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Ultrasound-Guided Radiofrequency Ablation versus Thyroidectomy for the Treatment of Benign Thyroid Nodules in Elderly Patients: A Propensity-Matched Cohort Study

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ABSTRACT

BACKGROUND AND PURPOSE: Ultrasound-guided radiofrequency ablation has been recommended as an alternative to surgery for benign thyroid nodules. However, little is known about the benefit from the application of radiofrequency ablation for benign thyroid nodules in elderly patients. The purpose of this study was to compare the clinical outcomes of radiofrequency ablation versus thyroidectomy for elderly patients with benign thyroid nodules.

MATERIALS AND METHODS: This retrospective study evaluated 230 elderly patients (60 years of age or older) with benign thyroid nodules treated with radiofrequency ablation (R group, $n = 49$) or thyroidectomy (T group, $n = 181$). Complications, thyroid function, and treatment variables, including procedural time, estimated blood loss, hospitalization, and cost, were compared after propensity score matching. The volume, volume reduction rate, symptoms, and cosmetic score were also evaluated in the R group.

RESULTS: After 1:1 matching, each group had 49 elderly patients. The rate of overall complications and hypothyroidism was 26.5% and 20.4% in the T group, respectively, but these complications were totally absent from the R group ($P < .001$, $P = .001$). Patients in the R group had a significantly shorter procedural time (median, 4.8 versus 95.0 minutes, $P < .001$) and lower cost (US $1979.02 versus US $2208.80, $P = .013$) than those treated by thyroidectomy. After radiofrequency ablation, the volume reduction rate was 94.1%, and 12.2% of nodules had completely disappeared. The symptom and cosmetic scores were both significantly reduced at the last follow-up.

CONCLUSIONS: Radiofrequency ablation could be considered as a first-line treatment for elderly patients with benign thyroid nodules.

ABBREVIATIONS: IQR = interquartile range; PSM = propensity score matching; PTMC = papillary thyroid microcarcinoma; RFA = radiofrequency ablation; RLN = recurrent laryngeal nerve; US = ultrasound; VRR = volume reduction rate

Thyroid nodules are common in general, with a prevalence of 20%–76% worldwide by ultrasound (US).[1,2] Thyroid nodules are more common in elderly individuals who have relatively large nodules compared with their young counterparts.[1,3] With the use of US, Gietka-Czernal detected thyroid nodules in 10% of individuals approximately 20 years of age and in 50% of those older than 60 years of age.[4] Recently, a study investigated the prevalence of thyroid nodules in China from 6,985,956 individuals. After analysis by age, the prevalence of nodules was decreased in subjects from 18 years of age or younger (30.8%) to 26 years of age (20.5%) and gradually increased after 26 years of age up to a maximum 71.4% in participants 80 years of age or older.[5]

Most nodules were benign and asymptomatic and could be managed with observation. Only a small proportion grew with local cosmetic or compressive problems and required intervention.[6] Currently, surgery is the standard treatment for benign thyroid nodules. Because the high prevalence and large nodule size in elderly patients were contributing to an increased number of thyroid surgeries, the risk of general anesthesia and surgery-related complications could not be ignored. Age was a risk factor of complications after thyroid surgery.[7,8] Any pre-existing comorbidities also increased the risk of complications in elderly patients.[7,9] Grogan et al[7] reported that the incidence of complications in young (16–64 years of age), elderly (65–79 years of age), and superelderly (>79 years of age) patients was 1.0%, 2.2%, and 5.0%, respectively. Consequently, elderly patients were a vulnerable population for surgery and often needed special consideration and medical care.[7] Moreover, some patients needed life-long

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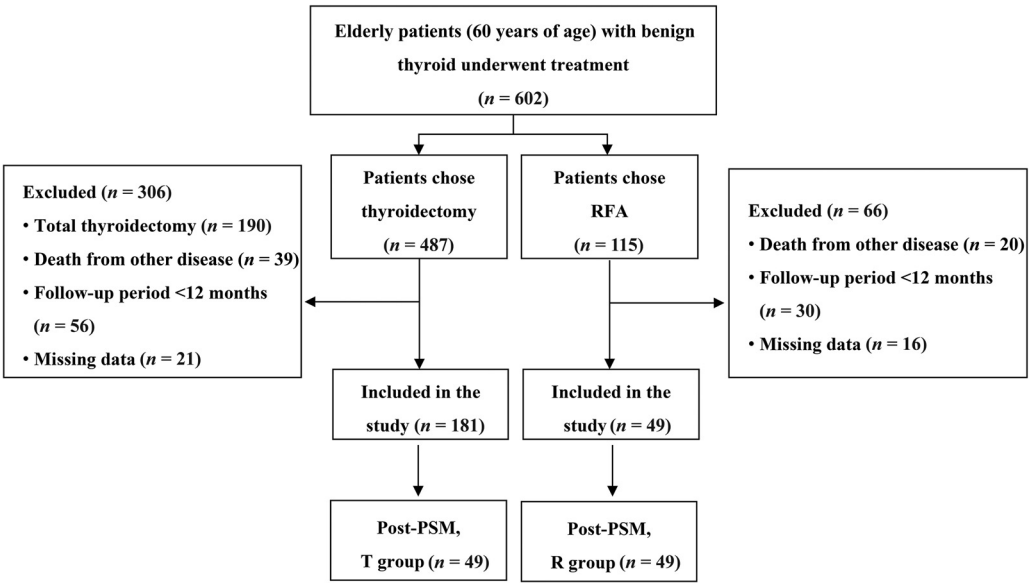

