Current Tumor Ablation Technologies: Basic Science and Device Review

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ABSTRACT

Image-guided tumor ablation is an increasingly utilized tool to treat focal malignancy. Tumor ablation can be divided into two large categories, thermal and chemical ablation. The authors provide an overview of the current methods used to achieve thermal and chemical ablation of tumors, specifically addressing the basic science behind the ablation methods as well as providing a brief synopsis of the commercial devices currently available for use in the United States.

KEYWORDS: Percutaneous, ablation, radiofrequency, cryoablation, microwave, chemical, high intensity focused ultrasound, laser, electroporation

Objectives: Upon completion of this article, the reader should be able to explain the current methods used to achieve thermal and chemical ablation of tumors, as well as the basic science behind the ablation methods. The reader should also be able to list the commercial ablation devices currently available for use in the United States.

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Tissue ablation has existed in basic form within the field of medicine for over a century,¹ but has seen increased utilization in recent years. In the 1970s and 1980s, tumor ablation became more mainstream due to advances in laparoscopic surgical approach. With the significant evolution of imaging devices and modalities during the past two decades, image-guided tumor ablation has become an ever more increasingly employed means for definitive treatment of primary and metastatic focal malignancy, tumors in poor operative candidates, and for pain palliation.

Both chemical and thermal methods have been applied toward focal tumor ablation therapy. Although

procedure indications, patient selection criteria, and techniques vary among these treatments, both methods take advantage of various physical, chemical, and biochemical properties of tumors to cause local cell necrosis. Thermal ablation directly alters the local temperature of the lesion, either with heating or cooling, causing either direct or indirect cell death. Radiofrequency ablation (RFA), microwave ablation, laser ablation, and high-intensity focused ultrasound (HIFU) employ heat to affect cell death, whereas cryoablation therapy uses rapid cycles of cooling to cause tissue destruction. In contrast, chemical ablative agents, such as absolute ethanol, rely on direct toxicity to produce necrosis.

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Familiarity with the basic scientific background and technical aspects of all ablative methodologies is necessary for interventional radiology operators to best approach and treat complex oncologic cases. As such, this article aims to review the basic science of thermal and chemical ablation technologies currently utilized in the percutaneous treatment of malignancy, and to present a discussion of commercially available thermal ablation devices to facilitate awareness with current technology.

RADIOFREQUENCY ABLATION

Heat-based locoregional tumor therapies are based on experiments examining the relationship between cellular viability and temperature.² Early investigations found that elevated tissue temperatures above 45°C cause cellular protein denaturation and cell membrane dysfunction that results in irreversible coagulative necrosis, a type of necrosis characterized by maintenance of tissue architecture.² Additional studies show an exponential relationship between temperature rise and rate of necrosis: at 45°C, necrosis occurs within 20 to 30 minutes, at 50 to 55°C, necrosis occurs within 5 minutes, and at temperatures between 60 to 100°C, necrosis occurs immediately.²⁻⁵ Above 100 to 110°C, tissue vaporization and carbonization occurs.

In general, the amount of heat distributed within a certain tissue volume is based on the rate of heat production minus the rate of heat dissipation. A zone of ablation within tissue occurs as a result of both active and passive heating, depending on the type of heating technique employed. Active heating indicates that heat is created directly where it affects cell death; passive heating represents spread of heat by conduction to cause cell death. Factors that negatively affect heat production within a tissue volume include tissue charring, high local blood flow, and increased distance from the heat source. As noted, carbonization and charring occur at temperatures above 100°C, and limit the rate and application of maximal heat energy.^{2,5} High blood flow within large blood vessels in close proximity to ablation sites causes a heat-sink effect in which heat is dissipated from tissue via convection, negating the rate of energy deposition.² Finally, heat deposition varies inversely with the distance from the energy source. These factors play an important role in the efficacy and design of thermal ablative technologies.

