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HPB ultrasound guidance techniques - Targeting

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ABSTRACT

Ultrasound is an indispensable tool for intraoperative assessment and treatment of hepatopancreatobiliary pathology. As minimally invasive approaches to HPB surgery continue to expand and the benefits of parenchymal-sparing liver surgery are increasingly appreciated, skillful targeting will play an even bigger role in HPB surgical practice. Techniques for intraoperative targeting of liver lesions for the purposes of biopsy and ablation, particularly in the laparoscopic setting, are the focus of this chapter.

Current evidence supports the use of ablation for a variety of liver lesions including hepatocellular carcinoma and metastatic colorectal cancer, particularly for smaller lesions.

Successful targeting requires optimization of patient position and port placement. When targeting multiple lesions, thoughtful treatment sequencing is critical to maintaining visualization and optimizing outcomes.

Introduction

Ultrasound (US) is an essential adjunct in the repertoire of the modern hepatopancreatobiliary (HPB) surgeon, not only as a diagnostic tool but also in providing critical visualization for the delivery of therapy. Since the overwhelming majority of lesions requiring targeting are malignant, the ability to target a lesion accurately is the ability to deliver precise cancer care.

The utility of ultrasound transcends surgical approach, and devices are available for use in the open, laparoscopic, or robotic settings. This chapter will specifically address considerations for using ultrasound to target lesions within the liver either for the purpose of biopsy and/or treatment with ablative technologies. Since laparoscopic ablation is the predominant surgical approach, this chapter will focus on technical considerations for the laparoscopic method.

For the purposes of clarity, use of the word ‘probe’ will refer to an ablation probe (radiofrequency [RFA], microwave, irreversible electroporation, etc.), and ‘transducer’ will be utilized for ultrasound.

Indications and contraindications

At its inception, microwave ablation (MWA) was predominantly utilized for patients who were otherwise not a candidate for resection, based on extent of disease or medical comorbidities, or for palliative reduction of tumor burden. However, the role of ablation continues to expand for the treatment of patients with both primary and metastatic lesions of the liver, as some of the advantages of ablation have been augmented by technological advances. Specific factors that have facilitated this development include improvements in energy delivery and consistency, refinement of ultrasound image quality, and dissemination of US-guidance and targeting techniques. Potential advantages of ablation in comparison to resection include the ability to maximize sparing of normal hepatic parenchyma, particularly for deep or central lesions, the ability to repeat the procedure multiple times, and an overall lower morbidity. For these reasons, ablation is particularly well-suited for patients who are at high risk for regional recurrence in the liver who may require additional operative intervention. This includes patients with colorectal liver metastases, hepatocellular carcinoma (HCC) arising in the setting of cirrhosis, as well as less common tumors such as metastases from neuroendocrine, breast, ovarian, endometrial, testicular, and other primary cancers.

The scope of pathology amenable to ablation includes any malignant process involving the liver, whether primary or metastatic, as well as lesions that pose a risk for bleeding or malignant degeneration, such as hepatic adenoma.

Ultrasound-guided ablation can be performed for curative or palliative intent, or in the case of hepatocellular carcinoma, as a method of bridging to liver transplantation. Ablation can also be used to achieve

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hemostasis in cases of a ruptured hepatic adenoma, often in conjunction with endovascular embolization by interventional radiology.

Guidelines published by the European Association for the Study of the Liver (EASL) utilizing the Barcelona Clinic Liver Cancer (BCLC) staging system recommend ablation for patients with early-stage HCC who are not candidates for liver transplantation [1]. Beyond this, ablation can be used for tumor debulking and palliation of symptoms from tumor mass effect or capsular stretching.

Specific indications for a surgical rather than percutaneous approach include concomitant surgical procedure such as combined liver resection or cholecystectomy. Nonetheless, a surgical approach also offers several advantages for all ablation candidates. First, laparoscopy can lead to more accurate disease staging. Peritoneal disease and liver surface lesions are more easily detected by laparoscopy compared to cross-sectional imaging. Furthermore, laparoscopic liver ultrasound may reveal additional lesions not previously seen. With a surgical approach, the ablation probe can be placed into the liver under direct visualization, avoiding any risk for damaging surrounding viscera. Intrahepatic structures including portal pedicles can be visualized by ultrasound in real time, as opposed to static CT images. Additionally, procedural complications such as bleeding are generally immediately detectable and can be treated directly in the laparoscopic setting, but may be occult with a percutaneous approach. Lesions at the dome of the liver can be treated without the need to traverse the thoracic cavity.

Absolute contraindications to microwave ablation of the liver for curative intent include vascular invasion, active decompensated cirrhosis, and tumor volume exceeding 70 % of the liver. Relative contraindications include coagulopathy (PT $>$ 30 s), platelet count $<$ 30,000, high extrahepatic tumor burden, and close proximity to major biliary structures, portal pedicles or hepatic veins.

Patient selection is critical for success. Cirrhotic patients are especially challenging because the risk of liver failure must be assessed and mitigated. In general, Child class A and B patients are tolerant of ablation with a low risk of hepatic decompensation. Child class C patients should be approached with caution. Often, the patient's physiologic response to transarterial therapy (i.e. TACE or TARE) can give clues as to how tenuous their liver function is.

Current evidence

Much of the current evidence on surgical liver ablation is comprised of single-institution case series studies [1–5]. These studies are heterogenous in terms of surgical approach (minimally invasive, open, and combination with liver resection), disease pathology (hepatocellular carcinoma, colorectal liver metastasis, neuroendocrine liver metastasis, other), ablation system used, definition of recurrence, and duration of followup.

Nonetheless, studies of surgical MWA uniformly conclude that ablation is both safe and efficacious. Short term outcomes for MWA include a relatively short length of stay, most commonly 1–2 days, as well as an acceptable complication rate ranging from 7 to 35.6 % [1–4]. Complication severity was uniformly low, typically well below 10 % for those studies restricted to ablation only; studies reporting high complication rates tended to include patients who underwent concomitant hepatectomy. Compared to liver resection, MWA appears to be associated with lower estimated blood loss, a lower complication rate and severity, and a shorter hospital length of stay [2].

Regarding long term outcomes, data are less conclusive. For patients with colorectal liver metastases, Tinguely et al. showed that MWA has equivalent survival outcomes to resection in a propensity-match analysis [3].

With respect to HCC, studies comparing surgical resection to MWA have yielded mixed results. A meta-analysis performed by Yang et al. demonstrated lower disease-free survival but improved overall survival for patients with HCC undergoing MWA vs. resection [2]. Wang et al. had similar findings in their cohort of patients with a solitary HCC of 3–5 cm [4]. Disease free survival was improved with resection, but overall survival was equivalent. In contrast to these studies, a meta-analysis performed by Glassberg et al. concluded that disease-free and overall survival was significantly lower for patients undergoing MWA vs. liver resection [5]. Given the inherent selection bias acknowledged in these studies that likely offers resection preferentially for technically easier and healthier patients, it is remarkable that survival after MWA may be equivalent to resection.

Technique

Once the decision has been made to perform an ablation, successful targeting starts with preoperative planning. Specific considerations for patient preparation include having any necessary blood products available for transfusion, which is particularly relevant for cirrhotic patients undergoing ablation of hepatocellular carcinoma. We routinely crossmatch blood, fresh frozen plasma and platelets for known cirrhotic patients who have a history of coagulopathy or thrombocytopenia.

Patient positioning is critical to successfully targeting a lesion for ablation or biopsy. Optimizing ergonomics facilitates more accurate targeting. For this reason, we position patients with posterior right-sided lesions in a partial left lateral decubitus position (Fig. 1). To facilitate exposure, we position the patient with the midpoint of the distance between the inferior costal margin and the anterior superior iliac spine in alignment with the break in the bed. Placing the operating table in slight extension then maximizes the potential abdominal surface area for introducing trocars, ablation probes or biopsy needles.

