Reviews

Advances in ultrasound-guided thermal ablation for symptomatic benign thyroid nodules

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Abstract

Benign thyroid nodules (BTNs), which account for 85–95% of all thyroid nodules (TNs), are a common clinical issue and have been increasingly detected over the last 2 decades due to the widespread use of ultrasound (US) imaging. The clinical treatment for BTNs is mainly focused on patients with nodular growth or clinical problems, either cosmetic or symptom-related. Percutaneous thermal ablation (TA) under US guidance has increasingly become a satisfactorily minimally invasive alternative to surgery for patients with symptomatic BTNs, especially for those in nonsurgical candidates, surgically high-risk individuals or patients refusing surgery. Based on the available English-language literature, the brief principles, procedures and clinical outcomes of 4 TA techniques, including laser ablation therapy (LAT), radiofrequency ablation (RFA), microwave ablation (MWA), and high-intensity focused ultrasound (HIFU) in the treatment of BTNs were retrospectively reviewed in this article. Good curative efficacy and clinical safety were noted in the published reports of the 4 TA techniques in the treatment of BTNs, with nodular volume reduction ratios of 46–93.5%, significant improvement in symptomatic and cosmetic problems, and euthyroid preservation for most patients. The conclusion is that all 4 TA techniques can be safe and effective treatment for patients with symptomatic BTNs; RFA seems to be the best because of the highest nodular volume reduction ratio (VRR) at follow-up. Furthermore, the image fusion navigation technique will play an important role through assisting in precise ablation for BTNs.

Key words: ultrasonography, thyroid nodule, ablation

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Introduction

Thyroid nodules (TNs) are a common clinical issue, and their prevalence has been increasing over the last 2 decades[1] due to the widespread use of ultrasound (US) imaging. In the general population, more than 50% of TNs are detected with US examination, while only 3–7% are detected with palpation.[2] It is estimated that benign thyroid nodules (BTNs) account for 85–95% among all TNs.[3] Regular observation is recommended for most BTNs because they present no clinical problems and grow slowly.[4] Treatment is mainly focused on patients with progressive nodular growth or clinical problems, either cosmetic or symptom-related, accociated with nodular volume. Partial thyroidectomy is a traditional and effective method for the treatment of BTNs with the advantages of significant symptomatic relief and definite pathological diagnosis, but the cervical scar and daily oral levothyroxine to maintain euthyroidism are common sources of dissatisfaction following surgery. On the one hand, the thyroid gland, which synthesizes and secretes thyroid hormones, plays a key role in human metabolism,[5] so it is critically important to preserve normal thyroid function. On the other hand, the thyroid is a small and superficial organ in the cervical region,[6] adjacent to several vital structures, such as the common carotid artery, internal jugular vein, vagus nerve, recurrent laryngeal nerve, superior laryngeal nerve, trachea, and esophagus, with high risks and possibilities of complications if surgical treatment is undertaken. This has led to an ongoing search for a minimally invasive procedure to maximize BTN patients' relief in terms of symptoms and cosmetics, and at the same time to minimize the occurrence of complications.

With over 10 years of development and improvement, 4 techniques of percutaneous US guided thermal ablation (TA) have become satisfactory minimally invasive alternatives to surgery for patients with symptomatic BTNs, especially for nonsurgical candidates, surgically high-risk individuals or those who refuse surgery: radiofrequency ablation (RFA), laser ablation therapy (LAT), microwave ablation (MWA), and high-intensity focused ultrasound (HIFU).[7,8] Besides significant improvement of the patients' clinical symptom-related and cosmetic problems related to BTNs,[9–18] other attractive advantages have been confirmed for TA treatment of BTNs, including low rates of both major and minor complications,[19] and good preservation of thyroid function.[20,21]

Therefore, based on the available English-language literature, the brief principles, procedures and clinical outcomes in the treatment of BTNs using 4 TA techniques were retrospectively reviewed, with the aim was of evaluating these 4 TA techniques in clinical applications, exploring feasible methods of further improvement, and providing an effective reference for clinical TA treatment of BTNs.