RFA evolved from the same experiments that led to the creation of the surgeon's electrocautery knife.² Radiofrequency ablation employs a generator to create alternating current, typically between 200 to 1200 Hz. The alternating current agitates ions in the adjacent tissue causing intense friction, leading to heat. This heat then spreads outwards into adjacent tissue by conduction away from the zone of active heat production. Sufficient heat causes rapid coagulative necrosis of

tumor cells and tumor-free margin. In general, the goal of thermal ablation is to produce of zone of coagulative necrosis that encompasses a 0.5 to 1.0 cm tumor-free margin, a rationale based on the known diminished risk of tumor recurrence after surgical resection with 1 cm tumor-free margins.⁶

During RFA, the patient completes a closed loop circuit, which also includes an RF electrode, RF generator, and grounding pads. For the procedure, an RF needle is directed under imaging guidance into a tumor site. Retractable electrodes within the needle, if present, are then deployed into the lesion. The generator connected to the needle creates current that is conducted to the electrode tip to produce heat. A grounding pad is typically placed on the patient's thigh to complete the conductive circuit. Ablation zones are generally limited in size to regions of active heating in the tissue immediately surrounding electrodes. Rapid or excessive heating leads to desiccation and charring of the tissue, and diminishes the number of ions that can generate heat. To control and limit heat, the generator has to undergo multiple cycles of controlled elevations in power, current, and temperature.

COMMERCIALLY AVAILABLE RFA DEVICES

Several companies in the United States currently manufacture RFA devices. These include AngioDynamics (Queensbury, NY), Boston Scientific (Natick, MA), and Covidien (Mansfield, MA).

The AngioDynamics family of RFA devices includes the StarBurst XL, StarBurst XLi-enhanced, StarBurst Talon (Fig. 1), StarBurst MRI, and StarBurst SDE. Each device is 14- to 17-gauge in caliber with multiple retractable curved tines that assume a Christmas tree configuration when deployed within a lesion. The devices are capable of producing ablation zones measuring 1- to 7-cm diameter, depending on the electrode utilized. The electrodes contain thermocouple devices that monitor temperature and provide real-time tissue temperature feedback during the ablation cycle. The Talon device uses a mechanical pump to deliver precise amounts of normal saline to the ablation zone to maintain appropriate ablation temperatures. AngioDynamics also manufactures the single electrode UniBlate probe, used for production of smaller, 1.0- to 2.5-cm diameter ablation zones. The RF generator produces a peak of 250 W power with a frequency of 460 Hz, resulting in a temperature range of 15 to 125°C. One or two pads are utilized on the patient's thigh for grounding. The generator is programmed to generate several ablative cycles. During the initial cycle, the generator slowly increases the power from 25 W to the respective peak within 30 to 120 seconds. The peak power is held constant as tissue temperature is increased to a peak of 95 to 105°C. The length of the ablation cycle

Figure 1 (A) 14-Gauge multitined StarBurst Talon radiofrequency ablation (RFA) device (photo courtesy of AngioDynamics). (B) 14-Gauge LeVeen needle showing 12 retractable electrodes (photo courtesy of Boston Scientific). (C) 17-Gauge Cool-tip RF electrode (photo courtesy of Covidien).

is dependent on the desired size of the ablation zone as well as target tissue composition. Following this cycle, if tissue temperature is greater than 50°C for at least one minute, ablation is likely adequate.²

The LeVeen Needle Electrode (Fig. 1) is made by Boston Scientific. Twelve retractable curved electrodes are housed within a 14-gauge, 12-, 15-, or 25-cm-long needle. The electrodes assume an umbrella configuration when fully deployed, with a 2.0-, 3.0-, 3.5-, 4.0-, or 5.0-cm array diameter. The generator produces current at 480 kHz with a peak power of 200 W. Two grounding pads are used. The needle is advanced to the target and the electrodes are fully deployed prior to the initiation of the heating cycle. The generator initiates at 30 W and increases the power by 10 W every 60 seconds until the peak is reached. Peak power, once achieved, is held for 15 minutes until a rapid rise in impedance stops current flow and the ablation. After 15 minutes, the generator is turned off for 30 seconds and then reinitiated at peak power for another 15 minutes or until impedance stops current flow again. If instead maximum impedance is reached in the first cycle, the repeated cycles are repeated at 70% of the peak.

