Radiofrequency Ablation in Nodular Thyroid Diseases

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Radiofrequency ablation is a minimally invasive technique that can produce tissue coagulation necrosis effectively and safely in humans with ultrasound or computed tomography guidance. The most frequent treatment site for radiofrequency ablation to date is the liver for hepatocellular carcinoma. Reviewing the history of radiofrequency ablation, we can see the evaluation of electrodes from conventional monopolar electrode to multiprobe arrays, hook expandable electrodes, and internally cooled electrodes. All of these are trying to ablate the tumor more widely and completely. From history, we also notice that the target can range from heart, neurological disorders, and thyroid diseases to a variety of other diseases, in addition to liver malignancy. Studies have already shown that radiofrequency ablation is an excellent alternative treatment for nodular thyroid disease, including benign and malignant lesions. For treatment of recurrent well-differentiated thyroid cancer, radiofrequency ablation has shown good results, such as no recurrence at treatment sites or reduced serum thyroglobulin level. The possible complications include hoarseness, hematoma, severe pain, esophageal perforation, or tracheal perforation. The reported rate for major complications in previous studies is low. Therefore, if the patients have severe comorbidity that is not suitable for reoperation for thyroid malignancy, radiofrequency ablation is a good alternative. Furthermore, radiofrequency ablation can be used for benign thyroid nodules to relieve local compressive symptoms. Some patients who receive such treatment for cosmetic reasons also show a satisfactory outcome. Here, we review previous studies about radiofrequency ablation in nodular thyroid disease in many aspects, such as ablation system, ablation techniques, ablation efficacy, and complications, both in benign thyroid nodules and recurrent thyroid cancer. © 2013, Elsevier Taiwan LLC and the Chinese Taipei Society of Ultrasound in Medicine.

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Introduction

Radiofrequency ablation is a minimally invasive technique that can produce tissue coagulation necrosis in humans. This technique is performed effectively and safely with ultrasound or computed tomography guidance. It can be used to treat a variety of lesions in different organs, including benign and malignant diseases. The most frequent treatment site of radiofrequency ablation is the liver for hepatocellular carcinoma. A lot of research and scientific reports about the efficacy of radiofrequency ablation in hepatocellular carcinoma have been available since the 1990s. Some pioneer radiologists have also tried to treat head and neck neoplasms with radiofrequency ablation. In 1998, the first paper about radiofrequency ablation in thyroid disease was published by Solbiati et al [1], reporting the initial experience for ablation in metastatic lymph nodes from papillary thyroid cancer. More recently, radiofrequency ablation has also been shown to relieve compressive symptoms and cosmetic problems caused by benign thyroid nodules and recurrent thyroid cancer. The purpose of this review article is to provide information about the basic principles of radiofrequency ablation, as well as a summary of previously published clinical research about radiofrequency ablation in nodular thyroid diseases. Possible complications and other safety issues are also reviewed in each section.

Basic principles of radiofrequency ablation

What is radiofrequency ablation?

Radiofrequency ablation is a technique to destroy tissues with heat generated from high-frequency alternating current. The alternating current is created by a radiofrequency generator. The electrode and grounding pads are both connected to the generator, with the electrode inserted into the ablation target and grounding pads attached to the body surface, mostly at both thighs. In that way, the electrical conducting circle is formed. When the generator is powered on, the alternating electric current oscillating between 200 kHz and 1200 kHz [2] in the electrode causes nearby tissue ion agitation, which can create frictional heat. With that heat, the electrode can cause target tissue coagulation necrosis. The grounding pads are large dispersive electrodes that can let the current go through the patient without causing significant heat as in the electrode tip. For complete target tissue coagulation, a higher temperature generated in the electrode needs less time to create sufficient necrosis. When the temperature is between 60 °C and 100 °C, tissue coagulation is noted almost immediately. When the temperatures fall between 50 °C and 52 °C, it takes 4–6 minutes to create irreversible cellular damage. If the temperature is just 46 °C, >1 hour is necessary to ablate the tissue successfully [3–5]. However, the higher temperature is not always better for ablation. When the temperature is higher than 100 °C, it results in adjacent tissue vaporization and carbonization [2]. Although the heat created by the electrode damages surrounding tissue quickly, tissue more remote from the electrode is heated by thermal conduction slowly. The carbonized or vaporized tissue is a heat insulator that prevents heat conduction from the electrode to the peripheral tissue, which results in a smaller ablation zone and is unfavorable for the treatment of malignant tissue.