Methods and results

Laser ablation therapy

Brief principles

Infrared laser energy originates from the emission of photons connected to a laser source and is delivered into tissue by a specially designed tiny fiber. It can be converted into heat due to tissue absorption. The heat causes a temperature rise and eventually a lethal level is reached around the active tip within a target tissue.[22] Laser is an efficient and precise energy source for tissue heating, but only a small ablation zone is formed due to its limited penetration of the tissue.[23] Additionally, laser cannot penetrate carbonized and dehydrated tissue. The most popular laser source is a continuous-wave neodimium:yttrium aluminum garnet (Nd:YAG) laser medium operating at a wavelength of 1064 nm and an output power ranging between 2 W and 5 W.

Procedure

Under US guidance, a flexible silica optical fiber 0.3 mm in diameter is advanced into the TN through the sheath of a 21-gauge Chiba needle. A 5 mm bare fiber tip is exposed and contacts nodular tissue directly after the needle sheath is withdrawn. To ablate nodules in different volumes, 1–4 fibers can be arrayed manually in the target. Ablation starts in the deep part, 10 mm from the deep margin of the nodule. By the sheath and fiber pull-back of 10 mm every time, laser energy is repeatedly administered until a distance of 5 mm from the sheath tip to the superficial margin of the nodule is reached.

Clinical results

For efficacy, after LAT-induced histologically spindle-shaped, well-defined necrosis surrounding central vaporization and carbonization in a TN was confirmed by a pilot feasibility study in 2000,[24] an initially prospective non-randomized control study was reported in 2002.[25] The nodular volumes of BTNs in 15 patients in a control group presented no change at a median of 12 months of follow-up; the mean nodular volume of BTNs pathologically proven by fine needle aspiration (FNA) in 16 euthyroid patients ablated by US-guided percutaneous LAT significantly decreased, from 10 ±7.9 mL at baseline to 5.4 ±5.1 mL at 6 months of follow-up. The overall nodular volume reduction ratio (VRR) was 46% and pressure symptoms were significantly improved. The conclusion was drawn that US-guided LAT could become a useful nonsurgical alternative for treating a solitary solid cold BTN in patients who could not or would not undergo surgery. An encouraging multicenter prospective randomized trial of US-guided LAT for solid BTNs with long-term follow-up was published in 2014.[26] At 4 thyroid referral centers, 200 consecutive patients who met the inclusion criteria (euthyroid, no prior thyroid treatment and benign cytological findings at least twice), were randomly assigned to 2 groups. One group underwent a single LAT session (101 cases); the rest (99 cases) had follow-up only. In the ablation group, the mean nodular volume significantly shrunk and VRR was 57 ±25% at 3 years of follow-up. The VRRs decreased more than 50% in 67.3% out of the cases. Local symptoms and cosmetic issues significantly improved after the treatment. In the follow-up group, the mean nodular volume was significantly increased by 25 ±42% at the three-year checkup and local symptoms became worse in 20.4% (20/98) of the cases. It was concluded that a single session of LAT offered an effective, safe and less expensive outpatient alternative to surgery for patients with clinical problems related to BTNs without influencing patients' thyroid function.

As far as safety in concerned, in a large-scale, three-year follow-up study of percutaneous LAT for cold BTNs,[13] major complications of a pseudocyst with fasciitis due to fluid leaks into the cervical muscle fascia occurred in 3 patients (2.5%), and were absorbed spontaneously in 3–6 months after an anti-inflammatory drug was prescribed. Two patients (1.6%) presented vocal cord paresis 12–24 h after the procedure. A six-week course of oral corticosteroids was administered, and indirect laryngoscopy showed recovery of vocal cord motility after 6–10 weeks. Out of 122 patients, only 24 (19.7%) complained of pain or significant discomfort during or following the procedure. Minor complications and side effects including mild pain (11.5%, 14/122), intense pain (8.2%, 10/122), intranodular or pericapsular bleeding (9.9%, 12/122), vasovagal reaction (4.1%, 5/122), cough (4.9%, 6/122), stridor (0.8%, 1/122), swelling (9.0%, 11/122), cutaneous burns (0.8%, 1/122), bruises (2.5%, 3/122), fever (37.5–38.5°C; 4.1%, 5/122), pseudocystic transformation (4.9%, 6/122), transient hyperthyroidism (1.6%, 2/122), and late hypothyroidism (1.6%, 2/122) that presented in intraoperatively, immediately postoperatively, in the periprocedural period, and during the follow-up were reported in detail. In 2012, a tracheal perforation – a rare but severe complication confirmed with tracheoscopy – occurred in a 73-year-old woman 50 days after a LAT procedure for multinodular goiter treatment; a total thyroidectomy plus tracheal repair were required.[27]