Covidien supplies the Valleylab Cool-tip RFA system, in which 17-gauge electrodes are available in both single probe (Fig. 1) and cluster varieties. The single probe devices are available in 10- or 15-cm length and 1- to 3-cm active tip length. The multiprobe devices include both two and three (triangular configuration) electrode systems in 10-, 15-, and 25-cm lengths and 2.5-, 3-, and 4-cm exposure lengths. The electrodes circulate water internally to reduce increases in tissue impedance, improve energy delivery, and limit tissue desiccation and charring. The electrodes interface with a generator with 0 to 200 W output at 480 kHz. Display parameters include impedance, current, power, time, and temperature. Safety parameters include impedance less than 25 ohms or greater than 1000 ohms, as well as temperature less than 10°C or greater than 99°C. Four grounding pads are utilized on the patient's thigh. Twelve-minute ablation cycles are typically utilized in which pulsed energy output and tissue impedance feedback typically result in peak tissue temperatures around 60 to 80°C.

CRYOABLATION

The use of cold temperatures in medicine dates back to the mid- 19th century.⁷ In the 20th century, the use of liquid nitrogen-based cryotherapy in open surgery became an important element in the treatment of liver tumors.⁷ More recently, the introduction of argon-based cryotherapy, which permits a reduced probe size, has allowed for percutaneous applications in locoregional tumor therapy. As such, percutaneous cryotherapy holds promise as a developing minimally invasive method for treating solid organ tumors.

Percutaneous cryoablation is based on the Joule-Thomson effect. In this process, gas in a region of high pressure travels through a porous plug into an area of lower pressure, thereby expanding and cooling the gas prior to exposure to tissue. The mechanism of cell destruction in cryoablation has been studied using liquid nitrogen, but remains the same with argon-based modalities. Cold temperatures emitted from a probe cause both intra- and extracellular ice crystal formation, which causes both a direct and indirect cell death. Intracellular crystal formation causes direct destruction of cellular membranes, resulting in direct cell death. Extracellular crystal formation results in an osmotic gradient that produces cellular dehydration, causing indirect cell death. Cryotherapy also results in small vessel thrombosis, which leads to indirect cell destruction. Interestingly, cryotherapy shows relative sparing of damage to larger vessels, which poses both advantages and disadvantages. Larger vessels allow surrounding tissues to remain viable, but also allow for potential complications such as tumor lysis syndrome and heat-sink (or "cold-sink") effects, and require colder thermal temperatures to cause cell death.

Due to the cellular composition of solid organ tumors, temperatures of at least -20 to -40°C are required to cause sufficient cellular death with resultant appropriate margins. As in RFA, margins should be equal to or greater than 1 cm.⁸ Increasing the number of freeze and thaw cycles also has a beneficial effect on cellular death, but beyond two freeze thaw cycles, further benefit is limited.⁸ Cryotherapy has been shown to be beneficial in tumor size less than 5 cm diameter, but with the use of multiple probes, tumors up to 10 cm diameter have been treated.⁹ The number and distributions of

probes used is determined by tumor size. The general rule of thumb adopted is that of the “2 to 1 rule.”¹⁰ Probes should be placed within 1 cm of the tumor margin and no more than 2 cm apart from one another.

The ice ball formed during cryoablation has been extensively described by all imaging modalities, and therefore any of the three prominent modalities can be used to monitor cryotherapy. Preferably, ultrasound is used due to the ability to monitor ice ball formation in real time. Computed tomography (CT) is somewhat limited due to lack of tissue contrast. Magnetic resonance imaging (MRI) is the best imaging modality to monitor the change in tissue contrast, but few institutions are using MRI-guided modalities.

The relative risk of complications due to cryoablation is similar to those of RFA. Some complications have theoretically increased risk, but no significant differences have been described in trials comparing RFA to cryoablation.¹¹ Hemorrhage is theoretically increased due to the lack of large vessel thrombosis. A theoretical risk of tumor lysis syndrome is also based on this same rationale. Other complications include liver cracking, which is more frequently described in open ablation than percutaneous ablation. Abscess, tumor seeding, and other biliary complications have also been described.