FIG 1. Study flow diagram.

thyroid hormone replacement after surgery. Thyroid hormone replacement was associated with adverse effects on bones and cardiovascular systems, which could be more prominent in elderly patients and postmenopausal women.[2,10] Thus, elderly patients often preferred the nonsurgical option rather than surgery, even if general anesthesia was possible or a dedicated surgery team was available.[11]

US-guided radiofrequency ablation (RFA) and other thermal ablation techniques have been recommended as alternatives to surgery for patients with benign thyroid nodules.[12-16] Well-established data from multiple centers demonstrated that a significant nodular volume reduction could be achieved after ablation with relief of local cosmetic concerns and compressive symptoms.[17-24] Although several studies compared the outcomes between RFA and surgery for benign thyroid nodules,[25,26] little is known about the benefit from the application of RFA in benign thyroid nodules in elderly patients.

Therefore, the purpose of this study was to compare the clinical outcomes of RFA versus thyroidectomy for benign thyroid nodules in elderly patients.

MATERIALS AND METHODS

The Institutional Review Board of the Chinese People's Liberation Army General Hospital approved this retrospective study. Written information consent was obtained from all the patients before RFA or thyroidectomy.

Patients

The inclusion criteria were as follows: 1) 60 years of age or older; 2) nodules confirmed as benign on 2 separate fine-needle aspiration or core-needle biopsy procedures before treatment; 3) maximum diameter of > 2.0 cm; 4) no suspicious malignant features on US, such as marked hypoechoic, irregular margins, taller-than-wide shape, or microcalcifications;[1] 5) solid (≤10% of fluid component) or predominantly solid nodules (11%–50% of fluid component);[27] 6) cosmetic and/or symptomatic problems reported; 7) serum thyroid hormone and thyrotropin levels within normal ranges; and 8) a follow-up period of >12 months. The exclusion criteria were as follows: 1) follicular neoplasm or malignancy reported by biopsy; 2) nodule with benign results on biopsy but suspected malignancy on US; and 3) coagulation disorder or serious heart, respiratory, liver, or renal failure.

The electronic medical records of 602 elderly patients with benign thyroid nodules confirmed by biopsy who underwent treatment between May 2014 and December 2018 were reviewed. After the exclusion of patients, 181 patients who underwent thyroidectomy (T group) and 49 patients treated with RFA (R group) were included in this study (Fig 1).

Pretreatment Assessment

All patients underwent laboratory tests that included complete blood count, coagulation tests, and thyroid function tests. The thyroid function tests were as follows: free triiodothyronine (normal range = 2.76–6.30 picomoles per liter [pmol/L]), free thyroxine (normal range = 10.42–24.32 pmol/L), and thyroid stimulating hormone (normal range = 0.23–5.50 milliunits per liter). Before treatment, each nodule underwent US to evaluate the size, location, component, margin, shape, echogenicity, calcification, and vascularity. The nodular volume was calculated as follows: $V = \pi abc/6$ (V is the volume, while a is the largest diameter, b and c are the other 2 perpendicular diameters). The ACR Thyroid Imaging, Reporting and Data System (TI-RADS) score was used to evaluate each nodule.[28] Measurements of symptomatic or cosmetic problems was performed using a scoring system according to Thyroid RFA Guidelines from the Korean Society of Thyroid Radiology.[12] The symptom score was self-measured by patients using a 10-cm visual analog scale (grades 0–10).[12] The cosmetic score was evaluated by a physician (1, no palpable mass; 2, no cosmetic problem but palpable mass; 3, a cosmetic problem on swallowing only; and 4, a readily detected cosmetic problem).[12]

RFA

All ablation procedures were performed by an experienced US physician with >20 years' experience in thyroid US and interventional US. Patients were treated under local anesthesia in an outpatient clinic. A bipolar RFA generator (CelonLabPOWER; Olympus Surgical Technologies Europe) and 18-ga bipolar readiofrequency electrodes with 0.9- or 1.5-cm active tips were used (CelonProSurge micro 100-T09; Olympus Surgical Technologies Europe). RFA was performed using recommended ablation techniques, including a hydrodissection technique, a transisthmic approach, and a moving shot technique.[12] The ablation procedure was terminated when the entire nodule had become hyperechoic. Contrast-enhanced sonography was performed immediately after RFA to evaluate the ablated area, which was performed after a bolus injection of SonoVue (2.4 mL; Bracco), followed by 5 mL of normal saline flush. Additional complementary ablation could be performed if any enhancement existed in the ablated area.[29]

After RFA, the clinical follow-ups were performed at 1, 3, 6, and 12 months and every 12 months thereafter. Volume, volume reduction rate (VRR), cosmetic score, symptom scores, and thyroid function were evaluated at each follow-up visit. The VRR was calculated as follows: VRR = [(initial volume-final volume) × 100%] / initial volume. Technical success was defined as a >50% volume reduction at last follow-up.[27]

Thyroidectomy

The thyroidectomy procedures were performed by surgeons with >20 years' experience in thyroid surgery. Patients were treated with lobectomy, with or without isthmusectomy, under general anesthesia in the operating room. After surgery, patients were regularly followed up every 6–12 months by US and thyroid function.