Evolution of electrodes

In an earlier study, the maximum coagulation zone produced from a conventional monopolar electrode is no more than 1.6 cm in diameter [6]. However, the target lesion such as hepatoma is usually >2 cm in diameter. Thus, several strategies have been tried to improve the ablation volume in larger tumors, such as modification of the electrode design or a different generator program setting to achieve better energy deposition. The first strategy is multiprobe arrays, which includes the use of multiple free-standing conventional radiofrequency electrodes in an array [7]. This design has evolved into hooked electrodes, available from two commercial vendors, RITA and Radiotherapeutics [8,9], which allows the deployment of an array of multiple, curved wires in the shape of an umbrella from a single 14 gauge or 16 gauge cannula. With such electrodes, the ablation diameter can be as large as 3.5 cm in human liver in vivo [10]. Another approach to increase ablation volume is the introduction of the internally cooled electrode [11,12]. Such electrodes have two hollow lumens that permit continuous internal cooling of the tip with cooled water, which can prevent overheating of the electrode tip and keeps the temperature at no more than 90 °C. As we have mentioned previously, high temperatures may cause tissue boiling and charring that interfere further with heat conduction. The internally cooled electrode can produce tissue coagulation of around 2.8 cm in diameter for metastatic hepatocellular carcinoma in clinical practice [13]. The next step to obtain a larger ablation volume is the development of clustered electrodes, which can apply radiofrequency current to a cluster of three closely spaced electrodes. It offers the potential of >3 cm coagulation diameter at a single treatment session. In a preliminary report, radiofrequency ablation using the cluster electrode technique induced coagulation necrosis of 5.3 cm in diameter in solitary intrahepatic colorectal metastases [14]. Other strategies to improve ablation efficacy include bipolar arrays and pulsed application of radiofrequency energy. Bipolar array means to place a ground electrode within approximately 4 cm of the active electrode. It increases the ablation volume a little, but the induced coagulation is elliptical rather than spherical in cross-section [15], which is not favorable for most tumor ablation. Pulsing of radiofrequency energy is not a modification of the electrode but to program the radiofrequency generator to output periods of high energy rapidly alternated with periods of low energy. If an appropriate balance between high and low energy deposition is achieved, preferential tissue cooling occurs adjacent to the electrode to prevent the adverse effects of tissue charring and boiling. In that way, a greater volume of tissue coagulation will be achieved with the same electrode [16].
Application of radiofrequency to heart, liver, and thyroid gland

The earliest experience of radiofrequency ablation was to ablate the aberrant neurofibril bundle in symptomatic cardiac arrhythmia [17]. It was also introduced for the treatment of hyperactive neurologic foci or other neurologic disorders [18]. In such diseases, it only needs creation of a precise small region of coagulation. Thus, the earlier conventional monopolar single electrode is adequate for that purpose. The ablation technique has then been used to treat a diversity of neoplasms, such as osteoid osteoma, primary and metastatic liver tumor, renal cell carcinoma, prostate cancer, and breast cancer percutaneously under the guidance of images, or intraoperatively. In the past two decades, the principal use of radiofrequency ablation was for liver malignancies, both primary and secondary. A lot of research related to the development and improvement of radiofrequency techniques to treat liver cancer with satisfactory results has been published [19]. The strategy to destroy a malignant lesion completely is different from the treatment of cardiac arrhythmia. This means that the ablation-induced necrosis covers the entire tumor and should also reach cytotoxic temperatures to kill all cancer cells. Therefore, the evolution of electrodes mentioned in the previous section is just to fit in with the requirement for complete ablation.