COMMERCIALLY AVAILABLE CRYOABLATION DEVICES

Two companies in the United States currently supply devices suitable for percutaneous image-guided cryoablation procedures. Several other companies manufacture cryoablation devices designed for surgical, prostatic, dermal, and neurologic pain palliation purposes. Both percutaneous systems use compressed argon gas for cooling, as it has very low viscosity and can be circulated very rapidly through small probes to achieve rapid cooling.

The Percryo device is distributed by Endocare, a division of Healthtronics, Inc. (Irvine, CA). In this system, multiple sharp probes are available, with diameters ranging between 1.7 mm and 4.9 mm as well as 13- to 28-cm length. The probes are capable of ablation zones measuring between 32×34 mm to 45×64 mm as measured at the 0°C isotherm. Up to eight probes can be inserted into the tumor at one time for the simultaneous ablation of larger lesions or multiple lesions. The system has an automated freezing mechanism with power settings based upon target endpoint temperatures. Thermocouple tips provide continual feedback throughout the procedure to optimize treatment to the tumor, and to confirm ablation at the tumor margins.

The Presice, SeedNet, and MRI SeedNet Systems (Fig. 2) are manufactured by Galil Medical (Yokneam, Israel), and use argon-based cooling for tumor cryother-

Figure 2 17-Gauge Presice, SeedNet, and magnetic resonance imaging SeedNet needle systems, in both straight and 90-degree angled varieties (photo courtesy of Galil Medical).

apy. All of the needles in these systems are 1.47-mm diameter and 17-gauge caliber, with a total usable shaft length of 175 mm. The cryotherapy applicators are available as color-coded IceSeed, IceSphere, IceRod, and IceBulb varieties, capable of ablation zones measuring 31×36 mm, 37×45 mm, 40×58 mm, and 40×67 mm, respectively, as measured at the 0°C isotherm. All devices feature thermal sensors located 5 mm from the needle tip that record temperatures during cryoablation, and the Presice system features multipoint thermal sensors located 5, 15, 25, and 35 mm from the applicator tip, and are used to sculpt the “ice ball” to the tumor size. The different applicators are available in both straight and 90-degree varieties to facilitate multiple probe placement during imaging guidance. MRI SeedNet needles are MRI compatible. Up to 25 needles can be inserted at one time for simultaneous ablation of a single large tumor or multiple tumors.

MICROWAVE ABLATION

Microwave ablation is a relatively newer technique that involves transmitting microwaves through a specifically suited antenna inserted into a tumor. Continuous microwave agitation of surrounding water molecules produces friction and heat, resulting in cell death. Microwave ablation was originally developed in Japan, and until recently the majority of experience was reported in Asia.^{12–14} Microwave ablation involves generating oscillating electromagnetic fields greater than 900 MHz in frequency. Under induction of an electromagnetic field, water molecules, which have weak unequal dipoles, attempt to orient within the field. As the field oscillates at a frequency above 900 MHz, water molecules oscillate rapidly and create friction and heat sufficient to lead to coagulative necrosis. Heat is also generated in part when polarized ions within the magnetic field gain kinetic energy, collide with other ions, and produce heat.

A microwave ablation system consists of a microwave generator, flexible coaxial cable, and microwave antenna. Microwaves are generated through a magnetron,

which is a high-powered vacuum tube that generates microwaves via interaction of a stream of electrons with a magnetic field similar in application to an x-ray tube. The antenna is connected to the magnetron by a coaxial cable.

Microwave ablation generates heat within a wider primary active heating zone, which minimizes desiccation and charring as compared to RFA. As a result, higher temperatures are achieved within a shorter duration, ideally resulting in a more complete and uniform zone of necrosis.^{14–16} Additionally, the resultant applied thermal profile overcomes the heat-sink effect that can occur with tumors near large vessels. Multiple probes can be utilized at the same time, allowing for larger or multiple small tumors to be simultaneously treated over a shorter duration.¹⁷ Unlike RFA, no grounding pads are required. Compared with RFA, small ablation sizes are a significant limitation, and experience is still limited.