Equipment and room setup

The operating room should be set up with monitors to display preoperative images, ideally immediately adjacent to the laparoscopic and ultrasonographic projections. The surgeon stands on the patient's left side, except in rare cases of a lesion at the extreme lateral portion of the left lateral section, or in a patient with situs inversus. The laparoscopic and ultrasound monitors should be positioned at eye level or slightly below, above the patient's right shoulder, and the monitors should be as close to one another as feasible in order to facilitate rapid correlation of US images to the anatomic location in the patient. For most surgeons, transducer orientation is most intuitive when the needle trajectory is towards the target lesion from the surgeon's perspective and matches the orientation of the needle as visualized by ultrasound. Most commonly, the surgeon (standing on the patient's left) will be advancing the ablation probe from left to right in relation to the surgeon's perspective. In this case, for many operators it would be most intuitive to have the probe entering the ultrasound field from screen left to screen right. Fig. 2 illustrates the surgeon, monitor, and transducer orientation as described above.

In depth familiarity with the ultrasound and ablation equipment is essential. Accurate targeting can only be achieved by creating ideal conditions for visualization of the tumor within the mind's eye of the operator. The surgeon must be familiar with modulating US frequency, utilizing color and doppler modes, adjusting gain and time-gain compensation, depth and scale, measuring the size of lesions, utilizing the needle guide, inverting the ultrasound image, and freezing and saving images. Educating staff regarding the operation of the ultrasound is essential for efficiency.

Open targeting

One of the major goals of targeting is to maximize the degrees of freedom of the ablation probe or biopsy needle. In other words, it is ideal to maximize the number of potential angles for approaching the lesion of interest. Approaching a liver lesion from the superior, right lateral, and posterior aspects are generally precluded by the thoracic cavity, ribs and chest wall, and retroperitoneum, respectively. Therefore, the window of

Fig. 1. The patient is placed in a partial left lateral decubitus position. This is accomplished with one rolled sheet on the patients left and two rolled sheets under the patient's right side. The bed is flexed to maximize the distance between the right costal margin and the right anterior superior iliac spine.

approach for targeting liver lesions is relatively narrow, limited principally to anterior/inferior approaches, with some ability to angle the probe either to the right or left in the coronal plane. Perhaps this is best illustrated by comparing potential angles of approach using CT scan images. Figs. 3–5 are CT scan images in the coronal, sagittal and axial projections for a segment 8 lesion at the dome of the liver. Viable angles of approach are show in green and angles that are precluded by the ribcage or other structures are shown in red. Note that the angle of approach is quite limited for lesions in this anatomic location. Conversely, Figs. 6–8 show CT scan images in the same projections for a lesion located in segment 5. Note that the area available for targeting is much larger than for the segment 8 lesion. Potential approach angles for targeting a lesion are determined in large part by the location of the lesion. Nonetheless, the volume of space available for introducing a probe for targeting can be modified. Mobilizing the liver may allow a lesion high in the dome of the liver to be brought inferiorly. This will increase potential angles of approach in the coronal plane, which is mostly limited by the costal margin. Likewise, bringing a posterior lesion more anteriorly can increase probe freedom in the sagittal plane.

Doing so will facilitate choosing the most direct and ergonomic angle of approach, optimizing the chances of success. Typically, we utilize the T-transducer for open ablation, although transducer selection is best made after considering which transducer and hand position will maximize the degrees of freedom for the ablation probe.

The T-transducer is held with the non-dominant hand and is positioned in such a way as to maximize the degrees of freedom for the dominant hand, which will deliver the probe or needle. The middle finger overlies the far aspect of the transducer, and the index finger overlies the near aspect of the transducer (see Fig. 9), where the ablation probe or biopsy needle will first be visualized in the ultrasound plane. In most cases, the probe will approach the patient's liver from inferior to superior, and will enter the anterior surface of the liver. Thus, to perform an in-plane ablation, the transducer must also be oriented in the sagittal plane.

As the surgeon scans over the lesion, the goal is to create a mental map of where the lesion is in space, so that this mental image can be transposed and visualized within the patient's liver. Placing the middle finger, which overlies the far aspect of the transducer, immediately over the target lesion permits a better sense of the location of the lesion in space, and provides an external reference point for the desired probe trajectory (Fig. 9). This facilitates visualization of the lesion in three-dimensional space and maximizes the probability that the probe will hit the target accurately.

The ideal angle of approach is in the same plane as the ultrasound transducer (i.e. in-plane targeting), with the lesion positioned at the far aspect of the ultrasound image, thereby maximizing the length of needle that can be visualized as it approaches the target lesion (see Fig. 10). Out-of-plane targeting may occasionally be necessary, but this makes the task significantly more difficult, since the portion of the ablation probe that can be seen is much smaller than with an in-plane approach (see Fig. 11).

Laparoscopic targeting

Laparoscopic targeting is more technically challenging than open targeting. First, as with all laparoscopic procedures, visualization is in two dimensions and depth perception is limited. Second, the distance from the lesion is increased, causing small changes in angle of approach to lead to more significant deviations in probe location by the time it reaches the intended target. Third, the abdominal wall represents an additional point of fixation that limits the freedom of the ablation probe or biopsy needle to adjust the angle of approach. Additionally, the laparoscopic ultrasound transducer may need to be flexed (especially for superior lesions near the dome of the liver) or inverted (for posterior lesions) which can be disorienting for the operator.

As with open targeting, the goal of the targeting setup is to provide the surgeon with the most accurate visualization of the lesion in three-dimensional space. A target that can be seen directly (i.e. a surface target) and felt directly (i.e. a hand-assisted procedure) is the scenario in which the surgeon would have the best understanding of the target's location. In the laparoscopic setting however, generally the target can neither be seen directly or felt. In these cases, the surgeon relies upon ultrasound as an adjunct to visualize the lesion. When performing laparoscopic liver ultrasound, it is usually most intuitive for the surgeon

Fig. 2. The surgeon stands on the left side of the patient and the assistant on the right. The US transducer is held in the surgeon's left hand, and monitors are positioned across the table. For most surgeons it is intuitive to orient the transducer such that screen left represents inferior and screen right represents superior.

to place the transducer on the anterior surface of the liver and visualize the target from that approach. Moving the target closer to the anterior abdominal wall will aid in the visualization of the location of the target. This can be accomplished by mobilizing the liver and placing the patient in reverse Trendelenburg to allow the liver to move inferiorly. Sponges can also be introduced into the abdomen and packed above or behind the liver to accomplish this as well.

Port placement

In most cases we prefer to access the abdomen via open Hasson technique in the location selected for the ultrasound transducer. For right-sided lesions, our convention is to position this initial 12 mm trocar in the right midclavicular line, usually above the umbilicus. How superior or inferior this port is placed in the midclavicular line is dictated by patient body habitus, liver size, and the position of the liver lesion along this axis. For left-sided lesions, the 12 mm port is placed in the midline, usually in a more inferior location because of the anterior anatomic location of the left liver as compared to the right. Figs. 12–14 depict our typical port placement for lesions in the right lateral liver, right superior liver, and left liver.

A second port is placed to facilitate the tasks of adhesiolysis, liver mobilization, cauterization of ablation tracks, introduction of topical hemostatics, and placement of radio-opaque markers to aid radiology in the interpretation of post-ablation cross-sectional imaging studies.

After performing any required adhesiolysis, the liver is mobilized if necessary. Typically, it is not necessary to divide the diaphragmatic attachments of the right and left liver. For high lateral right-sided lesion in segment 7, mobilization can be helpful to decrease the distance from the skin to the lesion. For posterior lesions, it may be useful to divide any posterior attachments so that the liver can be freely elevated off the retroperitoneum. Placing sponges posterior to the liver can help elevate it and protect the retroperitoneum from ablation energy. Division of the falciform ligament is usually not necessary, but may be helpful, particularly for lesions high in segments 2 or 4a. Sponges can be introduced and placed between the liver and the diaphragm or hepatic flexure of the colon to shield them from ablation energy. Introducing water or saline near the ablation site can not only improve the quality of the ultrasound image, but also protect nearby structures by absorbing ablation energy.