End Points and Definitions

The primary outcomes were complications and hypothyroidism. Complications included were recurrent laryngeal nerve (RLN) injury, hypoparathyroidism, and hypothyroidism. RLN injury was the impaired movement of one or both vocal cords by laryngoscopy.[30] Hypoparathyroidism was defined as a parathyroid hormone level after treatment of <15 pg/mL at 24 hours. Permanent RLN injury or hypoparathyroidism was defined as no recovery after 6 months.[30]

Secondary outcomes were procedural time and treatment cost. The procedural time of surgery was from incision to closure without general anesthesia time. The procedural time of RFA was defined from the electrode inserted in the tumor to ablation terminated without the time of local anesthesia and hydrodissection. The cost of the 2 treatments was based on the medical expenses determined by the government. The cost of RFA included the preoperative examination, ablation procedure, local anesthesia, and radiofrequency needle costs. The cost of surgery included the preoperative examination, surgery, general anesthesia, and hospitalization, such as the hospital bed, nursing costs, and postoperative medication costs.

Statistical Analysis

Statistical analyses were performed using SPSS statistical software, Version 25.0 (IBM) and R statistical and computing software, Version 3.6.2 (http://www.r-project.org/). Because the continuous data in this study were all non-normally distributed, they were expressed as median with interquartile range (IQR) and compared by the Mann-Whitney *U* test. Categoric data are presented as numbers with percentages and compared by the χ^2 or Fisher exact test. Wilcoxon signed-rank tests were used to compare the volume, symptom scores, and cosmetic scores before and after RFA. The Bonferroni correction was used for multiple comparisons. To control potential bias, we matched the 2 groups using propensity score matching (PSM). The propensity to undergo RFA versus thyroidectomy was estimated using a logistic regression model based on age, sex, largest diameter, nodule volume, location, and ACR TI-RADS. The matching algorithm was 1:1 genetic matching with no replacement. Patients' baseline characteristics and primary and secondary outcomes in the 2 groups were compared before and after matching.

RESULTS

Patient Characteristics

Baseline characteristics of elderly patients in the 2 groups are shown in the Online Supplemental Data. Before PSM, elderly patients in the R group had tumors of smaller diameters (median, 4.1 cm; IQR, 1.6 cm versus median, 3.2 cm; IQR, 1.5 cm; $P < .001$) and volume (median, 18.6 mL; IQR, 22.0 mL versus median, 7.4 mL; IQR, 10.1 mL; $P < .001$) than those in the T group. After 1:1 matching, 98 elderly patients were included, with 49 in each group (Fig 2).

Primary Outcomes

The comparisons of complications are summarized in the Online Supplemental Data. Before PSM, the overall incidence of complications was 36.4% (66/181) in the T group and 0% in the R group ($P < .001$). In the T group, 4 elderly patients (2.2%) experienced transient RLN injury. After treatment by dexamethasone, they recovered within 3 months. Three elderly patients (1.7%) had transient hypoparathyroidism and recovered after 7 days. One elderly patient (0.6%) experienced loss of consciousness once after surgery. Three elderly patients (1.7%) had fever and recovered in 3 days after medication. Four elderly patients (2.2%) had wound infection, which resolved in 5 days with antibiotics. One elderly patient (0.6%) had respiratory dysfunction and recovered after 3 days on a ventilator. A total of 50 elderly patients (27.6%) in the T group had hypothyroidism and needed thyroid hormone supplementation. However, thyroid function was not affected in elderly patients after RFA ($P < .001$).

After PSM, the overall incidence of complications (0% versus 26.5%, $P < .001$) and hypothyroidism was significantly lower in the R group than in the T group (0% versus 20.4%, $P = .001$).

Secondary Outcomes

The treatment-related variables are shown in the Online Supplemental Data. After PSM, the procedural time (median, 4.8 minutes; IQR, 4.1 minutes versus median, 95.0 minutes; IQR, 62.0 minutes; $P < .001$) and cost (median, US $1979.20; IQR, US $268.40 versus median, US $2208.80; IQR, US $886.90; $P = .013$) in the R group were significantly lower than those in the T group.

