.3% [23,43,52] (Supplementary Tables 9, 10). The major complication rate for RTCs was significantly higher than that for benign thyroid nodules (5.4% vs. 0.9%; $P = 0.002$). The use of high-resolution US imaging to target the tumors, knowledge of US-based nerve anatomy [48,52], use of thyroid-specific small active tips [38], and the application of hydrodissection techniques [48] are considered necessary to prevent complications.

Supplementary Table 10 summarizes the complications of MIT for RTCs reported in 35 studies [2,12,23,34,38,41-43,46-50,52,64,65,67-84]. These studies included 1039 patients and 1506 RTCs, with a mean follow-up period of 29.8 months. Among the included studies on RTC treatment, RFA was used in 18 studies [12,23,34,38,41-43,46-50,52,67-70,81], EA in eight studies [2,71-76,83], LA in four studies [64,65,77,82], MWA in three studies [78-80], and cryoablation in two studies [83,84]. The pooled overall complication rate in 29 studies was 6% (range, 2%–32%) [2,12,23,34,38,41-43,46-50,52,64,65,67,68,70,71,73,76,79-84], the pooled voice change rate in 28 studies was 3% (range, 0%–13%) [2,12,23,34,38,41-43,46-50,52,64,65,67,68,70,71,73,76,79-81,83,84], and the pooled major complication rate in 29 studies was 0% (range, 0%–11%) [2,12,23,34,38,41-43,46-50,52,64,65,67,68,70,71,73,76,79-84]. Because only one study used cryoablation for tumors abutting the trachea or nerve-related structures, the overall complication rate (33%) and major complication rate (20%) were the highest [84]. Most of the other studies reported similar complication rates.

According to the proposed classification systems for complications [52,56], the major complications that can occur after RFA for RTCs include nerve injuries (affecting the

recurrent laryngeal nerve, cervical sympathetic ganglion, brachial plexus, and spinal accessory nerve), tracheal injuries, and esophageal perforations. Transient mild mental confusion, probably due to lidocaine toxicity, hematoma, skin burns, and voice changes that recover within 1 month, can be categorized as minor complications. Muscle twitching, pain, edema, vasovagal reactions, hypertension that resolves without medication, vomiting/nausea, and coughing, are considered undesired side effects of RFA. Transient voice changes due to lidocaine injection, minimal hematoma/bleeding/parenchymal edema without any related symptoms, and tolerable mild pain/discomfort not requiring medication were not considered as complications or side effects [52].

More serious complications and side effects may develop in the central neck compartment than in the lateral neck compartment [43]. Critical organ structures such as the trachea, esophagus, and several ganglions and nerves are concentrated in the central neck compartment. Serious complications can occur if the tumor adheres to or invades these structures. In addition, the longer the RTC persists, the greater the extent of contact between the tumor and critical adjacent structures. Thus, early intervention with RFA may be necessary to achieve safe and complete local control of RTCs, particularly in the central compartment [38].

Voice change is the most common major complication after RFA and is caused by injury to the recurrent laryngeal nerve in the central compartment or the vagus nerve in the lateral compartment [23]. Its incidence has been reported to be 8% in RTCs, which is higher than that in benign thyroid nodules (1%) [52]. Direct thermal injury to nerves or the formation of a hematoma around a nerve are possible mechanisms that cause voice changes after RFA [15,16,52]. Therefore, operators should carefully monitor the distance between the nerves and electrode tip. However, the recurrent laryngeal nerve is not clearly visualized in the surgical bed using US and is therefore more vulnerable to thermal injuries [41]. Thermal damage to the middle cervical sympathetic ganglion could result in Horner syndrome. It initially manifests as redness of the conjunctiva, and finally progresses to a combination of ptosis, miosis, and anhidrosis on the ipsilateral side of the face [19]. The middle cervical sympathetic ganglion is located medial or lateral to the common carotid artery. Therefore, depending on its location, it may be vulnerable during RFA for RTCs in both the central and lateral compartments [19,85]. Meticulous evaluation of

the middle cervical sympathetic ganglion before ablation is crucial to minimize nerve injuries. Spinal accessory nerve and brachial plexus injuries have also been reported during ablation of RTCs in the lateral compartment [52]. Injuries to the spinal accessory nerve can lead to limited abduction of the shoulder joints, drooping of the affected shoulder, prominence of the scapula, and compensatory hypertrophy of other muscles of the affected shoulder [56]. Injuries to the supraclavicular component of the brachial plexus typically present with weakness, sensory loss, or paresthesia. The greater auricular nerve is located posterior to the external jugular vein and overlies the sternocleidomastoid muscle in the lateral compartment. If injured, it may cause radiating pain in the ipsilateral ear and paresthesia in the periauricular area during or after ablation if injured [85]. Therefore, knowledge of US-based neck anatomy and hydrodissection techniques is important to prevent nerve damage. Occasionally, tumors remain undertreated owing to serious complications. In patients with symptoms of nerve damage, a bolus injection of cold 5% DW may be useful for recovery [15,16]. Skin burns are another possible complication of RFA for RTCs involving the skin. Therefore, a proper understanding of the skin anatomy is essential for effective and safe RFA in such cases. The hydrodissection technique is effective in preventing skin burns, and the application of an ice pack at the ablation site can reduce this complication.

Pain is the most common complaint during RFA; however, it can be prevented by lidocaine injections and hydrodissection. If the pain does not subside, painkillers can be prescribed for 2–3 days to reduce postprocedural pain [55,56].