After introducing the US transducer into the abdomen, the first step is to perform a thorough survey of the liver. The goal is to identify the lesion of interest and neighboring structures and assess for any additional lesions that were not apparent on preoperative imaging. Ultrasound depth should be adjusted to reflect the shape of the liver; naturally the right liver will require more depth than the left. A systematic assessment should include imaging of the porta hepatis, tracking of the portal pedicles, and identification of the hepatic veins. A complete ultrasound of the liver can be accomplished either by tracing portal pedicles from the hilum to the periphery (Fig. 15), or by sweeping the transducer back and forth across the liver in overlapping rows ("lawnmower" method) (Fig. 16).

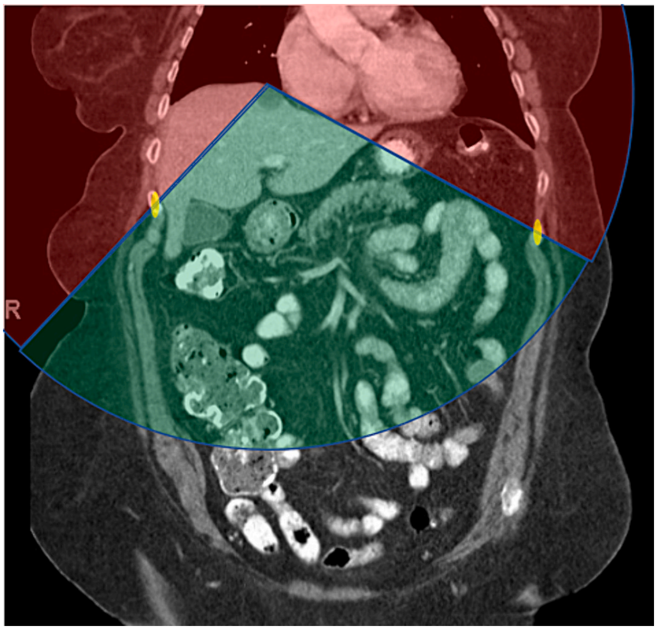

Fig. 3. A coronal CT scan showing a segment 8 liver lesion. Potential angles of approach are highlighted in green, limited by the lower border of the ribcage (highlighted in yellow). Red regions are non-viable angles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

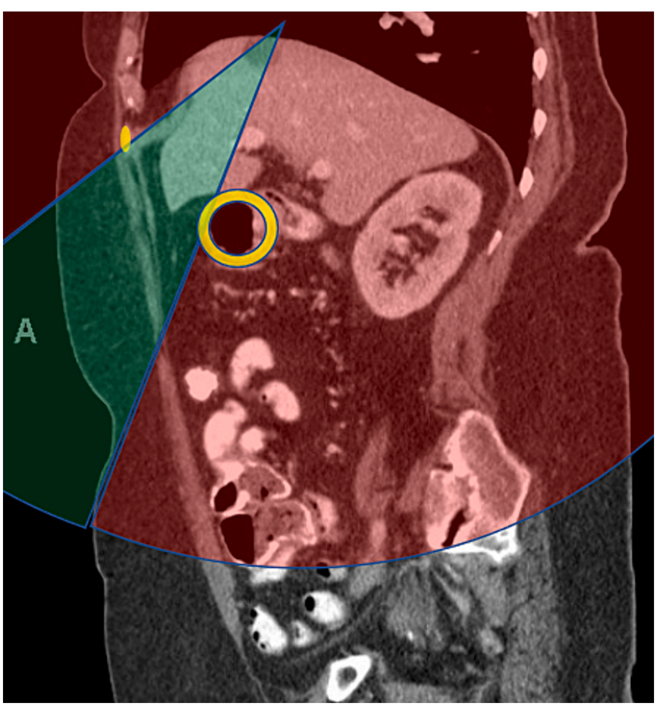

Fig. 4. Sagittal projection of the same lesion as Fig. 3. Note the narrow window between the costal margin anteriorly and the transverse colon.

Hand positioning and probe placement

The laparoscopic ultrasound transducer is held in the non-dominant hand. Our general approach is to lock the left-right flexion button in the neutral position and unlock the "up-down" extension-flexion button. This configuration enables the operator to maintain tissue apposition by flexing or extending the tip of the transducer. It also permits the surgeon to "scroll through" an area or lesion of interest by continuously

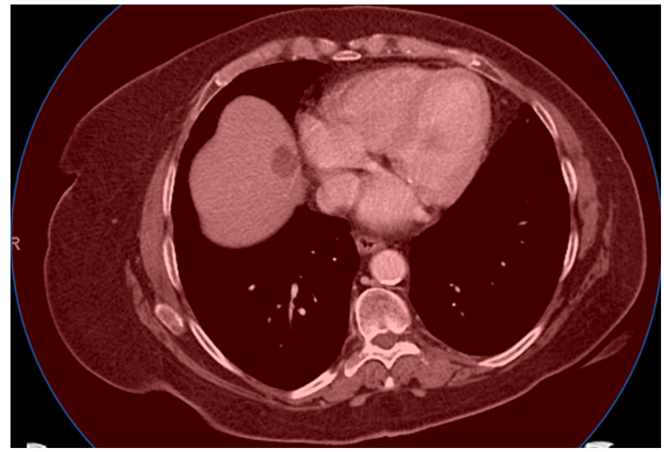

Fig. 5. Segment 8 lesion from the same patient as Figs. 3 and 4. Lesions in the dome of the liver are not accessible in the axial plane due to the thoracic cavity.

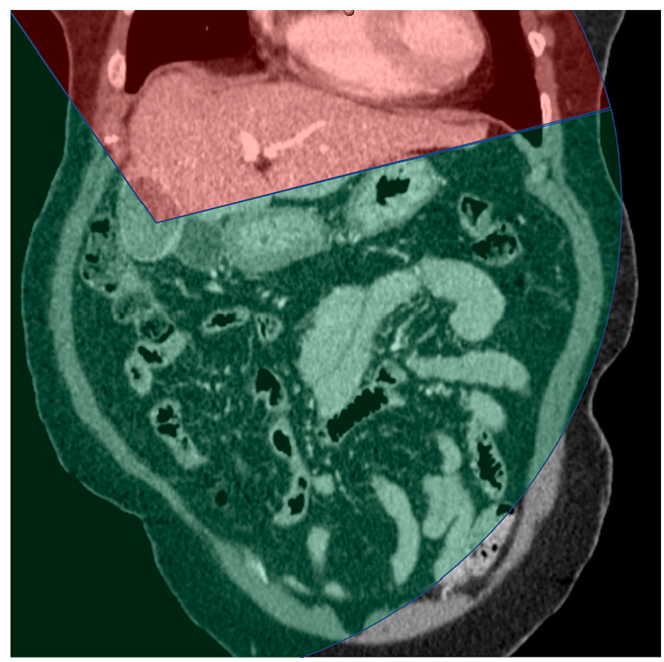

Fig. 6. Coronal CT projection of a patient with a segment 5 liver lesion. The gallbladder lies just medial to the lesion. Note the comparatively wider angle of potential approach compared to Fig. 3.

supinating and pronating the hand controlling the ultrasound transducer (i.e. rotating the ultrasound around its axis).

As with open targeting, the lesion is positioned so it lies below the distal tip of the laparoscopic transducer. At this point, the surgeon should be able to see the lesion in two dimensions on the ultrasound image. With continual, alternating, short supination and pronation movements of the wrist, the extent of the target lesion in the plane perpendicular to the ultrasound plane can be visualized. Alternatively, the ultrasound tip could be flexed 90 degrees to the right or left, but this is less practical and intuitive. Once the surgeon has a good sense of the position of the lesion in three-dimensional space, the liver is scanned along the planned needle or probe trajectory to ensure there are no intervening structures that should be avoided, such as major portal pedicles or veins.