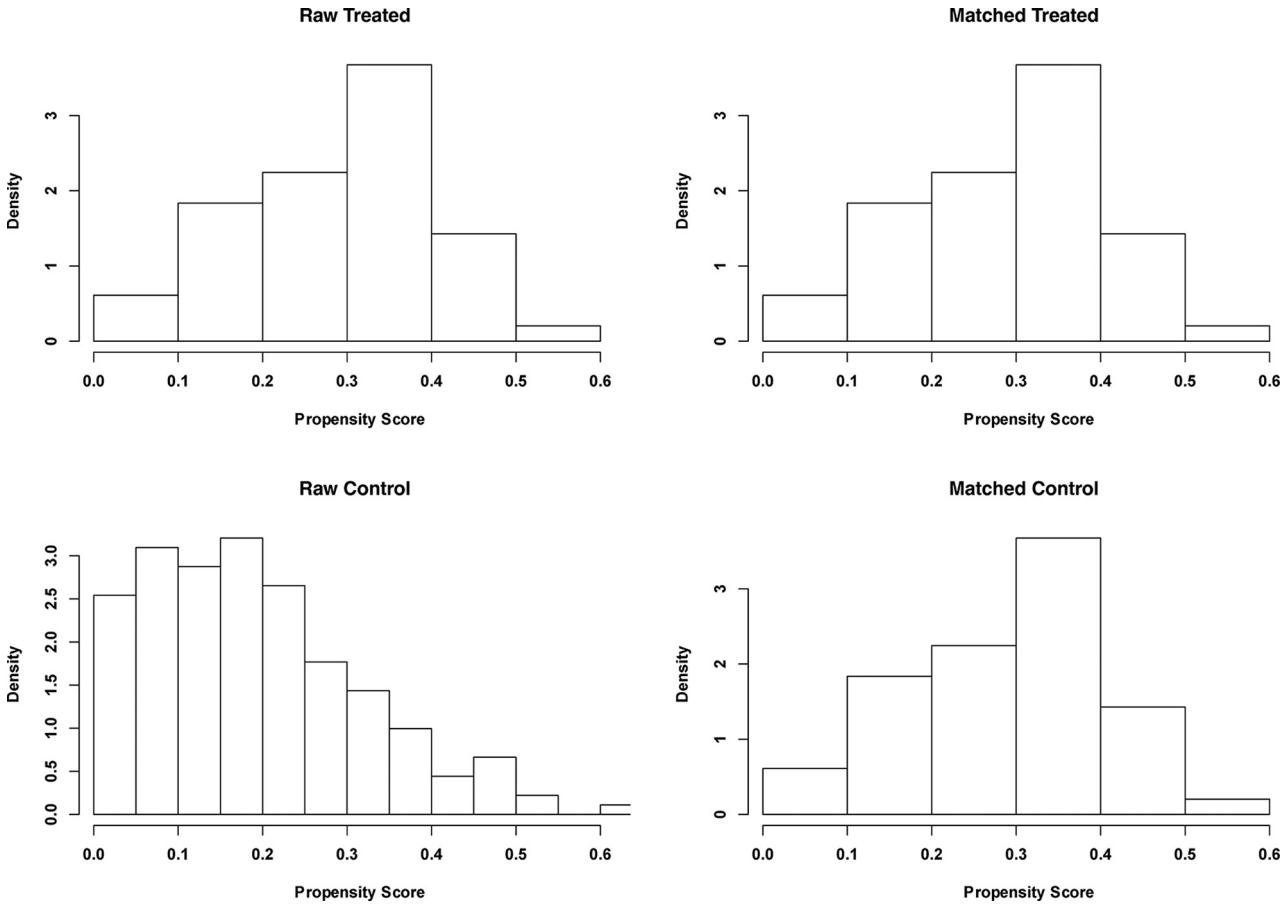

FIG 2. Histogram of PSM.

Other Outcomes

All patients underwent a single-session RFA procedure. During ablation, the median power was 7.5 W, and the mean energy was 1550 J. The Online Supplemental Data show the volume reduction during the follow-up for elderly patients treated by RFA. After ablation, the median volume of the nodules decreased significantly from 7.4 mL (IQR, 10.1 mL) to 0.3 mL (IQR, 1.4 mL) with a VRR of 94.1 (15.0%). Technical efficacy was achieved in all thyroid nodules. Nodule regrowth was not detected. Six ablated nodules (12.2%) disappeared during the follow-up. At the last follow-up, the symptom scores significantly decreased from median, 3 (IQR, 2) to median, 1 (IQR, 1) ($P = .001$), and the median cosmetic scores significantly decreased from median, 3 (IQR, 1.5) to median, 1 (IQR 1) ($P = .001$). Figure 3 shows a nodule in an elderly patient before and after RFA.

In the T group, the median hospitalization was 8.0 (IQR, 4.0) days, and the median blood loss was 20.0 (40.0) mL. After surgery, the symptom scores significantly decreased from median, 5 (IQR, 4) to median 2 (IQR, 2) ($P < .001$), and the cosmetic scores significantly decreased from median, 4 (IQR, 2) to median, 0 (IQR, 0) ($P = .001$). The final pathology in the T groups was as follows: 113 nodular goiters, 60 thyroid adenomas, 6 Hürthle Cell adenomas, and 2 cases of Hashimoto thyroiditis. Among 113 patients with nodular goiters, 2 patients also had a papillary thyroid microcarcinoma (PTMC) lesion of <2 mm.

DISCUSSION

This study compared the clinical outcomes of RFA versus thyroidectomy for benign thyroid nodules in elderly patients. The results were that the overall incidence of complications and hypothyroidism was 26.5% and 20.4% in the T group, respectively, but they were totally absent from the R group. The procedural time, estimated blood loss, hospitalization, and cost were significantly lower in the R group than in the T group. Moreover, the nodule volume was significantly decreased after RFA with a median VRR of 94.1%. The nodule-related symptoms and cosmetic problems were also clinically improved.