COMMERCIALLY AVAILABLE MICROWAVE ABLATION DEVICES

The Evident Microwave Ablation system (Covidien, Mansfield, MA) is the only system in the United States that is approved by the Food and Drug Administration (FDA) for partial and complete ablation of unresectable liver tumors (Fig. 3). The system consists of a microwave generator, coaxial cable, and microwave antennae. The generator produces microwaves via a magnetron. The resonant frequency that the generator produces is ~915 MHz, which allows for energy output of 45 W.

Figure 3 14-Gauge Evident Microwave Ablation antennae (photo courtesy of Covidien).

The coaxial cables conduct the energy produced to the microwave antennae. The specialized antenna acts as a filament that outputs microwave radiation. The Evident Microwave Ablation system allows for up to three straight-tipped antennae to be used in the ablation of tissue of interest. The antennae are positioned usually via imaging guidance when used percutaneously. The 14-gauge antennae are available in 12-, 17-, and 22-cm lengths with a 3.7-cm radiating active tip. The system can create ablations within 10 minutes at 45 W with the application of one, two, or three antennae simultaneously, producing individual lesions at each antenna or one combined lesion when antennae are spaced 1.5 to 2.0 cm apart. Various times are used to ablate the tissue depending upon tissue type and required margin size. Other ablation systems are available in the United States for different FDA-approved clinical applications, including the Microsulis system (Hampshire, United Kingdom) for endometrial ablation and the MicroThermX 100 (BSD Medical, Salt Lake City, UT) for dermatologic procedures.

CHEMICAL ABLATION

Chemical ablation was widely introduced in the late 1980s, and since that time has become a relatively safe and effective technique used for the treatment of hepatocellular carcinoma and to a lesser degree, metastatic liver disease.¹⁸ More recently, thermal ablative techniques have become more widespread. However, chemical ablation continues to be effective for small tumors and in clinical instances where thermal techniques are contraindicated.

The most widely used chemical for tumor ablation remains absolute ethanol. Acetic acid represents a less frequently used chemical ablation agent. Chemical ablation results in tumor necrosis by direct and indirect means. When the chemical ablative agent is injected into a tumor bed, cytoplasmic dehydration and cellular protein denaturation occur, which results in a direct tumor cellular necrosis. The endothelial cells surrounding the small vessels supplying the tumor are also affected, resulting in small vessel thrombosis and indirect cellular necrosis.

For chemical ablation, a small (20- to 22-) gauge single endhole or multi-sidehole needle is introduced into a lesion with the needle tip extending to the distal edge of the tumor. The needle is positioned at this level due to the resultant increased echogenicity that occurs when the chemical ablative agent is injected. This could potentially obscure the lesion on imaging and needle positioning at the distal edge of the tumor is used to avoid degrading lesion imaging. The volume of chemical agent to be used is calculated by the volume of a sphere, according to the formula $V = (4/3) * \pi * (r + 0.5)^3$, where V is the chemical agent volume in milliliters and r is the

tumor radius in centimeters, to which 0.5 cm is added to account for a tumor-free margin. Depending upon the size of the tumor, the needle is either repositioned as the chemical is injected or second or multiple needles can be introduced to ensure appropriate coverage of margins. The chemical ablative is slowly injected in a continuous fashion usually under real-time imaging guidance. As the ablative is injected, the needle is rotated and slowly withdrawn, allowing the chemical to diffuse through the tumor bed. During the procedure if the biliary system or hepatic vasculature fill, the injection is stopped and the needle repositioned. Rarely gallbladder filling can occur, in which case the procedure should be terminated due to risk of hemobilia.

Some criteria for the selection of patients for chemical ablation include tumor size usually no greater than 3 cm. This is due to the limited diffusive capabilities of the chemical ablative agents in the soft tissues and the extent of the small vessel thrombosis that occurs. Other situations in which chemical ablation can be considered include scenarios in which thermal ablative techniques are contraindicated, such as biliary–enteric reflux or gastrointestinal adhesions to the liver. When CT is used to guide ablation, the chemical ablative is usually mixed with a small volume of iodinated contrast to allow visualization of the portion of the tumor that has been treated. Interval images are obtained during the procedure due to the lack of real-time guidance. Once the area of interest has become completely echogenic, or contrast opacified, the needle is slowly withdrawn under aspiration via sonographic or CT guidance.