Benign or malignant nodular thyroid diseases are common. The prevalence of thyroid nodules has been reported as 4–8% of adults by palpation, 10–41% by ultrasound examination, and 50% by pathologic examination at autopsy [20]. Local surveillance in Taiwan has also shown that adult goiter prevalence was 19.4% in men, 33.6% in women, and estimated to be 25% in the total population [21]. If the nodule is malignant or benign but causes compressive symptoms, surgery is usually a better choice to remove the nodule effectively. If the patient has primary thyroid cancer, surgery is always the first choice. In some situations, if recurrent thyroid cancer is detected several years after primary surgical intervention, but the patient is not suitable for another session of surgery due to comorbidity, a nonsurgical and minimally invasive treatment modality is needed as an alternative. When it refers to benign thyroid nodule but with compressive symptoms, surgical intervention also has some disadvantages such as leaving scar tissue in the neck. It also calls for a nonsurgical, minimally invasive alternative for these patients who do not want to have surgery. Ethanol ablation [22,23] and laser ablation [24] have been tried previously in such scenarios. Radiofrequency has also been introduced to ablate malignancy and begin thyroid nodules. In 1998, the first paper about radiofrequency ablation in thyroid disease was published by Solbiati et al [1]. Since that time, several papers had been published about the efficacy for radiofrequency in thyroid glands. We review the literature about radiofrequency ablation in thyroid nodules. In reviewing the published literature, most authors have reported that radiofrequency ablation is both effective and safe when used to treat either benign thyroid nodules or recurrent thyroid cancer. By searching on PubMed, there were four articles about radiofrequency ablation in recurrent thyroid cancer, which included more than eight patients. There were also nine articles about radiofrequency ablation in benign thyroid nodules, ranging from solid, mixed, cystic to autonomously functioning nodules. The reviews and comparisons of these studies in malignant or benign lesions are discussed in the following sections.

Radiofrequency ablation in recurrent thyroid cancer

Papillary thyroid cancer, the most common subtype of thyroid cancer, has a good prognosis after standard treatment of surgery followed by radioiodine therapy and adequate thyroid hormone replacement. However, some patients may have recurrent cancer in the previous surgical bed or metastasis to local regional lymph nodes. If the recurrent disease is resistant to radioiodine therapy or difficult to reoperate due to scar tissue formation or multiple comorbidity, radiofrequency ablation could be a good alternative. Four studies [25–28] have shown encouraging results about radiofrequency ablation for local recurrent or metastatic well-differentiated thyroid cancer. The baseline tumor sizes ranged from 1.38 cm to 2.9 cm in diameter. Radiofrequency ablation reduced the tumor volume and serum thyroglobulin level significantly in most patients in these studies. Baek et al [28] have reported a best average volume reduction rate of 89.7%, with an average largest diameter reduction rate of 76.1%. All researchers have adopted the Radionics Cool-tip system as their ablation system. This system is equipped with an internally cooled electrode, with different lengths of the active tip ranging from 1 cm to 2 cm. The tumor sizes were relatively small compared with hepatocellular carcinoma, therefore, the longer active tip with a larger ablation zone was not absolutely an advantage. On the contrary, the shorter active tip may prevent damage to organs adjacent to the thyroid gland, such as the esophagus or recurrent laryngeal nerve. For that reason, no researcher has used hooked electrodes or clustered electrodes as the ablation tool. Baek et al [28] have introduced an electrode produced by Taewoong Medical, Seoul, Korea, which only has a 0.5 cm active tip in the electrode. In that way, the ablation could be performed more safely by easily handling the electrode.