Compared with young individuals, the elderly usually had a relatively large nodule.[1,3] Therefore, the pressure symptoms or cosmetic problems in the neck including pain, dysphasia, foreign body sensation, discomfort, cough, neck bulging, and tracheal compression, were more prominent and needed treatment. However, because of the complex anatomy in the thyroid and neck, thyroid surgery had a relatively high risk of complications, especially in elderly patients.[2,7,8,26] RLN injury was the most common major complication of thyroidectomy, and the rate of temporary and permanent injury was 0.4%–7.2% and 0–5.2%, respectively.[31] It was associated with not only the varied position and intraoperative injury during surgery but also with increased age.[9,32] Patients 65 years of age or older had a significantly higher rate of RLN injury compared with those younger than 65 years of age (8.0% versus 5.4%, $P < .001$).[9]

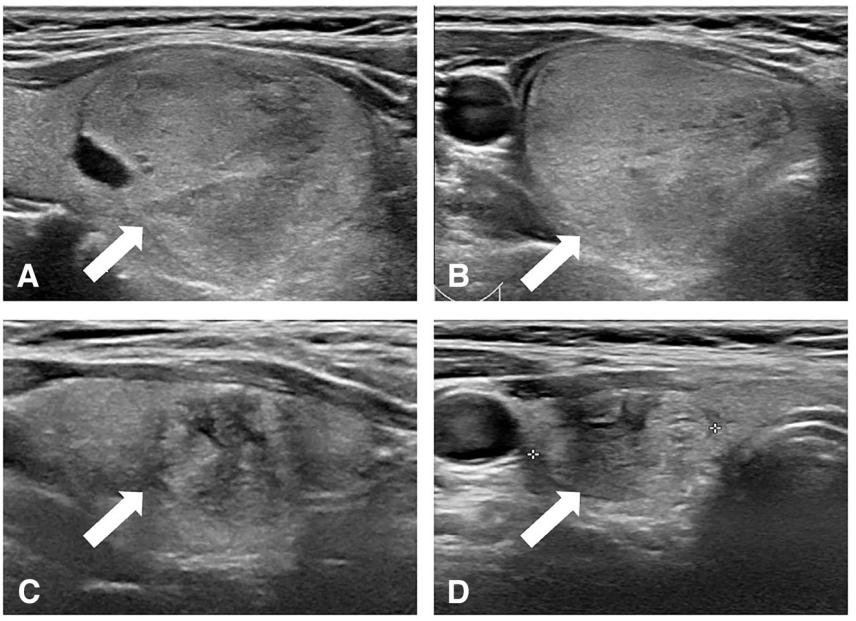

FIG 3. US image of a 61-year-old woman with a benign thyroid nodule in the right thyroid lobe. *A* and *B*, Before RFA, US image shows a solid benign nodule confirmed by biopsy in the right thyroid lobe with an initial volume of 14.3 mL (*arrow*). *C* and *D*, At 12 months after RFA, the volume of the ablated nodule was 2.0 mL (*arrow*) with a VRR of 86.2%.

Hypoparathyroidism was another major complication, mainly caused by the manipulation or incorrect removal of the parathyroid glands. The reported rate of transient and permanent hypoparathyroidism was 25.9%–27% and 1%–2.7% after thyroidectomy, respectively.[8,33-35] To prevent hypoparathyroidism, the most practical approaches included the identification of the parathyroid glands and protection of the vascular supply; however, these approaches were not always possible during surgery.[36] In this study, 4 patients (2.2%) experienced transient RLN injury and 3 patients (1.7%) developed hypoparathyroidism in the T group. In contrast, no patient in the R group had complications. The findings were consistent with those in a previous meta-analysis that reported the rate of temporary injury after RFA for benign thyroid nodules as 0.9% and of permanent injury as 0.04%.[37] Moreover, hypoparathyroidism caused by RFA has not been reported yet.[37]

To avoid complications during ablation, we used several strategies in this study. First, the physician can monitor the electrode tip and treat the nodule accurately by real-time US. Second, the moving shot technique, a transisthmic approach, and hydrodissection techniques were performed to minimize the thermal injury to the adjacent critical structures.[12] Third, the RFA procedure needed only local anesthesia in the outpatient clinic with a shorter procedural time, which also lowered the risk of complications.[12]

Hypothyroidism after RFA was rare,[38] and the reported rate of permanent hypothyroidism after RFA was 0.04%.[37] This study found that the thyroid function was well-maintained in all elderly patients treated with RFA, whereas 27.6% of elderly patients in the T group developed hypothyroidism and needed thyroid hormone replacement. As a minimally invasive technique, only the targeted nodule was treated during the RFA procedure, and most normal thyroid parenchyma was spared without thermal injury. However, a meta-analysis including 32 studies with 4899 patients who underwent hemithyroidectomy reported that the incidence of hypothyroidism was from 5.7% to 48.9% and the overall risk of hypothyroidism was 22%.[39] Kuo et al[40] also reported that because of partial removal of the thyroid parenchyma during the thyroidectomy, 22%–33% of patients developed hypothyroidism and needed life-long thyroid hormone replacement. Although thyroid hormone replacement is a safe and generally successful therapy for hypothyroidism, it was difficult to precisely predict the correct replacement dose in elderly individuals.[41] The gastrointestinal absorption of levothyroxine might be lower in elderly patients.[41] The preexisting comorbidities, such as diabetes, cirrhosis, hypertension, coronary artery disease, respiratory diseases, and malignancy, might also lower the levothyroxine dose required to normalize serum thyroid-stimulating hormone levels.[41] Furthermore, elderly patients were more susceptible to the adverse effects of thyroid hormone replacement, especially arrhythmia and osteoporotic fractures. These issues made it difficult to predict the appropriate levothyroxine dose precisely and carefully in this population.[10]