The probe is introduced into the abdominal cavity through a small, 2 mm skin incision. For right-sided lesions, probe passage through the skin approximately 2 to 3 cm below the right costal margin usually provides

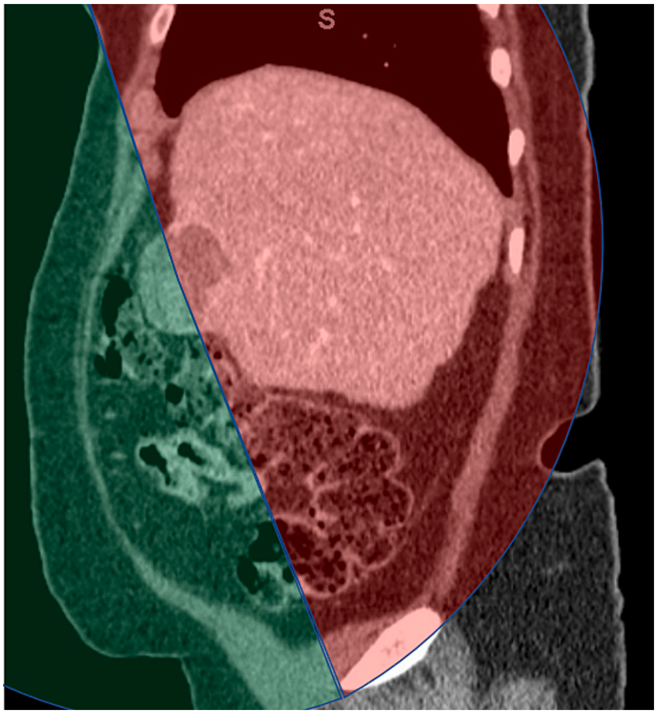

Fig. 7. A sagittal projection of the same lesion seen in Fig. 6. Note the wide angle of potential approach compared to the lesion depicted in Fig. 4.

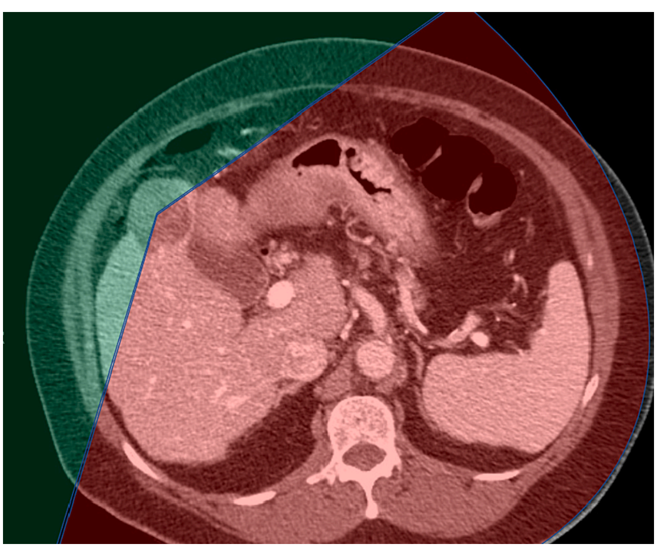

Fig. 8. An axial projection of the lesion depicted in Figs. 6 and 7. Note that there are viable angles of approach in this plane, as opposed to the lesion depicted in Fig. 5.

an appropriate trajectory (Fig. 12). Lesions located in the superior aspect of the right liver may need to be approached by introducing the probe through the epigastrium (Fig. 13). For left-sided lesions, we move the 10 mm port to the umbilius, and the ablation probe is typically introduced through the epigastrium or medial left costal margin (Fig. 14). If the probe is too close to the costal margin, it will lever against the inferior aspect of the rib and this may bend the probe or biopsy needle. Patients with a thick abdominal wall may be especially prone to this.

The needle is advanced towards the lesion of interest, in the plane of the ultrasound image. With the laparoscopic approach, a pure 'in-plane' probe trajectory is often not practical. This is because perfect alignment of the laparoscopic transducer with the ablation probe may leave little

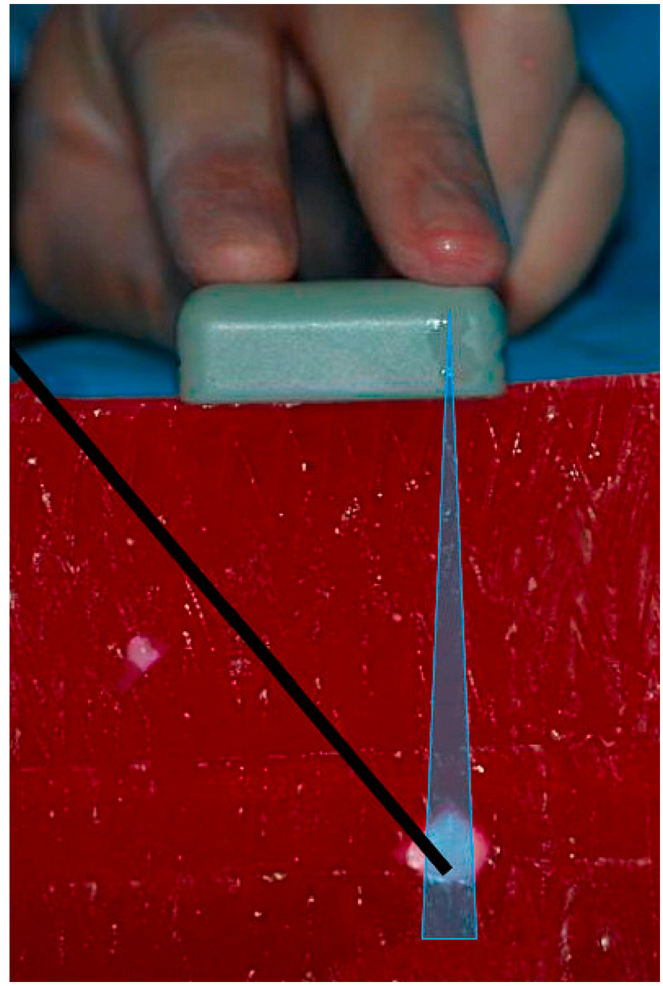

Fig. 9. Positioning the target lesion beneath the middle finger provides an external reference point for the lesion's location in space and also maximizes the length of the needle that can be seen approaching the lesion. Figure reprinted with permission [22].

room for the surgeon's hands to manipulate each one freely. Additionally, perfect alignment may obscure the surgeon's view of the ablation probe. For this reason, we commonly utilize a 'step-off' technique, in which the transducer moves slightly lateral to the probe trajectory and rotates back to the target lesion (Fig. 17). Ideally, the liver surface is pierced and traversed for only a short distance before the probe enters the plane of the ultrasound. More challenging lesions (often superior or posterior targets) may require the probe to pass through the liver for a long distance before it enters the ultrasound image. Regardless, prior to penetrating the liver surface, ultrasound is used to ensure no major structures lie in the path of the anticipated probe trajectory. Having created a mental map of the lesion location with respect to the laparoscopic view, the probe is advanced with proprioceptive intuition along the visualized trajectory until it can be seen in the ultrasound image. At this point, as before, smooth, alternating pronation-supination wrist rotations are used to identify and guide the ablation probe to the intended location. If the surgeon is not satisfied with probe placement, using the ultrasound to identify the location of the probe in relation to the lesion is essential to correcting the probe trajectory.