Percutaneous ethanol ablation may be performed as a staged procedure with multiple treatments occurring over a short period of time, or as a “one shot” technique in a single setting. A staged ablation may be used to limit potential ethanol intoxication as well as to assess treatment of tumor over time. Minor complications related to chemical ablation include local pain, transient fever, and intoxication. The potential intoxication is pretreated with agents that increase hepatic oxidation. Major complications are infrequent with multiple sessions, and are slightly increased in the one-shot technique. Major complications include death, portal venous thrombosis, variceal bleeding, hemoperitoneum, hemolysis, peritoneal seeding, liver failure, and transient renal insufficiency.

HIGH-INTENSITY FOCUSED ULTRASOUND

High-intensity focused ultrasound (HIFU) is a newer ablative technique in the clinical array of thermal ablative technologies, but was explored as early as the 1940s.¹⁹ Improvements in imaging technology led to a resurgence of interest in this technique. HIFU ideally provides an alternative to the more common ablative technology in difficult-to-treat tumors. HIFU is of particular clinical interest in that it has a more focused zone of ablation

that may be able to treat target lesions in anatomically risky locations.

In HIFU, an extracorporeal ultrasound probe with a piezoelectric transducer is placed on the patient and a focused beam of sound energy is sent to target lesions. The mechanical vibration of the focus sound waves is converted into heat within the lesion as well as cavitation from microbubbles that are created. The intense pulses last less than 3 seconds and result in a rapid rise in temperature within the target lesions. The area of necrosis is shaped like an ellipse with a long axis parallel to the ultrasound beam.

Currently, HIFU utilization is limited by small ablative zones less than 1 cm, need for multiple repeated treatments, difficult targeting, and difficulty in monitoring. Subdiaphragmatic and lesions below the rib cage are difficult to treat.

COMMERCIALLY AVAILABLE HIFU DEVICES

The only high-frequency focused ultrasound device that is FDA approved for noninvasive therapy in the United States is the ExAblate 2000 (InSightec Ltd., Tirat Hacarmel, Israel). The device works in combination with General Electric (GE-) based MRI systems (Buckinghamshire, United Kingdom) to provide MRI-guided focused ablation. For ablation, a patient is placed onto a specialized table that contains the high-frequency focused phased-array transducer. The transducer contains a specialized piezoelectric crystal. MRI provides imaging of the lesion of interest. A specialized workstation allows for targeted guidance of the ultrasound beam. The frequency generated by the device range from 0.2 to 10 MHz allowing for energy deposition in the tissue from 1000 to 10000 W/cm². The energy drops off almost immediately outside of the focal spot. The focal spot is ellipsoid shaped and known as the sonication. The sonication can range from 1 to 10 mm in diameter and 10 to 50 mm in length. Multiple sonications, each lasting 15 to 25 seconds in duration, are needed to ablate the entire zone of interest. Tissues 1 to 2 mm away from the focal spot are unharmed. MRI allows for exact tumor targeting and visualization of the beam path via the specialized workstation and computer software. MRI also allows for accurate tissue temperature measurement. The specialized equipment is modular, allowing for current GE MRI systems to be utilized for image guidance.

LASER INTERSTITIAL THERMAL ABLATION

Laser interstitial thermal ablation creates heat by directing laser energy into cells. Laser ablation of liver tumors was first described in the 1980s.⁵ Cells contain tissue-specific chromophores, which optimally absorb laser

energy at characteristic wavelengths, specifically 800 to 1100 nm in the liver. Absorbed energy is converted into heat within the chromophores and subsequently propagates via conduction into adjacent tissues. The zone of ablation is therefore also dependent on the depth of laser penetration and conduction of heat that is produced.