RFA and other thermal ablation techniques have been recommended as an alternative to surgery for benign thyroid nodules.[12-16] High-level evidence from prospective studies or randomized clinical trials revealed that after ablation, the nodule volume reduction was significant with improvement of clinical symptomatic and cosmetic problems.[17-24] A meta-analysis reported that the pooled proportion of VRR at 6, 12, 24, 36 months, and last follow-up was 64.5%, 76.9%, 80.1%, 80.3%, and 92.2%, respectively.[42] This study found that after RFA, the volume was significantly decreased with a median of 94.1% and a complete disappearance rate of 12.2%. Technical efficacy was achieved in all nodules, and nodule-related symptoms and cosmetic problems showed clinical improvement. These results were in line with previous studies suggesting that the efficacy of RFA was also satisfactory and sustainable for elderly patients.[42]

In this study, 2 elderly patients in the T group were also found to have occult PTMC, suggesting that some benign nodules might have microscopic foci that could not be detected by preoperative US evaluation.[43] Therefore, surgery was still the current first-line treatment for benign thyroid nodules.[1] However, in the absence of evidence of extrathyroidal extension, metastatic cervical lymph nodes, or distant metastases, PTMC often had an indolent nature. Current guidelines have recommended active surveillance as a conservative management option to immediate surgery for low-risk PTMC,[1,44] and this has had favorable results.[45-47] Although older age was one of the most important factors predicting poor prognosis, Ito et al[48] reported that the proportion of PTMC progression was lowest in the elderly patients older than 60 years of age and highest in the young patients (younger than 40 years of

age), suggesting that elderly patients with subclinical low-risk PTMC may be the best candidates for active surveillance.

This study had limitations. First, it was a retrospective study. Second, the sample size was relatively small. Third, because elderly patients in the R group had smaller nodules than those in the T group, large nodules in the T group were removed from comparison by PSM. RFA and other thermal ablation techniques have been used for large nodules and nodular retrosternal goiters and have had favorable results.[17-24,49] However, it was difficult to treat the periphery of a nodule completely by a single-session procedure. Patients with large nodules required multiple treatment sessions to achieve complete ablation.[50] The comparison between multiple RFA sessions versus thyroidectomy for very large nodules in elderly patients still needs further investigation. Fourth, the baseline disease status of elderly patients in the 2 groups might be different, despite PSM being used in this study to control potential biases. Fifth, because of medical insurance policies, the hospitalization and cost in this study might be different in other countries. In China, patients usually completed pretreatment examinations after hospitalization, and they were discharged about 3 days after the surgery. Therefore, the hospitalization and cost of elderly patients in other countries need further investigation.

CONCLUSIONS

For elderly patients with benign thyroid nodules, RFA could be considered as a first-line treatment with advantages of a lower incidence of complications and maintenance of thyroid function.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

