Liver Resection After Thermal Ablation of Parenchymal Transection Margin Using Microwave Energy

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Over the past quarter century, patients requiring liver resection have benefitted from significantly improved understanding of hepatic anatomy and physiology, imaging modalities, and surgical equipment and techniques.¹ More aggressive surgeries in higher-risk patients are performed with reduced morbidity and mortality. However, certain liver resections are prone to significant blood loss and/or hepatic decompensation. Many techniques have been developed to minimize bleeding during liver resection, including parenchymal transection by finger fracture or clamp crush and use of various dissectors and stapling devices. More recently, applying a zone of thermally induced necrosis at the resection margin before transection is employed to reduce blood loss, obviates the need for clamping of hilar inflow vessels, and spare parenchyma, especially in patients with cirrhosis or steatosis.²⁻⁵

Thermal energy has been used for many years to produce coagulative necrosis of unresectable primary and metastatic malignancies and some benign tumors of the liver. Cryotherapy was first employed but is cumbersome and was replaced by radiofrequency ablation (RFA), which has become a well-established treatment option over the last 15 years. Hasson was the first to widely publicize the use of RFA to coagulate a plane of liver tissue before resection.² Development of microwave ablation (MWA) devices and techniques that offer advantages over their RFA counterparts has led to increasing utilization of this modality for ablation of liver tumors and of parenchymal transection margins.³⁻⁵

Equipment

Both RFA and MWA heat tissue to cytotoxic temperatures, above 60 °C.⁵ MWA uses electromagnetic waves in the microwave energy spectrum (300 MHz to 300 GHz) to oscillate water molecules and produce frictional heating and

tissue necrosis.⁶⁻⁸ Microwave power is carried from a generator through coaxial cables to a rigid, straight shaft with a radiating antenna at the tip. There are a variety of shaft and antenna lengths and thicknesses. Most commonly, the outer surface of the cables and shaft are cooled with room-temperature fluid or carbon dioxide to prevent unwanted thermal damage.⁷ Currently, there are six MWA systems commercially available in the United States, that use either a 915-MHz generator (Evident, Covidien, Mansfield, MA; MicrothermX, BSD Medical, Salt Lake City, UT; AVecure, Medwaves, San Diego, CA) or a 2450-MHz generator (Certus 140, Neuwave, Madison, WI; Amica, Hospital Service, Rome, Italy; Acculis MTA, Microsulis, Hampshire, England).⁹

Unlike radiofrequency wave propagation, microwaves are not limited by charred tissue. Therefore, tissue temperatures can be elevated to very high levels without impairing microwave energy deposition. This leads to several benefits of MWA over RFA of liver. MWA provides (1) much faster treatment times than RFA; (2) larger volumes of tissue necrosis with a given application as compared with RFA; (3) cell death of tissue up to and around large vessels, which are abundant in liver, whereas cooler temperatures involved in RFA cannot overcome these heat sinks; and (4) coagulation of vessels up to 5 mm in diameter, whereas RFA is ineffective for sealing vessels greater than 3 mm in diameter.⁴⁻⁸ Compared with RFA, MWA produces higher temperature burns and is faster and more effective hemostatically and oncologically.⁴⁻⁸

Technique

The goals of precoagulation of a transection margin include (1) ablating a margin that will facilitate hemostatic resection, (2) providing a margin wide enough to address

Abbreviations: MWA, microwave ablation; RFA, radiofrequency ablation.

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Figure 1 Example of liver resection after thermal ablation of the parenchymal transection margin using microwave energy through two in-line antennas (A) Preoperative CT reveals 3.5 cm hepatocellular carcinoma near dome of right hepatic lobe of a Child B cirrhotic who is not a transplant candidate (segments 6 and 7). (B) For this particular procedure, two MWA antennas are attached for in-line, simultaneous coagulation, which is faster than using a single antenna (In this case, the Certus 140 2450 MHz generator with 17-g LK15 antennas are used, employing 20 second ablations at 95 W, Neuwave, Madison, WI). (C) Precoagulation starts with successive punctures of the hepatic capsule, approximately 1 cm deep, to create a superficial zone of necrosis. (D) Subsequent punctures are performed, approximately 2 cm deep. The punctures are kept approximately 1 cm apart to achieve some overlap of the areas being coagulated. It is important to apply the ablations in planar fashion, using parallel puncture tracks. (E) The first layer is transected with scissors. The plane of division is midway in the necrosis zone, leaving some hemostatic ablated margin in situ. (F) After further MWA and transection the lesion is undermined. The margins farthest from major vasculature are ablated and transected first, then the more central margins. The precoagulation plane is curved as appropriate for this lesion. (G) The resection bed encompasses an additional margin of ablated tissue and is hemostatic. Large vessels and ducts are tied, sewn or clipped. (H) The circular shaped hepatic dome specimen (7 x 5 cm) is assessed after removal to ensure there is an adequate margin. It includes the 3.5 cm tumor surrounded throughout by a margin of ablated parenchyma, 1-2 cm away from the tumor.

oncologic concerns, (3) avoiding excessive parenchymal damage to the hepatic remnant, (4) protecting against injury to critical structures, and (5) creating the ablation margin expeditiously.

The attached video, and Figures 1 and 2, depict different liver resection cases employing MWA of the parenchymal transection margins and highlight many of the procedural techniques described below.