In two earlier studies [25,26], patients received intravenous sedation with fentanyl and midazolam prior to ablation. In two other studies [27,28], patients were just prescribed local anesthesia in the neck. This change may have been due to the accumulative experience that showed that the possible local discomfort is only minimal, so generalized anesthesia is usually not necessary. The ablation power, which was only available from Park et al [27] and Baek et al [28], was relatively low at 10–90 W, as compared with that of ablation in hepatocellular carcinoma. The ablation time, which ranged from 2 minutes to 15 minutes in these four studies without much difference, was usually less than that in ablation for hepatocellular carcinoma. All of these points show that ablation in liver and thyroid gland is not the same because the thyroid is smaller than the liver. Recurrent thyroid malignancy is also smaller as compared with hepatocellular carcinoma. In the thyroid surgical bed or local lymph nodes, they almost have no safety margins. For that reason, we need a smaller electrode tip, lower power output, and less ablation time to control so that the exact
Radiofrequency Ablation in Nodular Goiters

Radiofrequency ablation in benign thyroid nodules

It is not always necessary for benign nodules to undergo surgery. However, when large nodules cause local compression or cosmetic problems, they need further treatment to relieve these symptoms. Levothyroxine suppression therapy is a popular choice, but the outcome is not satisfactory, especially in larger nodules [31]. Therefore, other treatment modalities such as thermal ablation or ethanol injection have been attempted in many studies to reduce nodular volume.

There are more academic reports about radiofrequency ablation for benign thyroid lesions than for malignant ones (Table 2) [29,30,32–38]. The characteristics of the nodules ranged from purely cystic nodules and mixed nodules to solid ones. Both autonomous functioning (hot) nodules and cold nodules were included among these trials, although not in every report. The volume of target nodules was also larger than that of malignant ones, ranging from 6 mL to 25 mL.

Interestingly, almost all of these papers came from two countries: Italy [32,33] and Korea [29,30,34–38]. They used different ablation systems and different approaches to erase thyroid nodules. Deandrea et al [32] and Spiezia et al [33] have used the RITA Starburst ablation system with hook-expandable electrodes, via the longest axis of the thyroid gland to ablate the nodules. By contrast, studies from Korea have used the Radionics Cool-tip ablation system with an internally cooled electrode. Most of these studies also introduced a transisthmus approach with moving-shot technique to treat larger tumors. As in a published consensus statement from the Korean Society of Radiology [39], this ablation technique has become a standard procedure in Korea.

All nine of these studies only gave local anesthesia in the neck, except for Kim et al [29], who administered intravenous sedation to 77% of the patients. The power output was not available from the studies of Deandrea et al [32] and Spiezia et al [33]. With the fixed-needle technique, the nodules from these two studies were heated to 95–105 °C for ≤10 minutes. The result of the volume reduction rate in the follow-up period of up to 2 years was reported as 47.7% by Deandrea et al and 79.4% by Spiezia et al. Deandrea et al also showed a little more effectiveness in volume reduction of hot nodules than cold ones (48.4% vs. 44.7%). Some patients who had hot nodules could be free from antithyroid drugs after ablation. The improvement rate in the thyroid function test was reported as 31% by Deandrea et al and 79% by Spiezia et al.

The power output and ablation time in seven studies conducted in Korea [29,30,34–38] ranged from 20 W to 120 W and up to 30 minutes. It took more time for the moving-shot ablation technique because this technique divides thyroid nodules into multiple small conceptual ablation units and performs ablation unit-by-unit by moving the electrode. Theoretically, this technique will ablate nodules more completely because the tumor shape is usually ellipsoid rather than round [40]. After a mean follow-up period of around 12 months (up to 41 months), these studies showed a better volume reduction rate, ranging from 75% to 92%, with a slightly better result in cystic nodules than solid ones. The autonomously functioning nodules also showed improvement in the thyroid function test and radioiodine scan, and four of nine patients had cold nodules and seven of nine patients became nearly euthyroid [34]. It is worth mentioning that Baek et al [36] conducted a prospective study that compared the efficacy of radiofrequency ablation versus control conditions. The control group had no resolution of nodule volume but increased slightly after 6 months. In the radiofrequency ablation group, mean nodule volume decreased from 7.5 mL to 1.3 mL after 6 months follow-up. Another study [37] has demonstrated that radiofrequency ablation for predominantly cystic nodules is as effective as ethanol ablation (average volume reduction at last follow-up, 92%). However, because ethanol ablation is much less expensive than radiofrequency ablation, the authors have suggested that ethanol ablation should be the first-line treatment for predominantly cystic nodules.