Ablation execution

Currently available ablation probes typically generate a microwave field that is centered at the shaft of the probe about 1–2 cm from its tip. Practically, this means that the tip of the probe should generally be

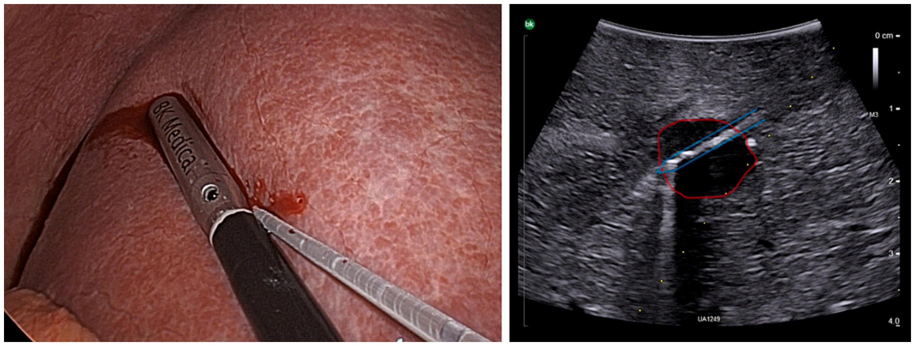

Fig. 10. Depiction of laparoscopic in-plane targeting. Note in the left image that the Ultrasound Transducer and Ablation Probe are oriented approximately in parallel. The corresponding ultrasound image on the right shows the ablation probe (outlined in blue) within the target (outlined in red). Note that the probe can be seen for much of its length. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

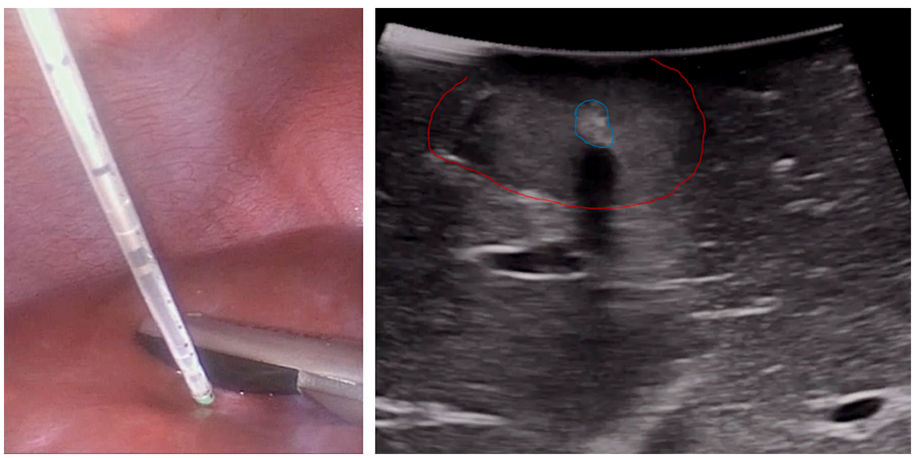

Fig. 11. Depiction of laparoscopic out-of-plane targeting. In this case a surface target is treated with out-of-place targeting. Note in the left image that the US transducer and the ablation probe are oriented in perpendicular. The corresponding ultrasound image on the right shows the ablation probe in cross-section (outlined in blue) within the target (outlined in red). Compared to in-plane targeting, the portion of the probe that is visualized is much smaller and hence more challenging to visualize. Note the posterior shadowing deep to the ablation probe. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

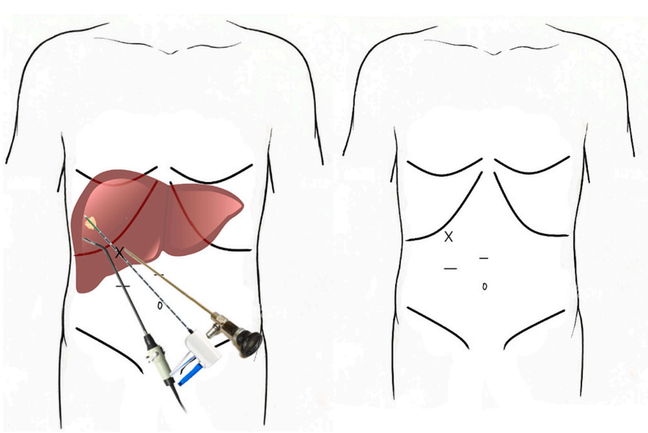

Fig. 12. Schematic showing port placement and instrument locations for a lateral right sided ablation. The image on the left depicts the placement and relationship of the laparoscope, ultrasound, and ablation probe. On the right, the sites of skin incision are shown. The 'X' is the site of a 2–3 mm skin incision for passing the ablation probe percutaneously. The longer and shorter horizontal lines depict the sites for 12 mm and 5 mm trocars, respectively.

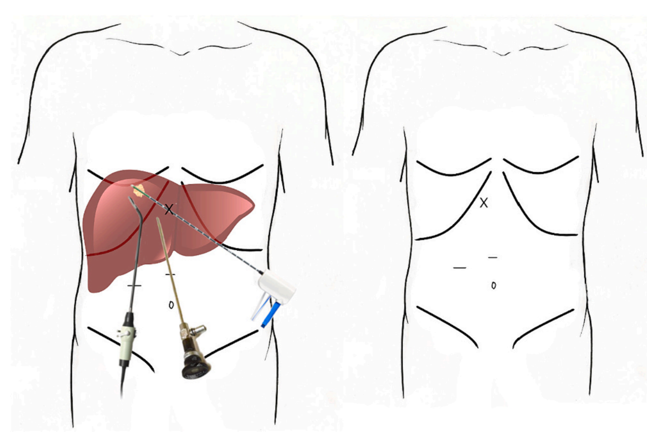

Fig. 13. Schematic showing port placement and instrument locations for a medial or superior right lesion or central lesion. The image on the left depicts the placement and relationship of the laparoscope, ultrasound, and ablation probe. On the right, the sites of skin incision are shown. The 'X' is the site of a 2–3 mm skin incision for passing the ablation probe percutaneously. The longer and shorter horizontal lines depict the sites for 12 mm and 5 mm trocars, respectively. The port placement is identical for other right sided lesions, but the site of skin entry of the ablation probe is in the epigastrium.

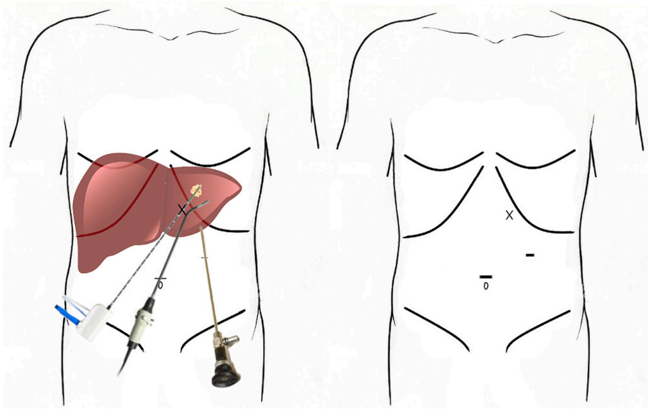

Fig. 14. Schematic showing port placement and instrument locations for a left-sided lesion. The image on the left depicts the placement and relationship of the laparoscope, ultrasound, and ablation probe. On the right, the sites of skin incision are shown. The 'X' is the site of a 2–3 mm skin incision for passing the ablation probe percutaneously. The longer and shorter horizontal lines depict the sites for 12 mm and 5 mm trocars, respectively.

closer to the far side of the lesion (usually the posterior or superior aspect) in order to properly align the center of the tumor with the center of the ablation zone (Fig. 18). The exact location of the center of microwave energy emission along the shaft of the ablation probe varies among manufacturer; consult your device manufacturer to determine the specifications for the device you are using. If the target lesion is small enough to permit a single application of microwave energy, the center of the lesion is targeted. Some surgeons prefer a slightly off-center alignment, such that there is greater coverage of the deep or central aspect of the lesion, which theoretically provides better coverage of the pedicle supplying blood flow to the lesion. Fig. 19 demonstrates a small lesion that would be amenable to a single application of microwave energy. In this case, the surgeon attempts to superimpose the perceived center of the microwave energy with the center of the target lesion. When overlapping zones of ablation are required for a particular lesion, it is generally most prudent to ablate the deepest aspect of the lesion (deepest with respect to the ultrasound image), since ablation will cause gas formation in the tissue and alter its ultrasonographic characteristics, making it much more difficult to see a lesion after it has been ablated. Likewise, when multiple lesions require ablation, this phenomenon should be taken into account to ensure that the first ablation does not obscure the view of any subsequent target lesions. A minimum ablation margin of 5 mm is desirable. Utilization of the color mode on the ultrasound permits visualization of the microwave near field and may aid in estimating the zone of adequately ablated tissue (Fig. 20). After the target lesion has been ablated, track ablation can be performed, which can aid in hemostasis and theoretically prevents tumor seeding along it. Topical hemostatic agents can be injected into the ablation track, if necessary. To aid in the interpretation of subsequent cross-sectional imaging studies, we deploy metallic clips into the target lesion immediately after ablation.