The components of a laser include a power source, laser medium, and reflecting mirrors. As with alternative techniques, laser delivery can be performed percutaneously, laparoscopically, or through open surgery. A laser fiber is introduced into a target lesion through a cannula, typically 13 to 15 gauge for modern quartz fibers. The laser then is set to emit low energy ranging between 3 to 20 W for 2 to 20 minutes. As in alternative techniques, carbonization limits the maximal zone of ablation. Attempts to circumvent this limitation are similar to those in RFA, particularly with the creation of water-cooled probes. Water-cooled sheaths have been designed to be paired with higher laser power outputs up to 50 W. Ablational zones up to 80 mm have been produced with the introduction of water-cooled probes.

COMMERCIALLY AVAILABLE LASER INTERSTITIAL THERMAL ABLATION DEVICES

The most common laser device is the neodymium-yttrium-aluminum-garnet (Nd-YAG) laser. The Nd-diode laser is another device less commonly employed. The Nd-YAG generates a wavelength of 1064 nm; the Nd-diode achieves wavelengths of 800 to 980 nm.⁵ In the early stages of laser therapy, laser energy was delivered through bare-tip fibers introduced via a small-gauge cannula into the target lesion. Generated power ranges from 2 to 4 W. Maximal ablation zones of up to 2 cm may be achieved. Subsequently, the introduction of beam-splitting devices has allowed for combining multiple fibers that create larger zones of ablation up to 5 cm. Modern systems utilize quartz fibers, which are 1 to 2 mm in diameter and cylindrical. More efficient larger areas of light energy are delivered to the target tissue at higher power levels ranging from 4 to 10 W. Ablation zones of up to 5 cm have been achieved in this setting.^{5,20}

OTHER ABLATION TECHNOLOGIES

Multiple potential ablative technologies are currently being developed. These technologies are primarily non-thermal and may surmount current limitations of thermal ablative technologies. Irreversible electroporation (IRE) is the most appealing of these technologies. IRE has been utilized for over three decades in molecular biology and induces changes in cell membrane permeability through application of electrical pulses. Reversible electroporation has been utilized for gene therapy and delivery of chemotherapeutic drugs. IRE involves applying electric field

pulses lasting hundreds of microseconds to cells on an order of a few kV/cm. Recent studies have demonstrated the ability for IRE to induce significant tissue volumes of cellular necrosis through apoptosis following irreversible membrane permeability changes.²¹ Further studies have demonstrated the ability to produce definable volumes of cell necrosis without inducing heat and without affecting adjacent blood vessels.²² IRE has the potential to overcome limitations of other ablative techniques by avoiding the heat-sink effect, possibly ablating tumors that would otherwise be risky to thermally ablate, and can be monitored percutaneously under ultrasound more accurately without interference of artifacts (such as microbubble formation) caused by thermal ablation. Additionally, ablative times would be on the factor of 10 to 100 microseconds in comparison to the extended times seen with current thermal ablative technologies.

COMMERCIALLY AVAILABLE LASER INTERSTITIAL THERMAL ABLATION DEVICES

AngioDynamics manufactures the NanoKnife IRE System, which uses electrode probes to transmit energy from its generator to a target area. The system includes an energy generator, a footswitch, and single-use disposable electrodes. NanoKnife works in a two-pole operating mode, and up to six electrodes can be placed at a fixed distance apart in soft tissue to create several two-pole electrode configurations. The NanoKnife generator can support 1 to 6 probe outputs, with 90 pulses per pair of electrodes resulting in a maximum current of 50 A. Parameters that can be adjusted include pulse duration, electrode configuration, and geometry. Single electrode probes are 1-mm diameter and 15-cm length; bipolar electrode probes are 1.5-mm diameter and 15- or 25-cm length.

CONCLUSION

Image-guided tumor ablation is an increasingly utilized tool to treat focal malignancy, with RFA, cryoablation, microwave ablation, and chemical ablation commonly used. HIFU, laser ablation, and IRE represent developing ablation modalities. A thorough understanding of the basic science of these thermal and chemical ablation technologies and knowledge of commercially available thermal ablation devices is important for interventional radiologists to practice safe and effective minimally invasive percutaneous tumor ablation.

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