The complications reported by Deandrea et al and Spiezia et al were only minor local pain and edema after ablation, which could be controlled easily by acetaminophen and betamethasone, if necessary [32]. Oral antibiotics were not routinely administered after the procedure. Some patients had fever up to 38.8 °C after ablation, which however spontaneously returned to normal around 1 day after ablation [33]. Major complications such as recurrent laryngeal nerve injury, cutaneous burning, local infection or damage to the vital structures of the neck, and severe damage induced along the needle track were not observed. Hot
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Year of publication</td>
<td>2001</td>
<td>2006</td>
<td>2011</td>
<td>2011</td>
</tr>
<tr>
<td>Tumor type</td>
<td>Recurrent WTC in neck</td>
<td>Recurrent WTC in neck</td>
<td>Recurrent WTC in neck</td>
<td>Recurrent WTC in neck</td>
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<tr>
<td>No. of pts</td>
<td>8</td>
<td>16</td>
<td>16 recurrent sites in 11 patients</td>
<td>12 recurrent sites in 10 patients</td>
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<td>Baseline nodule size, mean</td>
<td>Diameter 2.4 cm</td>
<td>Diameter 1.7 cm</td>
<td>Diameter 2.9 cm; volume 9 mL</td>
<td>Diameter 1.38 cm; volume 55.5 mm³</td>
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<tr>
<td>Premedication</td>
<td>IV sedation (fentanyl and midazolam)</td>
<td>IV sedation (fentanyl and midazolam)</td>
<td>Local anesthesia (xylocaine)</td>
<td>Local anesthesia (xylocaine)</td>
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<td>Approach</td>
<td>Unavailable</td>
<td>Unavailable</td>
<td>Transisthmus or vertical</td>
<td>Transisthmus or vertical</td>
</tr>
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<td>Ablation technique</td>
<td>Fixed-needle</td>
<td>Fixed-needle</td>
<td>Moving-shot</td>
<td>Moving-shot for large tumor; fixed-needle for small tumor</td>
</tr>
<tr>
<td>Generator</td>
<td>Radionics Cool-tip system</td>
<td>Radionics Cool-tip system</td>
<td>Radionics Cool-tip system</td>
<td>Radionics Cool-tip system</td>
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<tr>
<td>Electrode</td>
<td>18G, 1 cm, 2 cm active tip</td>
<td>18G, 1 cm, 2 cm active tip</td>
<td>18G, 0.5 cm, 1 cm, 1.5 cm, 2 cm active tip</td>
<td>18G, 0.5 cm, 1 cm active tip</td>
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<tr>
<td>Mode</td>
<td>Unavailable</td>
<td>Unavailable</td>
<td>Unavailable</td>
<td>Unavailable</td>
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<tr>
<td>Power output</td>
<td>Unavailable</td>
<td>Unavailable</td>
<td>Mean 67.3 W</td>
<td>Mean 14.7 W</td>
</tr>
<tr>
<td></td>
<td>Mean 60 W Range 30–90 W</td>
<td>Mean 11.7 min Range 1–22 min</td>
<td>Mean 6.7 W Range 1–14 mo</td>
<td>Range 10–40 W</td>
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<tr>
<td>Ablation time</td>
<td>2–12 min</td>
<td>2–12 min</td>
<td>Mean 6.7 min Range 1–15 min</td>
<td>Range 12–24 mo</td>
</tr>
<tr>
<td>Follow-up period</td>
<td>Mean 10.3 mo</td>
<td>Mean 40.7 mo</td>
<td>Mean 6 mo Range 1–14 mo</td>
<td>(1) Average volume reduction, 89.7% (2) Average largest diameter reduction 76.1% (3) Thyroglobulin decreased in 7 of 10 pts</td>
</tr>
<tr>
<td>Results</td>
<td>(1) 6 of 8 pts: decreased serum thyroglobulin level (2) 6 of 8 pts: no evidence of recurrence in the treated LNs histologically (3) No recurrent disease in 100% pts</td>
<td>(1) 11 of 16 pts: decreased serum thyroglobulin level (2) 7 of 11 pts (63.6%) relieved local compressive symptoms</td>
<td>(1) Average volume reduction, 50.9% (2) 7 of 11 pts (63.6%) relieved local compressive symptoms</td>
<td>(1) Average volume reduction, 89.7% (2) Average largest diameter reduction 76.1% (3) Thyroglobulin decreased in 7 of 10 pts</td>
</tr>
<tr>
<td>Complication</td>
<td>1 vocal cord paralysis 1 minor skin burn</td>
<td>1 permanent vocal cord paralysis 1 minor skin burn</td>
<td>No reported major complications</td>
<td>1 dysphonia</td>
</tr>
</tbody>
</table>

