

monitored via real time US during the procedure to prevent possible thermal damage to adjacent critical structures.

Hydrodissection

When the target nodule abuts critical structures, hydrodissection using 5% dextrose solution in water (D5W) should be considered.^{6,8,30,36} Slow injection of D5W creates a barrier between the target nodule and critical structures. This may need to be repeated multiple times depending on the length of the ablation. Given that thyroid tissue deep to the capsule is nearly devoid of sensory innervation, the sensation of pain on the part of the patient could be an indicator of potential trauma to critical structures.

The application of local anesthesia adjacent to critical structures such as the trachea should, therefore, be avoided so that the pain reflex can improve safety. For the same reason, avoiding general anesthesia or conscious sedation may enhance the safety profile and should be encouraged for operators with limited experience.

US-guided techniques for thyroid vascular ablation

Artery-first ablation is effective to minimize the heat-sink effect in hypervascular nodules. The concept is similar to that of thyroid arterial embolization, in that direct puncture and destruction of the feeding artery by ablation is performed before ablation of the nodule parenchyma, allowing for lower currents to be utilized during parenchymal ablation and thus reducing the risk of heat transmission to surrounding critical structures.

The counterpart, marginal venous ablation, is a technique to destroy veins around the thyroid nodule. Destruction of a marginal vein may help achieve rapid volume reduction at the early follow-up period by maximizing the initial ablation zone as well as minimizing marginal regrowth at long-term follow-up.⁴¹ When used together, arterial ablation should precede venous ablation.

Management of peri-procedural complications

Power used adjacent to critical structures should be carefully monitored, with lower power utilized if ablating near neck viscera, in the posterior danger zone or superiorly near the external branch of the superior laryngeal nerve.⁴⁰ If vocal hoarseness or sudden cough is noted during the procedure and there is concern for RLN injury, tracheal injury, or esophageal injury, ablation should be halted.

A bolus of cold D5W can be injected into the perithyroidal region adjacent to the ablated area where the hoarseness occurred, as it can potentially dissipate the heat already transmitted to the nerve.^{30,36} If the decision is made to continue with the ablation, the ablated area where the voice change occurred should be avoided for the remainder of the procedure. Hemorrhage is usually self-limited and controlled with simple compression of the hemorrhagic portion.

In the case of large hemorrhage directly from an artery, direct ablation of the injured artery is the treatment of choice if the artery can be detected and is of small enough caliber to ablate. For more profuse bleeding, endovascular or surgical intervention is needed. Lidocaine toxicity is a rare complication. Early signs include perioral numbness, tinnitus, and agitation. With larger doses, muscle twitches and seizures are possible.⁴²

To minimize lidocaine toxicity, it is recommended to use <4.5 mg/kg of 1% lidocaine. Treatment is conservative in

mild toxicity cases, with consideration for lipid emulsion therapy with lipofundin 20% and transfer to a higher level of care as appropriate.⁴³

Post-procedural

Criteria for safe discharge

Complication rates following thyroid nodule ablation are low as reported in international series and corroborated by the small number of North American series reported to date.^{12–14,21,29,30,44–46} To detect an early complication, all patients should be observed for a period of at least 30 minutes following ablation, or longer if sedative medications are utilized.

Vital signs, including heart rate, blood pressure, and oxygen saturation, should be monitored. The patient's breathing should be assessed for stridor, cough, or respiratory distress. The patient's voice should be assessed to confirm it is comparable with pre-procedure, as recurrent laryngeal or vagus nerve injury can result in vocal hoarseness and decreased ability to project the voice above background noise.

If there is concern for voice change, US or laryngoscopy assessment of the vocal cords should be performed, with laryngoscopy being the gold standard examination modality. Laryngeal nerve injury can also cause patients to cough when swallowing liquids and, if nerve injury is suspected, patients should be given a sip of water to assess whether they are able to swallow normally and to gauge their risk of laryngeal aspiration.

Patients should be counseled on identifying early complications such as expanding hematoma, and when to seek urgent medical care. Patients are instructed to avoid submerging the access site or sites in water for 24 hours. Patients are encouraged to avoid strenuous physical activity for 2–3 days following the procedure, and to avoid pressure or trauma to the neck. The neck puncture site should be checked before discharge to assess for hematoma or bruising. If conscious sedation or anxiolytic medications were used, the patient will require assistance with transportation home.

In the absence of conscious sedation, patients should still be encouraged to arrange for a ride home due to potential soreness after the procedure. Patients who require air transport should be advised to stay in a local hotel for the first 24 hours following the procedure. Routine use of antibiotics is not required unless perioperative complications are detected.

Immediate safety considerations (up to 72 hours)

After thyroid nodule ablation, pain and soreness in the neck are expected. In addition, some swelling of the nodule and surrounding tissues is common during the first week. These symptoms will usually peak in the first 3–5 days following the procedure. In most cases, pain and inflammation can be managed with ice packs and over-the-counter analgesics (e.g., ibuprofen and acetaminophen).¹³

Patients rarely require opioid pain medications and their use should be avoided. A steroid taper may alleviate discomfort in the case of pain or early compressional symptoms due to initial nodule volume increase.

Early complications are usually a result of injury to critical structures that surround the thyroid gland, such as the esophagus, trachea, RLN, carotid artery, vagus nerve, and cervical sympathetic ganglion.^{19,47,48} Since heat, and therefore injury, can extend for a distance of 1–5 mm beyond the applicator tip (depending on the active tip size