Followup

Clinical and cross-sectional imaging followup should be performed after hepatic ablation. We obtain cross-sectional imaging, typically triphasic liver CT, one month after ablation to assess for evidence of incomplete ablation and for a postoperative baseline. This is followed by radiographic surveillance every 3–4 months for the first two years, particularly for patients at high risk for hepatic recurrence.

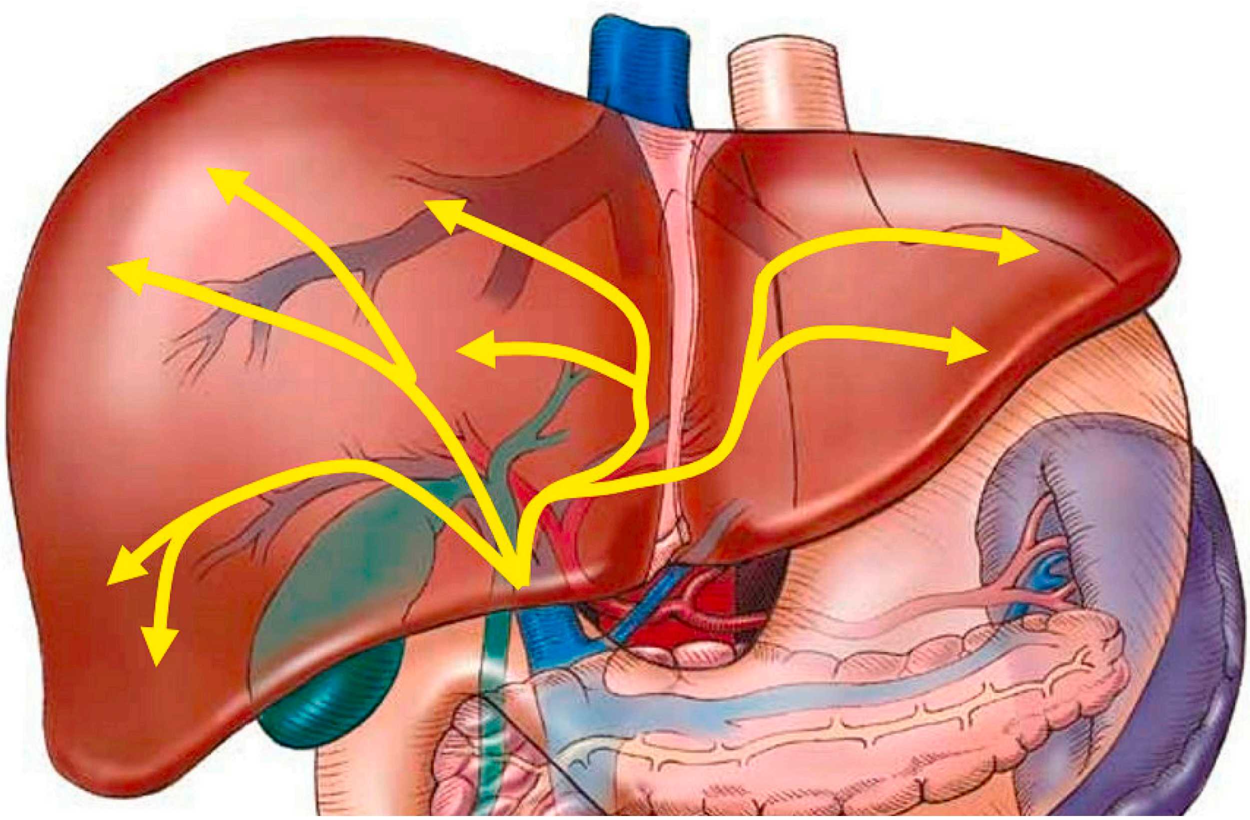

Fig. 15. One method to ensure that a complete liver has been performed is to trace the portal pedicles from the hilum to the periphery. Figure reprinted with permission [22].

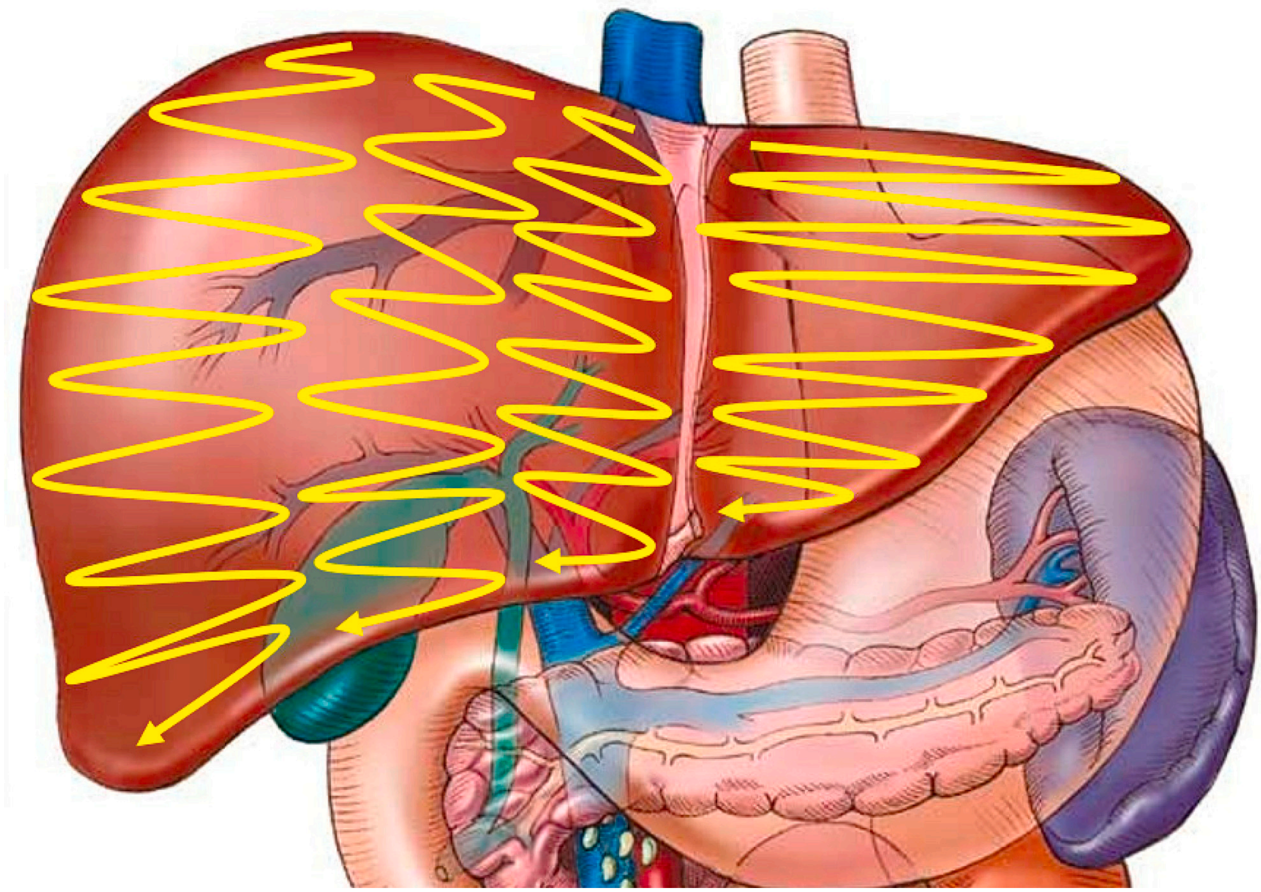

Fig. 16. An alternative method to pedicle tracking is to scan the entire liver surface systematically – the 'lawnmower' method. Figure reprinted with permission [22].