Radiofrequency ablation

Brief principles

During RFA in most biological tissue, a high-frequency electric current (200–1200 kHz) flows through ionic channels and causes frictional heat at the ion level, followed by a local temperature increase. The most efficient heating is produced by the high current within several millimeters of the electrode tip and results in tissue necrosis, and then heat conduction causes damage to the tissue further away from the electrode thermal damage.[28] The heating effect of RFA that causes thermal tissue necrosis is a combination of frictional and conductive heat. Tissue carbonization when the temperature is higher than 100°C and the heat sink effect originating from tissue blood flow perfusion are the most important factors reducing the efficacy of RFA.

Procedure

The moving shot technique under US-guided free-hand operation with local anesthesia, implementing a transisthmic approach and hydrodissection, is the recommended technique in BTN ablation using RFA.[29] First, the target nodule is divided into multiple conceptual ablation units, whose sizes might vary within the nodule. Then, following local anesthesia, the electrode is advanced into the targeted nodule from the direction of the thyroid isthmus. The electrode tip is then placed in the deepest portion of the nodule. Next, the active tip is fired and gradually pulled back unit by unit to ablate from a deep to a superficial area. Finally, the electrode is re-inserted in another direction in the nodule to start the next ablation unit by unit until the whole nodule is ablated. If the target nodule is adjacent to critical structures such as the trachea, esophagus, large vessels, and nerves, hydrodissection is a useful technique to separate the nodule from the structures.

Clinical results

In terms of efficacy, the initial clinical report about RFA for BTNs was published in 2006, presenting the use of US-guided percutaneous RFA in treating 35 cold BTNs in 30 euthyroid patients.[30] One patient was lost to follow-up, but the mean nodular volume in 29 patients had a trend toward gradual shrinkage during a mean follow-up period of 6.4 months (range: 1.1–18.5 months). Among the 25 patients who complained of nodule-related symptoms, the symptoms improved in 22 patients (88%) after ablation, and it was concluded that RFA might be a non-surgical treatment for cold BTNs. In the 2010s, the efficacy of RFA in treating symptomatic BTNs has been increasingly confirmed by a number of non-randomized and randomized control trials. In 2013, a promising report with a mean follow-up period of 49.4 ±13.6 months presented the clinical outcomes of 111 patients, whose 126 BTNs underwent US-guided percutaneous RFA.[10] The mean VRR was 93.5 ±11.7% at the last follow-up, and the mean nodular volume significantly reduced from 9.8 ±8.5 mL before ablation to 0.9 ±3.3 mL after ablation. Compared to the original values, the mean nodular maximal diameter (3.3 ±1.0 cm), vascularity classification (1.7 ±0.7), cosmetic score (3.2 ±0.8), and symptomatic score (4.3 ±1.6) were significantly decreased after RFA to 1.1 ±0.8 cm, 1.1 ±0.4, 1.3 ±0.6, and 0.8 ±0.9, respectively. A reduction in the VRR of more than 50% was observed in 124 (98.4%) out of 126 nodules, and 28 target nodules (18.3%) had disappeared completely at follow-up. The authors found RFA to be a safe non-surgical method to effectively decrease nodular volumes and improve clinical problems related to BTNs, as confirmed by the long-term follow-up results.

Additionally, normal thyroid function was well-preserved in most patients following RFA,[9,10] except for cases that had undergone previous thyroid lobectomy[20] and bilateral BTNs.[21]

In terms of safety, a large multicenter study of complications related to RFA treatment of BTNs was published in 2012.[19] Among 1459 patients with 1543 ablated nodules, the incidence rate of complications and side effects were 3.15% (46/1459) and 3.3% (48/1459), respectively. Only 20 patients (1.4%) underwent major complications, including voice changes in 15 cases (1.02%), nodular rupture in 2 cases (0.14%), nodular rupture with abscess formation in 1 case (0.07%), hypothyroidism in 1 (0.07%), and brachial plexus injury in 1 (0.07%). Minor complications were reported in 28 patients (1.92%), including hematoma (1.02%), vomiting (0.62%) and skin burn (0.27%). Side effects of pain (2.6%), vasovagal reaction (0.34%) and coughing (0.21%) were presented by 48 patients (3.15%).