IV = intravenous; pts = patients; WTC = well-differentiated thyroid cancer.
<table>
<thead>
<tr>
<th>Year of publication</th>
<th>Tumor type</th>
<th>No. of pts</th>
<th>Baseline nodule size, mean</th>
<th>Premedication</th>
<th>Approach</th>
<th>Ablation technique</th>
<th>Generator</th>
<th>Electrode</th>
<th>Mode</th>
<th>Power output</th>
<th>Ablation time</th>
<th>Follow-up period</th>
<th>Results</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Benign cold nodules (solid component 0–100%)</td>
<td>35 nodules in 30 pts</td>
<td>Volume 6.3 mL</td>
<td>23 in 30 pts (77%) required iv sedation. All with local anesthesia</td>
<td>Longest axis</td>
<td>Moving-shot for large nodule; fixed-needle for small nodule</td>
<td>Radionics Cool-tip system</td>
<td>18G, 1 cm active tip</td>
<td>Unavailable</td>
<td>Range 20–60 W</td>
<td>&gt;12 min</td>
<td>Median 6.4 mo, range 1–18 mo</td>
<td>(1) Average volume reduction, 88.1% (2) Mainly solid one: 82.2% at 9 mo (3) Mixed/mainly cystic one: 90.0% at 9 mo (4) Improvement of symptoms in 88% pts</td>
<td>(1) 1 pt vocal cord palsy (2) 1 pt hematoma (3) 1 pt first-degree burn at the puncture site (4) 1 pt mild to moderate pain at the anterior neck for 2 d</td>
</tr>
<tr>
<td>2008</td>
<td>Benign nodules (solid component 0–100%)</td>
<td>302 nodules in 236 pts</td>
<td>Volume 6.13 mL</td>
<td>Local anesthesia (xylocaine)</td>
<td>Transisthmus</td>
<td>Moving-shot</td>
<td>Radionics Cool-tip system</td>
<td>18G, 1 cm active tip</td>
<td>Unavailable</td>
<td>Range 20–70 W</td>
<td>5–30 min (mean, 14 min)</td>
<td>Range 1–41 mo</td>
<td>(1) Average volume reduction at last follow-up, 84.11% (2) Complete disappearance of index nodule, 27.8% (3) More effective in cystic lesion than solid lesions</td>
<td>(1) Voice change 1.3% (2) Extrathyroid hematoma 2.1% (3) Subclinical hyperthyroidism 1.3% (4) 1 pt suspect tracheal injury (cough) (5) 1 pt suspect brachial plexus injury (4th finger numbness)</td>
</tr>
<tr>
<td>2008</td>
<td>Benign nodules, hot or cold (solid component &gt;30%)</td>
<td>33 nodules (10 cold, 23 hot) in 31 pts</td>
<td>Volume 27.7 mL</td>
<td>Local anesthesia (xylocaine)</td>
<td>Longest axis</td>
<td>Fixed-needle</td>
<td>RITA Starburst system</td>
<td>9-hook expandable electrodes</td>
<td>Unavailable</td>
<td>Unavailable</td>
<td>6–10 min (at 95 °C)</td>
<td>Mean 6 mo</td>
<td>(1) Average volume reduction at 6 mo, 47.7% (2) A little more effective in hot nodules than cold ones (48.4% vs. 44.7%) (3) 10 pts with cold nodules remained euthyroid (4) 5 of 16 pts who had hot nodules showed partial/full remission of hyperthyroidism</td>
<td>No reported major complications</td>
</tr>
<tr>
<td>2009</td>
<td>Benign nodules, hot or cold (solid component &gt;30%)</td>
<td>94 pts (66 cold, 28 hot)</td>
<td>Volume 24.5 mL</td>
<td>Local anesthesia (xylocaine)</td>
<td>Longest axis</td>
<td>Fixed-needle</td>
<td>RITA Starburst system</td>
<td>4-hook expandable electrodes, 14G to 3.5 cm</td>
<td>Unavailable</td>
<td>Unavailable</td>