REFERENCES

1. Haugen BR, Alexander EK, Bible KC, et al. **2015 American Thyroid Association Management Guidelines for Adult Patients with Thyroid Nodules and Differentiated Thyroid Cancer: The American Thyroid Association Guidelines Task Force on Thyroid Nodules and Differentiated Thyroid Cancer.** *Thyroid* 2016;26:1–133 CrossRef Medline
2. Gharib H, Papini E, Garber JR, et al; AACE/ACE/AME Task Force on Thyroid Nodules. **American Association of Clinical Endocrinologists, American College of Endocrinology, and Associazione Medici Endocrinologi Medical Guidelines for Clinical Practice for the Diagnosis and Management of Thyroid Nodules: 2016 update.** *Endocr Pract* 2016;22:622–39 CrossRef Medline
3. Russ G, Leboulleux S, Leenhardt L, et al. **Thyroid incidentalomas: epidemiology, risk stratification with ultrasound and workup.** *Eur Thyroid J* 2014;3:154–63 CrossRef Medline
4. Gietka-Czernel M. **The thyroid gland in postmenopausal women: physiology and diseases.** *Prz Menopauzalny* 2017;16:33–37 CrossRef Medline
5. Li Y, Jin C, Li J, et al. **Prevalence of thyroid nodules in China: a health examination cohort-based study.** *Front Endocrinol (Lausanne)* 2021;12:676144 CrossRef Medline
6. Hamidi O, Callstrom MR, Lee RA, et al. **Outcomes of radiofrequency ablation therapy for large benign thyroid nodules: a Mayo Clinic case series.** *Mayo Clin Proc* 2018;93:1018–25 CrossRef Medline
7. Grogan RH, Mitmaker EJ, Hwang J, et al. **A population-based prospective cohort study of complications after thyroidectomy in the elderly.** *J Clin Endocrinol Metab* 2012;97:1645–53 CrossRef Medline
8. Medas F, Tuveri M, Canu GL, et al. **Complications after reoperative thyroid surgery: retrospective evaluation of 152 consecutive cases.** *Updates Surg* 2019;71:705–10 CrossRef Medline
9. Gunn A, Oyekunle T, Stang M, et al. **Recurrent laryngeal nerve injury after thyroid surgery: an analysis of 11,370 patients.** *J Surg Res* 2020;255:42–49 CrossRef Medline
10. Jonklaas J, Bianco AC, Bauer AJ, et al; American Thyroid Association Task Force on Thyroid Hormone Replacement. **Guidelines for the Treatment of Hypothyroidism: prepared by the American Thyroid Association Task Force on Thyroid Hormone Replacement.** *Thyroid* 2014;24:1670–751 CrossRef Medline
11. Ding AS, Xie DX, Zhang L, et al. **Public perceptions of radiofrequency ablation versus standard surgery for benign thyroid nodules.** *Surgery* 2022;172:110–17 CrossRef Medline
12. Kim JH, Baek JH, Lim HK, et al; Guideline Committee for the Korean Society of Thyroid Radiology (KSThR) and Korean Society of Radiology. **2017 Thyroid Radiofrequency Ablation Guideline: Korean Society of Thyroid Radiology.** *Korean J Radiol* 2018;19:632–55 CrossRef Medline
13. Papini E, Pacella CM, Solbiati LA, et al. **Minimally-invasive treatments for benign thyroid nodules: a Delphi-based consensus statement from the Italian Minimally-Invasive Treatments of the Thyroid (MITT) group.** *Int J Hyperthermia* 2019;36:376–82 CrossRef Medline
14. Dobnig H, Zechmann W, Hermann M, et al. **Radiofrequency ablation of thyroid nodules: "Good Clinical Practice Recommendations" for Austria—An interdisciplinary statement from the following professional associations: Austrian Thyroid Association (ÖSDG), Austrian Society for Nuclear Medicine and Molecular Imaging (OGNMB), Austrian Society for Endocrinology and Metabolism (ÖGES), Surgical Endocrinology Working Group (ACE) of the Austrian Surgical Society (OEGCH).** *Wien Med Wochenschr* 2020;170:6–14 CrossRef Medline
15. Papini E, Monpeyssen H, Frasoldati A, et al. **2020 European Thyroid Association Clinical Practice Guideline for the Use of Image-Guided Ablation in Benign Thyroid Nodules.** *Eur Thyroid J* 2020;9:172–85 CrossRef Medline
16. Ha EJ, Baek JH, Che Y, et al. **Radiofrequency ablation of benign thyroid nodules: recommendations from the Asian Conference on Tumor Ablation Task Force—secondary publication.** *J Med Ultrasound* 2021;29:77–83 CrossRef Medline
17. Baek JH, Ha EJ, Choi YJ, et al. **Radiofrequency versus ethanol ablation for treating predominantly cystic thyroid nodules: a randomized clinical trial.** *Korean J Radiol* 2015;16:1332–40 CrossRef Medline
18. Cesareo R, Pasqualini V, Simeoni C, et al. **Prospective study of effectiveness of ultrasound-guided radiofrequency ablation versus control group in patients affected by benign thyroid nodules.** *J Clin Endocrinol Metab* 2015;100:460–66 CrossRef Medline
19. Deandrea M, Sung JY, Limone P, et al. **Efficacy and safety of radiofrequency ablation versus observation for nonfunctioning benign thyroid nodules: a randomized controlled international collaborative trial.** *Thyroid* 2015;25:890–96 CrossRef Medline
20. Jung SL, Baek JH, Lee JH, et al. **Efficacy and safety of radiofrequency ablation for benign thyroid nodules: a prospective multicenter study.** *Korean J Radiol* 2018;19:167–74 CrossRef Medline
21. Deandrea M, Garino F, Alberto M, et al. **Radiofrequency ablation for benign thyroid nodules according to different ultrasound features: an Italian multicentre prospective study.** *Eur J Endocrinol* 2019;180:79–87 CrossRef Medline
22. Cesareo R, Pacella CM, Pasqualini V, et al. **Laser ablation versus radiofrequency ablation for benign non-functioning thyroid nodules: six-month results of a randomized, parallel, open-label trial (LARA Trial).** *Thyroid* 2020;30:847–56 CrossRef Medline
23. Jin H, Lin W, Lu L, et al. **Conventional thyroidectomy vs thyroid thermal ablation on postoperative quality of life and satisfaction for patients with benign thyroid nodules.** *Eur J Endocrinol* 2021;184:131–41 CrossRef Medline