Lidocaine administration can also cause symptoms including mental changes, muscle twitching, tremors, and seizures owing to its toxicity, although this is a rare side effect [52,86]. A previous study reported a patient with RTC who experienced transient mild confusion after lidocaine injection [52]. Therefore, understanding these symptoms and lidocaine toxicity can help surgeons manage patients more effectively. Treatment involves maintaining airway oxygen supply and hydration. Prevention involves minimizing lidocaine use (the recommended dose is usually 4.5 mg/kg), ensuring that it is not injected into vessels, and using hydrodissection to control pain (anterolateral hydrodissection has been reported to be effective in controlling pain) [14,86].

Tracheal necrosis has been reported to occur after RFA of

benign isthmus nodules. When treating RTC at a pre-tracheal location, the procedure should be performed under local anesthesia using the hydrodissection technique between the trachea and RTC. Excessive cough is an early sign of tracheal mucosal damage.

In summary, RFA is a relatively safe alternative to repeat surgery for the management of RTCs, with a low incidence of complications. Knowledge of US-based neck anatomy and its clinical significance, as well as prevention of complications, are essential for safe and effective ablation.

Further Considerations

Harms and Benefits

US is widely used to guide and monitor RFA in patients with RTCs. It is not associated with any risk of radiation exposure and enables evaluation of the thyroid operation bed or cervical lymph nodes. Although RFA may lead to increased medical costs, its cost-effectiveness compared with surgery can vary depending on whether medical insurance is covered. In Korea, RFA of RTC is covered under insurance.

Acceptability and Applicability

RFA for RTC should be performed by well-trained thyroid RFA experts at the appropriate hospitals and facilities. Based on the evaluation of the domestic acceptability and applicability of these guidelines, we concluded that the applicability of RFA for the treatment of RTCs was reasonable.

Supplement

The Supplement is available with this article at <https://doi.org/10.3348/kjr.2024.0963>.

Conflicts of Interest

Jung Hwan Baek: Consultant of radiofrequency company, STARmed since 2017.

Jung Hwan Baek, Ji-hoon Kim, Jae Ho Shin, Soo Yeon Hahn, and Young Hen Lee, who hold respective positions as Editorial Board Members, Jeong Hyun Lee and Dong Gyu Na, who hold respective positions as Section Editors, of the *Korean Journal of Radiology* were not involved in the editorial evaluation or decision to publish this article. The remaining author has declared no conflicts of interest.

Author Contributions

Conceptualization: all authors. Data curation: Eun Ju Ha, Min Kyoung Lee, Ji Ye Lee, Leehi Joo. Formal analysis: all authors. Funding acquisition: Eun Ju Ha. Investigation: Eun Ju Ha, Min Kyoung Lee, Jung Hwan Baek. Methodology: Jung Hwan Baek, Miyoung Choi. Project administration: Jung Hwan Baek. Resources: Eun Ju Ha, Min Kyoung Lee, Jung Hwan Baek, Miyoung Choi, Dong Gyu Na. Software: Eun Ju Ha, Min Kyoung Lee. Supervision: all authors. Validation: Eun Ju Ha, Min Kyoung Lee, Jung Hwan Baek, Dong Gyu Na. Visualization: Eun Ju Ha, Min Kyoung Lee, Miyoung Choi. Writing—original draft: Eun Ju Ha, Min Kyoung Lee, Jung Hwan Baek, Hyun Kyung Lim, Hye Shin Ahn, Sae Rom Chung, Jae Ho Shin, Ji Ye Lee, Hyun Kyung Lim, Soo Yeon Hahn. Writing—review & editing: Eun Ju Ha, Min Kyoung Lee, Jung Hwan Baek.

ORCID IDs

Eun Ju Ha
<https://orcid.org/0000-0002-1234-2919>
Min Kyoung Lee
<https://orcid.org/0000-0003-3172-3159>
Jung Hwan Baek
<https://orcid.org/0000-0003-0480-4754>
Hyun Kyung Lim
<https://orcid.org/0000-0003-2319-3135>
Hye Shin Ahn
<https://orcid.org/0000-0001-7260-7467>
Seon Mi Baek
<https://orcid.org/0000-0001-8075-0730>
Yoon Jung Choi
<https://orcid.org/0000-0001-7223-5421>
Sae Rom Chung
<https://orcid.org/0000-0003-4219-7166>
Ji-hoon Kim
<https://orcid.org/0000-0002-6349-6950>
Jae Ho Shin
<https://orcid.org/0000-0001-5922-5720>
Ji Ye Lee
<https://orcid.org/0000-0002-3929-6254>
Min Ji Hong
<https://orcid.org/0000-0001-7818-4346>
Hyun Jin Kim
<https://orcid.org/0000-0002-3411-3690>
Leehi Joo
<https://orcid.org/0000-0002-5527-0476>

Soo Yeon Hahn
<https://orcid.org/0000-0002-4099-1617>
So Lyung Jung
<https://orcid.org/0000-0002-3267-8399>
Chang Yoon Lee
<https://orcid.org/0000-0001-8645-3569>
Jeong Hyun Lee
<https://orcid.org/0000-0002-0021-4477>
Young Hen Lee
<https://orcid.org/0000-0001-7739-4173>
Jeong Seon Park
<https://orcid.org/0000-0002-5550-6645>
Jung Hee Shin
<https://orcid.org/0000-0001-6435-7357>
Jin Yong Sung
<https://orcid.org/0000-0002-8163-4624>
Miyoung Choi
<https://orcid.org/0000-0002-2424-9965>
Dong Gyu Na
<https://orcid.org/0000-0001-6422-1652>

Funding Statement

This study was supported by a grant by 2022 Clinical Practice Guideline Research Fund by Korean Society of Radiology & Korean Society of Thyroid Radiology.

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