<td>Range 12–24 mo</td>
<td>Range 12–24 mo</td>
<td>(1) Average volume reduction 2 y after RFA, 79.4% (2) Nodules completely disappeared in 88% pts (3) Compressive symptoms improved in 100% pts (4) Hyperthyroidism resolved in 79% pts with hot nodules</td>
<td>No reported major complications</td>
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(continued on next page)
<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Type of Lesion</th>
<th>Size (Solid Component)</th>
<th>Volume</th>
<th>Anesthesia</th>
<th>Approach</th>
<th>Instrument</th>
<th>Power Range</th>
<th>Treatment Time</th>
<th>Follow-up Time</th>
<th>Outcome 1</th>
<th>Outcome 2</th>
<th>Outcome 3</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Baek et al [34]</td>
<td>Hot nodules</td>
<td>60–100%</td>
<td>14.98 mL</td>
<td>Local anesthesia (xylocaine)</td>
<td>Transisthmus approach</td>
<td>Radionics Cool-tip system</td>
<td>17G, 1 cm active tip</td>
<td>Unavailable</td>
<td>Range 30–80 W</td>
<td>Range 5–22 min</td>
<td>Average volume reduction at last follow-up, 75%</td>
<td>No reported major complications</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Lee et al [35]</td>
<td>Benign cold nodules</td>
<td>10–50%</td>
<td>Volume 4.2 mL (after EA but prior to RFA)</td>
<td>Local anesthesia (xylocaine)</td>
<td>Transisthmus approach</td>
<td>Radionics Cool-tip system</td>
<td>18G, 1 cm active tip</td>
<td>Unavailable</td>
<td>Range 20–70 W</td>
<td>Range 5–30 min</td>
<td>Mean 21.2 mo</td>
<td>No reported major complications</td>
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<tr>
<td>2010</td>
<td>Baek et al [36]</td>
<td>Benign cold nodules</td>
<td>&gt;50%</td>
<td>Volume 7.5 mL</td>
<td>Local anesthesia (xylocaine)</td>
<td>Transisthmus approach</td>
<td>Radionics Cool-tip system</td>
<td>18G, 1 cm active tip</td>
<td>Unavailable</td>
<td>Mean 32.4 W</td>
<td>Mean 15.5 min</td>
<td>Average volume reduction after additional RFA, 88%</td>
<td>No reported major complications</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>Sung et al [37]</td>
<td>Benign cystic nodules</td>
<td>&lt;10%</td>
<td>Volume 10.19 mL</td>
<td>Local anesthesia (xylocaine)</td>
<td>Transisthmus approach</td>
<td>Radionics Cool-tip system</td>
<td>18G, 1 cm active tip</td>
<td>Unavailable</td>
<td>Range 30–100 W</td>
<td>Range 3–32 min</td>
<td>Average volume reduction after 6 mo, 83%</td>
<td>No reported major complications</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>Hun et al [38]</td>
<td>Benign cystic nodules</td>
<td>&gt;50%</td>
<td>Volume 13 mL (similar in 2 groups)</td>
<td>Local anesthesia (xylocaine)</td>
<td>Transisthmus approach</td>
<td>Radionics Cool-tip system</td>
<td>17G, 18G, 1 cm, 1.5 cm active tip</td>
<td>Unavailable</td>
<td>Range 30–120 W</td>
<td>Mean 19.5 mo</td>
<td>Average volume reduction after 1 session, 70.2%/2 sessions, 78.3% (but no statistic significance)</td>
<td>No reported major complications</td>
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</table>