24. Kandil E, Omar M, Aboueisha M, et al. **Efficacy and safety of radiofrequency ablation of thyroid nodules: a multi-institutional prospective cohort study.** *Ann Surg* 2022;276:589–96 CrossRef Medline
25. Che Y, Jin S, Shi C, et al. **Treatment of benign thyroid nodules: comparison of surgery with radiofrequency ablation.** *AJNR Am J Neuroradiol* 2015;36:1321–25 CrossRef Medline
26. Yan L, Deng C, Song Q, et al. **Radiofrequency ablation versus reoperation for benign thyroid nodules that developed after previous thyroid surgery.** *Int J Hyperthermia* 2021;38:176–82 CrossRef Medline
27. Mauri G, Pacella CM, Papini E, et al. **Image-guided thyroid ablation: proposal for standardization of terminology and reporting criteria.** *Thyroid* 2019;29:611–18 CrossRef Medline
28. Tessler FN, Middleton WD, Grant EG, et al. **ACR Thyroid Imaging, Reporting and Data System (TI-RADS): white paper of the ACR TI-RADS Committee.** *J Am Coll Radiol* 2017;14:587–95 CrossRef Medline
29. Zhang M, Luo Y, Zhang Y, et al. **Efficacy and safety of ultrasound-guided radiofrequency ablation for treating low-risk papillary thyroid microcarcinoma: a prospective study.** *Thyroid* 2016;26:1581–87 CrossRef Medline
30. Anuwong A, Ketwong K, Jitpratoom P, et al. **Safety and outcomes of the transoral endoscopic thyroidectomy vestibular approach.** *JAMA Surg* 2018;153:21–27 CrossRef Medline
31. Sun W, Liu J, Zhang H, et al. **A meta-analysis of intraoperative neuromonitoring of recurrent laryngeal nerve palsy during thyroid reoperations.** *Clin Endocrinol (Oxf)* 2017;87:572–80 CrossRef Medline
32. Francis DO, Pearce EC, Ni S, et al. **Epidemiology of vocal fold paralyses after total thyroidectomy for well-differentiated thyroid cancer in a Medicare population.** *Otolaryngol Head Neck Surg* 2014;150:548–57 CrossRef Medline
33. Edafe O, Antakia R, Laskar N, et al. **Systematic review and meta-analysis of predictors of post-thyroidectomy hypocalcaemia.** *Br J Surg* 2014;101:307–20 CrossRef Medline
34. Farkas EA, King TA, Bolton JS, et al. **A comparison of total thyroidectomy and lobectomy in the treatment of dominant thyroid nodules.** *Am Surg* 2002;68:678–82; discussion 682–83 CrossRef Medline
35. Perigli G, Cianchi F, Giudici F, et al. **Thyroidectomy for cancer: the surgeon and the parathyroid glands sparing.** *J Clin Med* 2021;10:4323 CrossRef Medline
36. Puzziello A, Rosato L, Innaro N, et al. **Hypocalcemia following thyroid surgery: incidence and risk factors—a longitudinal multicenter study comprising 2,631 patients**. *Endocrine* 2014;47:537–42 CrossRef Medline
37. Chung SR, Suh CH, Baek JH, et al. **Safety of radiofrequency ablation of benign thyroid nodules and recurrent thyroid cancers: a systematic review and meta-analysis.** *Int J Hyperthermia* 2017;33:920–30 CrossRef Medline
38. Wang N, Zheng B, Wu T, et al. **Thyroid dysfunction following radiofrequency ablation for benign thyroid nodules: more likely to occur within one-week and in high-risk population.** *Int J Hyperthermia* 2021;38:1060–68 CrossRef Medline
39. Verloop H, Louwerens M, Schoones JW, et al. **Risk of hypothyroidism following hemithyroidectomy: systematic review and meta-analysis of prognostic studies.** *J Clin Endocrinol Metab* 2012;97:2243–55 CrossRef Medline
40. Kuo JH, Sinclair CF, Lang B, et al. **A comprehensive review of interventional ablation techniques for the management of thyroid nodules and metastatic lymph nodes.** *Surgery* 2022;171:920–31 CrossRef Medline
41. Biondi B, Cooper DS. **Thyroid hormone therapy for hypothyroidism.** *Endocrine* 2019;66:18–26 CrossRef Medline
42. Cho SJ, Baek JH, Chung SR, et al. **Long-term results of thermal ablation of benign thyroid nodules: a systematic review and meta-analysis.** *Endocrinol Metab (Seoul)* 2020;35:339–50 CrossRef Medline
43. Bernardi S, Dobrinja C, Fabris B, et al. **Radiofrequency ablation compared to surgery for the treatment of benign thyroid nodules.** *Int J Endocrinol* 2014;2014:934595 CrossRef Medline
44. Sugitani I, Ito Y, Takeuchi D, et al. **Indications and strategy for active surveillance of adult low-risk papillary thyroid microcarcinoma: consensus statements from the Japan Association of Endocrine Surgery Task Force on Management for Papillary Thyroid Microcarcinoma.** *Thyroid* 2021;31:183–92 CrossRef Medline
45. Chou R, Dana T, Haymart M, et al. **Active surveillance versus thyroid surgery for differentiated thyroid cancer: a systematic review.** *Thyroid* 2022;32:351–67 CrossRef Medline
46. Kim K, Choi JY, Kim SJ, et al. **Active surveillance versus immediate surgery for low-risk papillary thyroid microcarcinoma patients in South Korea: a cost-minimization analysis from the MAeSTro study.** *Thyroid* 2022;32:648–56 CrossRef Medline
47. Hughes DT, Reyes-Gastelum D, Ward KC, et al. **Barriers to the use of active surveillance for thyroid cancer results of a physician survey.** *Ann Surg* 2022;276:e40–47 CrossRef Medline
48. Ito Y, Miyauchi A, Kihara M, et al. **Patient age is significantly related to the progression of papillary microcarcinoma of the thyroid under observation.** *Thyroid* 2014;24:27–34 CrossRef Medline
49. Li Y, Li X, Xiao J, et al. **Ultrasound-guided microwave ablation combined with ethanol injection for the treatment of solitary nodular retrosternal goiter: a prospective study of 72 patients.** *Eur Radiol* 2023;33:752–62 CrossRef Medline
50. Chen MH, Lin WC, Luo SD, et al. **Residual, regrowth, and new growth of radiofrequency ablation for benign thyroid nodules of different volumes: two-year follow-up results.** *Int J Hyperthermia* 2022;39:1172–78 CrossRef Medline