Ultrasound Guidance in Tumor Ablation

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KEYWORDS

• Ultrasound guidance • Ablation • Tumor • Radiofrequency • Cryoablation • Liver • Kidney

KEY POINTS

- Ultrasonography is increasingly being used during the targeting phase of ablation procedures.
- Contrast-enhanced ultrasonography and sonoelastography have significantly improved lesion visualization before, during, and after ablation.
- The use of various imaging modalities and ablative techniques is encouraged to allow appropriate individualization of treatment.
- Ultrasonography will be used in the future to aid irreversible electroporation and microwave ablation as these techniques gain in popularity.

INTRODUCTION

Ablation is a minimally invasive procedure used to treat both cancerous and noncancerous conditions. The International Group on Image-Guided Tumor ablation stressed, in their 2005 consensus statement, the "direct" nature of this therapy aimed at "eradication or substantial tumor destruction."[1] Applications for percutaneous ablation have broadly expanded since the initial treatment of hepatocellular carcinoma with percutaneous ethanol injection in 1986[2] largely due to improvements in technology, increased procedure availability, and mounting evidence that percutaneous ablation is equally effective to other oncologic treatments in the hands of an experienced operator. Alternative, and often coexisting, treatment options include chemotherapy, radiation, surgery, and transcatheter delivery of chemotherapy.

Methods of ablation vary in both their applications and mode of treatment. For example, radiofrequency ablation (RFA) may be applied to many different organ systems ranging from lung metastases to the osteoid osteomas. Most ablations performed by radiologists target the liver, kidneys, and lung. Understanding technical differences between modalities and target organs is essential to optimal treatment.

Ablative modalities are characterized as thermal, chemical, or electrical (**Table 1**). Each has advantages and disadvantages with respect to lesion size, location, and treatment intent. Thermal ablation induces cell death through the transmission of energy to water molecules, as in RFA, cryoablation, and microwave ablation. Chemical ablation refers to cell coagulation from the direct injection of a toxic agent such as alcohol. Electrical ablation techniques disrupt the cell-membrane electric gradient and thereby the inducing cell. The authors do not advocate strict adherence to one particular modality. The use of various modalities is encouraged to ensure optimal, individualized treatment options.

A comprehensive discussion of all ablative modalities is beyond the scope of this article. This review focuses on sonographic applications for 2 common methods of ablation, namely RFA and

The authors have nothing to disclose.
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Ultrasound Clin 9 (2014) 67–79
http://dx.doi.org/10.1016/j.cult.2013.09.001

Table 1
Types of ablation

Category	Ablative Technique
Chemical	Alcohol, acetic acid
Thermal	RFA, cryoablation, microwave, laser, HIFU
Electrical	IRE

Abbreviations: HIFU, high-intensity focused ultrasonography; IRE, irreversible electroporation; RFA, radiofrequency ablation.

cryoablation, in treating hepatic and renal tumors. Brief mention is given to microwave ablation and irreversible electroporation (IRE).

PRINCIPLES OF RADIOFREQUENCY ABLATION

RFA is based on the principle of vibrational energy transmission. Electromagnetic waves are transmitted to a probe that align water-molecule dipole moments. Alternating current is applied with subsequent shifts in alignment of the water molecules to the direction of current at a given time (**Fig. 1**). The rapid vibration of the molecules transmits thermal energy into cells.[3] Cell death is achieved when temperatures exceed 60°C. The optimal temperature range used during a procedure ranges from 60°C to 105°C. Above 105°C, cellular vaporization and charring occur that rapidly increase electrical resistance, decrease ablation times, shrink ablation zones, and thereby undertreat tumors.

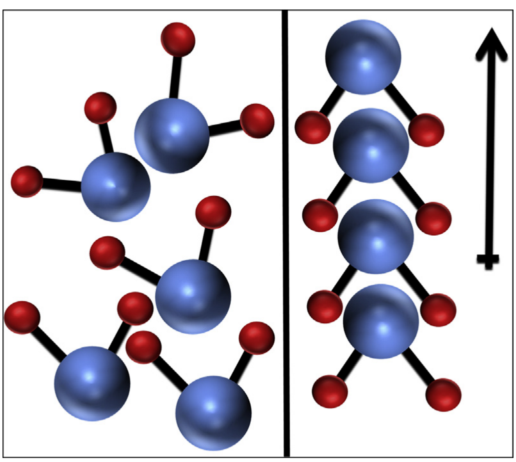

Fig. 1. Normal random orientation of water molecules within cells (*left*) and subsequent alignment of the negatively polarized oxygen molecules along the dipole moment (*right*). Molecules change direction with the shifting dipole moment of alternating current, producing vibrational energy. Red spheres indicate hydrogen, blue spheres oxygen.

Power requirements are dependent on the efficiency of energy transmission in vivo and the organ being targeted. Typical power ranges for generators applied to hepatic tumors are 150 to 250 W, whereas power requirements in the kidney are closer to 50 W.[4] The kidney is a smaller organ and lacks the dual blood supply present in the liver.

Probes used during the procedure deposit energy at their tips through a closed-loop circuit created using anode grounding pads attached to the patient. The probe may have a single tip or use metal tines that fan out from the probe tip. These tines are curvilinear and equidistant, forming an umbrella shape as they leave the probe, and determine the zone of ablation (**Fig. 2**). Complete deployment of the tines is necessary to ensure an adequate ablation zone diameter (see **Fig. 2**). Multiple probes with typical separation distances of approximately 1 cm may be used, which are internally cooled by instillation of a coolant during the procedure. Perfusion probes that allow injection of a solution into the tumor during the ablation are also available. **Box 1** summarizes the principles of RFA.

PRINCIPLES OF CRYOABLATION

Cryoablation is the induction of cell death by thermal conduction. Cell-membrane permeability and osmolar concentrations are drastically altered as intracellular and extracellular water molecules crystalize below −25°C. This process induces necrosis and apoptosis, and can cause surrounding dehydration and ischemia, particularly at temperatures lower than −40°C.[5]

Subzero cryoprobe temperatures are reached using the Joule-Thompson effect. Inert gases pass through a tiny opening in the probe to a large-volume chamber. The sudden increase in volume lowers the pressure and temperature of the gas, cooling the probe. Circulating coolant is used to complement heat exchange between the probe and surrounding tissue.[5] Up to 8 cryoprobes have been reported for use in a single session, geometrically oriented within 1 cm of the tumor and 2 cm of the nearest probe.[6] Probes used in cryoablation do not have tines. **Box 2** summarizes the principles of cryoablation.

GENERAL SELECTION CRITERIA

Patient selection, treatment intent, and tumor location are important considerations prior to the procedure. A multidisciplinary team