EA = ethanol ablation; RFA = radiofrequency ablation.
nODULES THAT TURNED INTO COLD ONES OR REMISSION OF HYPOTHYROIDISM AFTER ABLATION WERE THE DESIRABLE RESULTS AFTER ABLATION. ON THE CONTRARY, HYPOTHYROIDISM AFTER ABLATION TO COLD NODULES WAS NOT REPORTED IN BOTH STUDIES.

ANOTHER SEVEN STUDIES [29,30,34–38] OFFERED MORE DETAILS ABOUT THE POSSIBLE COMPLICATION RATE BECAUSE THEY HAD MORE STUDY PARTICIPANTS. MOST OF THE REPORTED COMPLICATIONS WERE MINOR, SUCH AS VARIOUS DEGREES OF PAIN AT THE ABLATED SITE, AND PAIN RADIATING TO THE HEAD, EAR, SHOULDER, OR TEETH DURING OR AFTER ABLATION. SUCH PAIN COULD BE EASILY CONTROLLED BY REDUCING GENERATOR OUTPUT DURING ABLATION OR BY ORAL ANALGESICS AFTER THE PROCEDURE. FEW MAJOR COMPLICATIONS HAVE BEEN REPORTED IN THESE STUDIES. JEOG ET AL [30] HAD THE MOST PARTICIPANTS IN A SINGLE STUDY AND REPORTED VOICE CHANGE IN 1.3%, EXTRA-THYROID HEMATOMA IN 2.1%, AND SUBCLINICAL HYPOTHYROIDISM IN 1.3% AFTER ABLATION. ACCORDING TO A RECENTLY PUBLISHED ARTICLE FROM THE KOREAN SOCIETY OF THYROID RADIOLOGY [41], RADIOFREQUENCY ABLATION FOR 1543 THYROID NODULES IN 1459 PATIENTS CONDUCTED IN 13 THYROID CENTERS WAS SURVEYED. THERE WERE 48 COMPLICATIONS IN ABOUT 3.3% OF ALL PATIENTS. THE MAJOR COMPLICATIONS WERE VOICE CHANGES IN 15 PATIENTS, BRACHIAL Plexus Injury IN ONE PATIENT, TUMOR RuptURE IN THREE PATIENTS, AND PERMANENT HYPOTHYROIDISM IN ONE PATIENT. THE MINOR COMPLICATIONS WERE HEMATOMA IN 15 PATIENTS, SKIN BURN IN FOUR PATIENTS, AND VOMITING IN NINE PATIENTS. THE AUTHORS HAVE CONCLUDED THAT THE COMPLICATION RATE OF RADIOFREQUENCY ABLATION IN BENIGN THYROID NODULES IS LOW, BUT VARIOUS COMPLICATIONS MAY STILL OCCUR. THEREFORE, COMPREHENSION OF THE COMPLICATIONS AND TRAINING FOR ABLATION TECHNIQUES ARE NECESSARY TO PREVENT MAJOR COMPLICATIONS. ALL NINE OF THESE STUDIES ARE SUMMARIZED IN TABLE 2.


References