Patients should undergo careful preoperative assessment, including computed tomography or magnetic resonance

imaging of the liver. Precoagulation can be performed during open surgery or laparoscopically. The liver should be adequately mobilized for exposure. Blood loss is minimized by reducing the central venous pressure. Pringle's maneuver is rarely required when a resection margin is precoagulated, but access to the porta hepatis should still be obtained prior to transection. Intraoperative ultrasonography and manual palpation are performed to delineate the lesion and mark the resection margin approximately 2 cm from the lesion. Such marking should be done prior to commencing

Figure 2 Example of liver resection after thermal ablation of the parenchymal transection margin using microwave energy through a single antenna (A) This image depicts resection of hepatic segment 6 with portions of 5 and 7, for a patient with three colorectal carcinoma metastases in the resection zone, and underlying heavy chemotherapy-associated steatohepatitis. (B) For this particular procedure, a single MWA antenna is used (in this case, the 17-g CertuSurg antenna is used, employing 15 second ablations at 75 W, Neuwave, Madison, WI). The handle includes a finger-switch that controls power delivery. This antenna produces rapid, focal areas of coagulation that quickly encompass the probe tip without extensive lateral ablation; each application produces a coagulation zone approximately 2 cm long and 2 cm wide). (C) The resection bed is thoroughly hemostatic. (D) This image shows an example of a MWA generator (in this case, the Certus 140 2450 MHz generator, Neuwave, Madison, WI, was used).

ablation, which will cause hardening of parenchyma and difficulty palpating the tumor. Also, ablation causes severe artifact on ultrasonography, decreasing subsequent imaging accuracy.

It is useful to have a manufacturer's specialist available during surgery to assist with the device and to help select the most appropriate antenna(s), power level, and burn durations. Ablations can be performed using a single antenna or an array of multiple, in-line antennas simultaneously to precoagulate the margin faster. Precoagulation starts with successive punctures of the liver, approximately 1 cm deep, to create a superficial zone of necrosis. Subsequent punctures are performed, approximately 2-4 cm deep, depending on the particular antenna. The

punctures should be kept approximately 1 cm apart to achieve some overlap of the areas being coagulated. It is important to apply the ablations in a planar fashion, using parallel puncture tracks. The margins farthest from major vasculature are ablated first, then the more central margins. The precoagulation plane should be curved as appropriate for a particular lesion. Energy is applied in applications of 10-20 seconds, depending on the particular case. Power-level selection also depends on the particular case. The time and power settings may be adjusted to ensure hemostasis. Oozing is typically controlled by additional tissue puncture for nearby ablation.

Although thermal ablation distorts ultrasound imagery, sonography is still used to help anticipate large vessels that

require longer-duration ablations, ligation, or preservation. Ultrasonography can also help to delineate the width of the developing ablation zone in a particular liver by revealing echogenicity and nitrogen outgassing in the burn zone. It is important to avoid overablation, an increased risk with steatotic livers, which are prone to conducting heat, and with cirrhotic livers, which are at higher risk for postoperative hepatic decompensation. Tissue temperatures during ablation can be measured with a separate thermal couple, which most devices include. During MWA, the specimen can become very hot, so the surgical team needs to take care to avoid sustaining an accidental burn.

Parenchymal transection may be performed with scissors, a knife, or more sophisticated dissectors. The plane of division should be midway in the necrosis zone, leaving some hemostatic ablated margin *in situ*. Large vessels and ducts are tied, sewn, or clipped. The specimen can be assessed after removal to ensure there is an adequate margin. It is important to convey to the pathologist and subsequently to radiologists that MWA was used, as it affects the histologic and radiologic interpretations. Unwary radiologists may misinterpret follow-up imaging to reveal tumor progression rather than a precoagulation zone.

Results

It has been shown that liver resection after thermal ablation of the parenchymal transection margin is one effective way to decrease blood loss, blood transfusion, hilar clamping, operative time, hospital stay, and hepatic decompensation.²⁻⁸ In certain cases, this technique markedly facilitates parenchymal sparing. For example, cirrhotic and steatotic livers can be transected after precoagulation, without Pringle's maneuver. Right dome tumors can be easily removed after precoagulation of a curvilinear margin that approximates the lesion, without Pringle's maneuver. Other dissecting and stapling techniques are less effective in the face of cirrhosis, steatosis, or circular-shaped resections.

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Thermal precoagulation carries a risk of biliary leak and perihepatic abscess, just as low as with other hepatic resection techniques.^{2-5,10-12} Precoagulation rarely can result in inadvertent burning of extrahepatic structures, directly by the device or indirectly by transmission of heat through the liver.⁴ It can yield a damaged hepatic remnant by coagulation of more liver than intended or by unintentional thrombosis of major intrahepatic vasculature. The exact incidence of these complications is unknown but extremely low; nonetheless, these should be heightened concerns when ablating a patient with cirrhosis, steatosis, or a lesion near major vasculature, particularly when MWA, which is more powerful than RFA, is used.⁴ Although the power, speed, and effectiveness of MWA are assets, overzealous use, even of relatively short duration, can cause immense damage. Another concern about precoagulation, particularly when the ablation margin is kept near the tumor, is the potential risk of marginal recurrence of disease. Theoretically, the greater heat intensity generated by MWA compared with other thermal modalities should decrease the risk of recurrence.⁴ Currently, there are no data on tumor recurrence after precoagulation techniques.

In conclusion, MWA of the hepatic transection margin is a relatively new, very useful technique that spares blood loss, obviates the need for hilar clamping, and facilitates dissection, particularly in patients with cirrhosis, steatosis, or circular-shaped resections such as of the hepatic dome. MWA rapidly deploys powerful thermal energy, can cause significant morbidity if misused, and should be used for hepatic precoagulation only by experienced hepatobiliary surgeons. Comparative studies of MWA, RFA, and other hepatic resection techniques would shed additional light on the risks, benefits, and role of these treatment options.

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