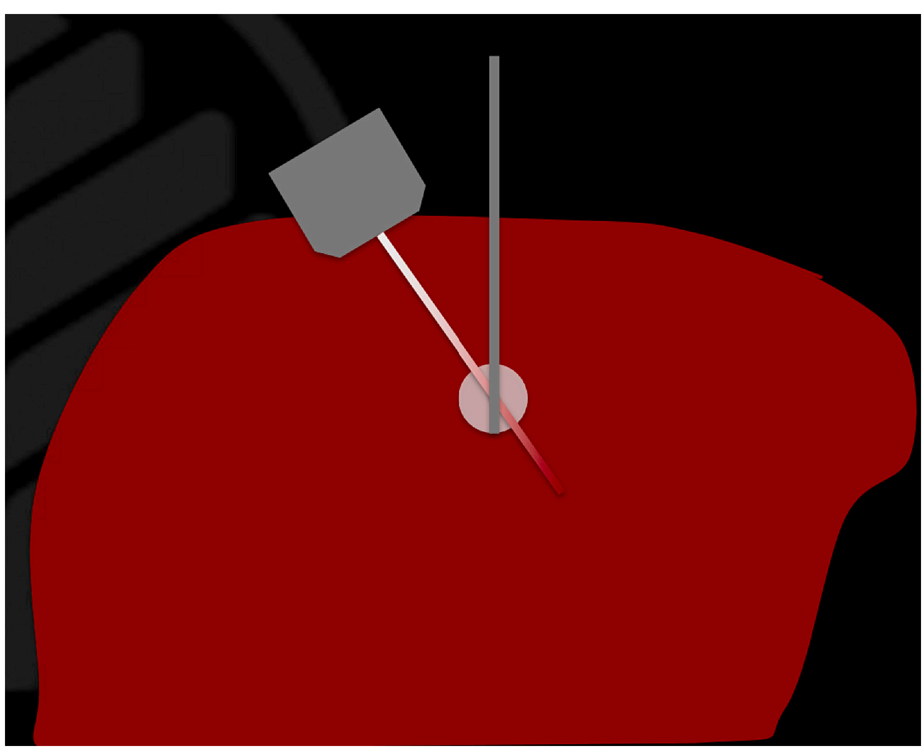

Fig. 17. In the 'step-off' technique for laparoscopic targeting, the transducer is positioned slightly to the side of the lesion of interest and rotated to look back at it. This permits the ablation probe free passage along the chosen trajectory while keeping the probe in view. Figure reprinted with permission [22].

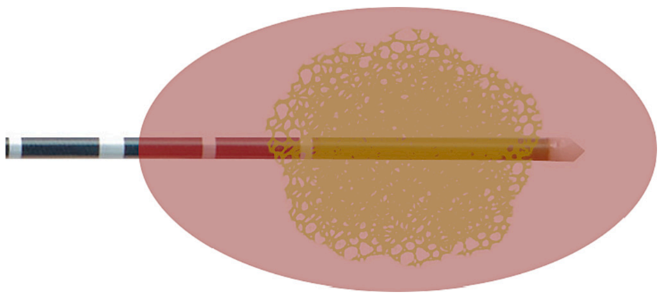

Fig. 18. The ablation zone produced by the microwave probe is centered somewhere between 1 and 2 cm from the tip of the probe, depending on the manufacturer. In order to superimpose the center of the ablation zone (depicted in red) with the center of the tumor (depicted in yellow), this practically means that the tip of the ablation needle is positioned closer to the aspect of the tumor that is furthest from the ablation probe. Predicted ablation zones vary by manufacturer and are dependent on Watts delivered and time. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Troubleshooting

Pitfalls

Numerous pitfalls can befall a planned microwave ablation. Of course, the necessary ultrasound transducer and ablation equipment must be well maintained and available. Capable operating room staff and device representatives are ideally present in the operating room to immediately assist in troubleshooting any technical difficulties, but if not, they must be immediately available by phone.

For patients undergoing ablation of HCC who may have portal hypertension, the surgeon must be cognizant of the possibility of a recanalization umbilical vein, which can cause significant bleeding and complicate abdominal access. For these patients, preparation of blood products should be routine.

It is prudent to devote adequate time for liver mobilization and the placement of protective sponges to avoid damage to any adjacent structures. Failure to adequately protect adjacent organs can lead to injury - the diaphragm, duodenum, and hepatic flexure of the colon are most at risk.

Failing to sequence ablations appropriately is another potential pitfall when targeting liver lesions. Whether overlapping ablations will be needed for a single lesion or multiple lesions will be targeted, planning the sequence of ablations is critical. As stated previously, hepatic ablation will obscure visualization of tissue deep to the site of ablation.

For tumors located near portal pedicles or hepatic veins, we utilize a high energy, short duration ablation rather than a low energy, long ablation. High energy, short ablations will generate a more predictable and uniform ablation field. Intraoperative systemic heparinization can be utilized to mitigate the risk of vascular thrombosis when ablating near hepatic veins.

Disappearing lesions or lesions that are not visualized well with ultrasound can present an intraoperative challenge. Immediate access to preoperative cross-sectional imaging in the operating room is essential in these cases. Correlating lesion location with structures that can be seen well, such as portal pedicles or hepatic veins, can be helpful for localization. Blind ablation based on anatomic landmarks can be performed, but our practice is to perform followup imaging and return to the operating room for repeat ablation if necessary.

Complications

Complications specific to ablation include vascular injury or thrombosis, hollow viscus injury, diaphragmatic injury, postoperative liver dysfunction, biliary stricture, and infection of the ablation cavity.

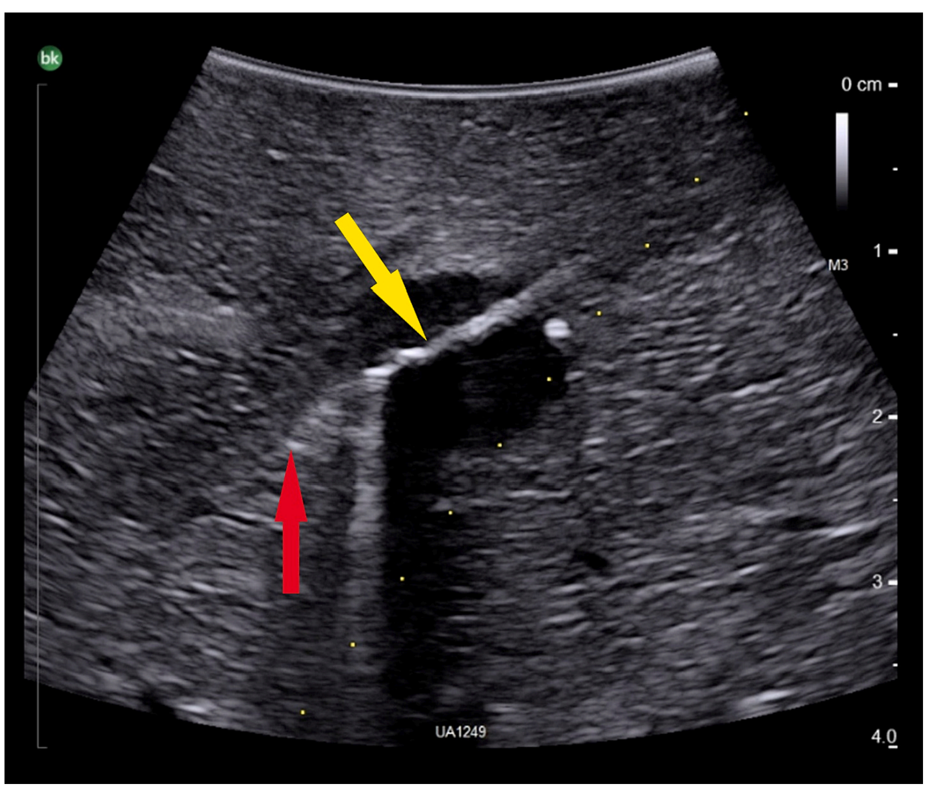

Fig. 19. Needle placement into a hypoechoic ablation target. The red arrow indicates the tip of the needle. The yellow arrow indicates the perceived center of energy delivery, about 1 cm from the tip of the needle. The surgeon attempts to superimpose the center of the microwave field with the center of the target lesion. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