Microwave ablation

Brief principles

The frequencies of electromagnetic wave commonly used for medical MWA range from 915 MHz to 2450 MHz. Dielectric hysteresis, known as rotating dipoles, is the physical principle of heat generation in a microwave field.[31] Molecules with an intrinsic dipole moment, such as water, are forced to realign under the alternating electromagnetic field. The increase in kinetic energy produced by polar molecular rotation results in local tissue temperatures rising high enough to cause irreversible coagulative tissue necrosis. The high central temperature of 150°C or more easily penetrates biological tissue, including dehydrated or charred tissue. Microwave ablation was less affected by the heat sink effect than RFA,[32] and might be suitable for treating nodules with rich blood flow or to block the blood supply of large vessels adjacent to the ablated lesion.[33]

Procedure

As in RFA, the moving shot technique under US-guided free-hand operation with local anesthesia is the usual MWA technique for ablation of BTNs. Fixed-antenna ablation could be used to ablate an area with rich blood flow in the target nodule, or to block large vessels around the nodule prior to undertaking the moving shot technique.[33] An easy operating approach is decided according to the nodular location in the thyroid and the peripheral structures around the nodule; trans-isthmic approach is the generally preferred choice. If necessary, hydrodissection is used to separate the target nodule from surrounding critical structures. Usually, 5–10 s of microwave fire is enough for a conceptual ablation unit, and then the antenna is pulled back about 10 mm to ablate the next unit. Internally cooled-shaft needle antenna can be helpful in effectively decreasing overheating of the needle, to prevent skin burns and efficiently increase the energy transferred to the tissue.[34] While the energy is firing, the antenna tip cannot be placed beyond the target nodular margin.

Clinical results

In terms of efficacy, after the development of an internally cooled-shaft antenna with a 16 gauge diameter, 10 cm in length and 3 mm active tip, the pilot clinical application of 2450 MHz MWA for BTNs was reported in 2012.[15] The researchers concluded that MWA was a feasible technique for BTNs, based on the results of 11 solid or mixed BTNs in 11 human patients treated using MWA under US guidance following an ex vivo feasibility study on swine liver tissue. After that, a large-scale clinical study of 222 patient with 477 BTNs but only short-term follow-up was published, using the same microwave system and antenna as in the pilot study.[16] Data at the six-month follow-up was obtained in 254 out of 477 nodules with a mean nodular VRR of 65 ±65%. Nodular VRRs over 50% and complete the disappearance rates were 82.3% (209/254) and 30.7% (78/254), respectively. The conclusion was drawn that MWA seemed to be a safe and effective technique for the treatment of BTNs. A clinical study for BTN ablation was documented using a microwave system at a frequency of 902–928 MHz in 2015.[35] Three kinds of antennas, with diameters from 14 G to 16 G, were used and the power output was 24–36 W. The mean volume of 18 nodules in 14 patients shrank from 19.8 ±21.3 mL at the baseline to 8.9 ±8.9 mL 3 months after ablation, and the mean VRR was 55.4 ±17.9%. It was concluded that MWA can be considered an effective and low-risk new approach to treating BTNs.

In terms of safety, the largest clinical study to date reported that mild sensations of heat during the procedure were complained of by most patients, but it was easy to tolerate and cessation was not necessary.[16] The most serious short-term complication was voice change, which presented in 8 patients (3.6%) out of 222, and improved in 3 months. Using the microwave system at frequencies of 902–928 MHz resulted in no major complications such as nerve injuries, severe infections, secondary hemorrhage, or nodular rupture.

High-intensity focused ultrasound

Brief principles

The basic principles of HIFU for tumoral ablation are the typical clinical application of thermal effects between US waves and biological tissue.[36] During the HIFU procedure, some low-intensity US beams produced by a curved or phase-arrayed piezoelectric probe with a central frequency of 1–7 MHz are concentrated on a focused zone in the target tissue in the body. The procedure is totally noninvasive because no needle puncture into the skin is necessary.[37] When an acoustic wave is propagated in tissue, part of the acoustic energy is absorbed and transformed into thermal energy. In the focused zone, due to the high density of acoustic energy, the temperature rises over 60°C in several seconds and can result in lethal damage to local tissue. At the same time, tissue beyond the focused zone remains intact due to the low density of acoustic energy. A focused acoustic zone can cause a small ellipsoidal necrosis unit in the target tissue.

Procedure

In accordance with pre-treatment planning, HIFU therapy is performed unit by unit to result in an ablated lesion in the target tumor. A pause between every 2 sonication pulses was necessary to prevent tissue overheating and gas bubble formation, which might cause reflections and distortions of incident waves, unexpected increases in ablation or even unpredictable injuries beyond the target tumor. The patient undergoes conscious sedation in the HIFU procedure to ablate BTNs. The HIFU is a time-consuming therapy; from 1 h to several hours is needed to ablate the target tumor.[37] To monitor the focused US energy reaching the target tissue, HIFU therapy is usually guided using US or magnetic resonance imaging (MRI).

Clinical results

As far as efficacy is concerned, only a few clinical reports about HIFU treatment for BTNs have been published. The initial clinical application of HIFU ablation was documented in 2010, to treat a 26-year-old male patient with hyperthyroidism.[38] A 9 × 8 mm solid isoechoic nodule, which was a clearly hot on a ^{123}I thyroid scan, with rich blood flow, was located in the right isthmic lobe. The ablated nodule became cystic 2 weeks after treatment with 15 min of HIFU ablation at 4 kJ. The patient's thyroid function recovered to normal range in 3 months. After 18 months of follow-up, the ablated lesion shrank and presented a 1.4 × 1.6 mm hypoechoic scar with no blood flow. Thyroid function remained in the normal range and iodine uptake was recovered on thyroid scintigraphy. The authors of this pilot clinical study concluded that HIFU seemed to be a safe and effective treatment for AFTNs, with excellent clinical, biologic, ultrasonographic, and scintigraphic results. In 2015, a prospective clinical study reported the results of HIFU ablation of 20 BTNs in 20 euthyroid patients.[17] The average duration of the procedures was 86.8 min. The mean nodular volume decreased significantly from 4.96 ±2.79 mL at baseline to 3.05 ±1.96 mL 3 months after ablation. The results of a six-month follow-up were obtained in 16 out of 20 patients, whose mean nodular and maximal VRR was 48.7 ±24.3% and 92.9%, respectively. The cosmetics improved significantly, with the mean cosmetic score decreasing from 2.6 ±1.0 to 1.9 ±0.9. Vascularity in the nodules was reduced significantly. It was the conclusion that US-guided HIFU ablation is safe and effective treatment for BTNs, and that the clinical outcomes could be affected by US echoic features and vascularity.

In terms of safety, the clinical outcomes of a feasibility study showed no major complications, but 3 patients (12%) underwent insufficient HIFU ablation because of pain or the appearance of skin blisters during the procedure.[39] The results of the 2015 prospective study outlined above indicated that all 20 patients tolerated HIFU ablation well, with a mean pain score during procedures of 2.8 ±2.6 on a visual analog scale ranging from 0 to 7.5.[17] No additional analgesics were administrated after ablation. Subcutaneous edema was observed in 1 patient; it gradually disappeared after 1 week. Mild skin redness presented in 1 case after ablation and became a small rash area with red papules after 1 week, and disappeared by the one-month follow-up. No major complications such as dysphonia or thermal injury of the trachea or esophagus occurred.

Discussion

The clinical applications of RFA and LAT, which have been employed for a decade, with hundreds of published documents, are considered a minimally invasive alternative to surgery for patients with symptomatic BTNs, especially for nonsurgical candidates due to high surgical risk, comorbidities or refusal of surgery. Comparing the clinical outcomes of RFA and LAT for BTNs, the procedures are similar in terms of safety, but the efficacy of RFA has been found to be superior to LAT,[5,40,41] although no randomized controlled trials with large-scale cohorts and long-term follow-up have been published. Under local anesthesia, the moving shot technique with a trans-isthmus approach monitored using real-time US imaging has been recommended as a standard procedure in RFA for BTNs and could be helpful to improve the curative efficacy of other methods. Unfortunately, the moving shot technique is difficult to adapt to the LAT procedure. This might be a crucial reasons limiting its clinical efficacy in low nodular VRR compared to RFA.[40]

The moving shot technique could easily and conveniently be applied in MWA for BTNs, so MWA might technically achieve similar clinical outcomes to RFA. However, only a small number of clinical results of MWA for BTNs have been published in recent years, due to the complexity of the design and development of microwave antennae. In principle, MWA is more effective in ablating nodules with rich blood flow. However, it is undeniable that dehydrated or charred tissue caused by higher central temperatures during MWA is difficult to absorb and non-beneficial to shrinking the nodular volume. Obviously charred thyroid tissue was present on a gross thyroidectomy specimen after MWA treatment with a power output of 30–50 W.[16] Microwave ablation with low power outputs (20–30 W) is therefore recommended in BTN ablation in order to minimize tissue charring. The results of a recent large-scale prospective multicenter comparative study between MWA and RFA concluded that both MWA and RFA are safe and effective techniques for selected patients with symptomatic BTNs, and the VRR achieved in the RFA group was greater than in the MWA group at 6 months and later.[42]

Theoretically, HIFU should be a non-invasive method to ablate BTNs because skin penetration is not required[43]; there is a short approach to the target nodule without bone and gas to influence acoustic propagation; and unit-by-unit ablation in spatially proper order according to the treatment planning is similar to the moving shot technique. However, its disadvantages also originate mainly from its non-invasive nature: Acoustic beams reach the target nodule after propagating through several non-target tissues including skin, subcutaneous adipose and muscles. It might be possible to damage non-target tissue due to excessive energy deposition, and results after HIFU ablation have observed that the range of necrosis was beyond the target nodule.[18] Therefore, the most primary challenges in the clinical application of HIFU ablation are to deliver enough acoustic energy to the target nodule, and meanwhile to avoid or minimize injuries to important surrounding structures.

So far, surgery has been the most common therapy for BTNs. Except for nodules with large volume (over 35 mL) or behind the sternum and autonomously functioning thyroid nodule (AFTN), a comparative clinical study concluded that RFA is an effective alternative to surgery for treating BTNs in patients with local cosmetic and symptomatic problems.[44] A large-scale comparative study between RFA and surgery in treating BTNs was published in 2015.[45] Four hundred patients with BTNs were enrolled and separated into 2 groups: RFA and surgery, with 200 patients in each group. The results indicated that nodular volume in the RFA group shrank significantly at the one-year follow-up, with a mean nodular VRR of 84.8 ±17.1% (range: 61.3–100%). The RFA group had a significantly lower residual rate, lower complication rate, lower hypothyroidism with medication rate, and shorter mean hospitalization after treatment than the surgery group did: These rates in the surgery group compared to the RFA group were 11.9% vs 2.9%, 6% vs 1%, 71.5% vs 0%, and 6.6 ±1.6 days vs 2.1 ±0.9 days, respectively. The conclusion was that RFA was as effective as surgery for treating BTNs and should be considered a first-line therapy because of the advantages of a low complication rate, good preservation of thyroid function and shortening of mean hospitalization time. Nevertheless, it would be indispensable to carry out further prospective multicenter and large-scale randomized controlled trials between TA and surgery for BTNs before a non-surgical therapy can be recommended as an effective alternative to surgery.

Thermal ablation treatment for BTNs has shown several obvious advantages in terms of safety, such as low rates of complications and side effects, being an outpatient procedure under local anesthesia; however, because of the occasional occurrences of several major complications, it is essentially necessary to recommend that the procedure should be performed in special clinics and by experienced teams, ensuring good clinical outcomes and minimal complications. In addition, ablation treatment guided by virtual navigation techniques or image fusion navigation[46,47] could provide beneficial support, and be helpful in decreasing most of the complications caused by US guidance alone,[48] shortening the learning curve and minimizing the influence of microbubble formation obscuring the view of the needle tip during ablation.[46] Fortunately, image fusion navigation has become standard software in modern US imaging systems for the precise and safe clinical application of TA techniques.[49]

The last issue that must be mentioned is that the benignity of TNs ablated by a nonsurgical treatment such as TA have to be proven using fine needle aspiration (FNA), the sensitivity and specificity of which are not 100%. In other words, there is a possibility, albeit very low, that a malignant TN could theoretically be ablated. Therefore, regular follow-up to promptly detect and manage the recurrence of any potential malignant nodules is strongly recommended for patients with TNs treated with a nonsurgical TA technique.

Conclusions

As non-surgical treatments, all 4 TA techniques can be safe and effective treatment for patients with symptomatic BTNs. The RFA seems to be the best one, because of the highest nodular VRR at follow-up. Furthermore, image fusion navigation techniques promise to provide significant assistance in the precise ablation of BTNs.

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