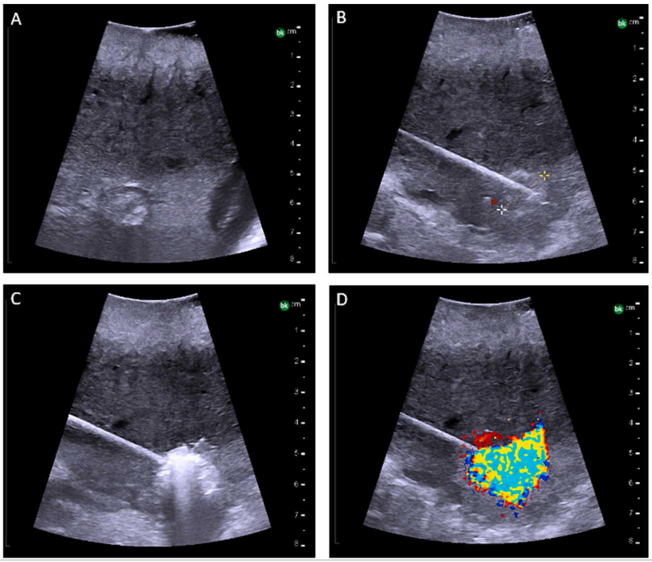

Fig. 20. Lesion measuring 1.8 cm in the right liver. Panel A shows the lesion at discovery.
Panel B shows advancement of the ablation probe into the lesion.
Panel C: Ablation has begun and the gas bubbles generated in the tissue obscure the view of the tumor.
Panel D: Activation of the color mode approximates the microwave near field.

The most effective method to avoid vascular injury is to perform a careful ultrasonographic assessment along the planned ablation probe trajectory, to ensure no major vascular pedicles are present. If a peripheral pedicle is traversed by an ablation probe, bleeding typically stops with pressure or topical hemostatic agents alone. In the unlikely event that significant bleeding does occur due to traversing a pedicle, track ablation can be attempted. In rare cases, if this does not control bleeding, urgent vascular embolization may be necessary.

Most commonly, vascular thrombosis is typically peripheral and clinically occult, but if there is thrombus propagation or involvement of the main portal veins, anticoagulation may be necessary.

Hollow viscus injury can result in delayed perforation or stricture, but these injuries are extremely rare. Surgical ablation (as opposed to percutaneous ablation) permits mobilization of any local structures, most commonly the stomach, duodenum or right colon, and saline-soaked surgical sponges can pack these organs away and disperse any heat generated during ablation. Likewise, diaphragmatic injury can be avoided by careful mobilization of the liver and the introduction of sponges to separate the liver from the diaphragm.

Postoperative liver decompensation can be encountered in patients with underlying cirrhosis. In general, postoperative care in these cases does not differ from patients with medical liver decompensation, with the exception that new portal vein thrombosis and infection of an ablation cavity must be considered as possible contributing factors. Therefore, a low threshold for liver duplex and/or cross-sectional imaging is prudent.

Biliary stricture is a very rare complication of surgical ablation. Its true incidence may be higher than reported because most biliary injuries are peripheral and clinically inconsequential. In the unlikely event of recurrent cholangitis from a peripheral biliary stricture, segmental hepatectomy may be necessary.

Infection of an ablation cavity can occur, but is rare and is more commonly reported in those undergoing percutaneous ablation. Liang et al. reported a rate of 0.2 % in a series of 1928 tumors ablated [6]. Prior bilioenteric anastomosis is a significant risk factor for ablation cavity abscess, but this may be mitigated with administration of prophylactic antibiotics [7] or with the use of irreversible electroporation (IRE). Rather than causing tumor necrosis, IRE induces apoptosis, which may reduce the risk of infection.

Outcomes

Published studies indicate with uniformity that surgical ablation is a safe and low morbidity treatment modality, with a low frequency of complications that are mild in severity. Postoperative mortality is 0 % in most studies and does not exceed 2 % in the remainder. Predictably, mortality tended to be highest in patients undergoing MWA for HCC, where underlying liver disease was a contributing cause of postoperative death. Postoperative morbidity ranged from 7 to 54 % [3,8–20], but the vast majority of complications reported were Clavien-Dindo grade 1 or 2.

With respect to oncologic outcomes, the reported incidence of incomplete ablation and local recurrence vary widely, from 0.7 % to 29.4 % [3,8–20], likely related to differences in tumor type and size, variation in surgical approach, variable followup, and lack of a standard definition. For example, some reports designate any new tumor arising within 1 cm of an ablation site a local recurrence, while others require new lesions to be confluent with prior ablation sites to be considered locally recurrent. Furthermore, some studies report disease recurrence without specifying whether recurrence is local or elsewhere in the liver. The following table summarizes results from studies of surgical microwave ablation of the liver completed since 2010 (Table 1).

Conclusion

Ultrasound-guided targeting of liver lesions is a fundamental skill for the modern liver surgeon. The surgeon, and ideally the operating room staff, must be intimately familiar with the ultrasound machine to optimize operative efficiency and patient outcomes. Successful targeting starts with high quality cross-sectional imaging to fully characterize the lesion and note its relationship with portal pedicles and hepatic veins.

Once in the operating room, optimizing surgical ergonomics is the foundation for precise targeting. This includes patient positioning to shorten the distance to the target lesion and maximize the abdominal surface area available for trocar and probe placement. The importance of generating high quality ultrasound images cannot be overstated. In addition to adjusting ultrasound parameters such as image depth, gain, time-gain compensation, and frequency, optimizing visualization may also include liver mobilization or instillation of saline to improve ultrasound transmission. Intentional, ergonomic placement of video monitors and ultrasound images, intuitive orientation of ultrasound probes, and utilization of external reference points are key aspects to generating an accurate mental image of the target lesion's position in 3D space within the liver. Proprioceptive intuition is the primary modality for advancing the probe to the target, and visual input from ultrasound images refines this path once the probe enters the ultrasound plane. Thoughtful sequencing of ablation targets is essential to permit adequate visualization throughout the procedure.

Ethics approval

Not applicable.

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CRediT authorship contribution statement

Matthew S. Strand: Writing – review & editing, Writing – original draft. **David A. Iannitti:** Writing – review & editing, Supervision, Resources, Conceptualization.

Table 1
Summary of surgical microwave ablation studies.

1st author	Publication year Study years	Patient population n (patients, lesions)	30-d mortality (%) Complications (%) Notes	Inc. ablation rate Local recurrence rate Median followup Median time to recurrence	Notes/conclusions
Pickens [8]	2021 (2008–2018)	NET (50, 166)	2 % 0 % Clavien-Dindo Grade 3 or 4 MWA alone 27 % Clavien-Dindo Grade 3 or 4 with combined procedure	IA: 0.6 % LR: 0 % 32 mo 24 mo	• OS: 94 % 1 year; 70 % 5 year • RFS: 86 % 1 year; 28 % 5 year
Abreu de Carvalho [9]	2021 (2013–2018)	HCC, CRLM (47, 70)	0 % 12.8 % 6.4 % Clavien-Dindo gr. 3 or 4	IA: 8.6 % LR: 29.4 % 26 mo 6 mo (CRLM), 12 mo (HCC)	• Laparoscopic only • RF for recurrence: vascular proximity, OR 3.4 • Median time to LR: 8 months
McEachron [17]	2021 (2009–2018)	CRLM (36, 135)	0 % 20 % None > Clavien-Dindo gr. 3	NR LR: 4.4 % (per lesion) 28 mo NR	• Concomitant hepatectomy: 42 % • 67 % laparoscopic • 33 % open
Cillo [11]	2019 (2009–2016)	HCC (674, 815)	0.4 % 30.8 % 2 % Clavien-Dindo gr. 3 or 4	NR LR: 23.2 % 18.4 mo 4.4 mo	• Laparoscopic only • HCC only
Takahashi [19]	2018 2014–2017	NET, CRLM, HCC, other (100, 301)	0 % 7 %	IA: 0 % LR: 6.6 % per lesion 12 % per patient 16 mo 7.4 mo	• RF for local recurrence: • tumor >3 cm • tumor type (CRLM vs. HCC or other) • ablation margin <5 mm
Baker [10]	2017 (2007–2014)	HCC (219, 340)	1.8 % 35.6 % 4.5 % Clavien-Dindo gr. 3 or 4	IA: 2.9 % LR: 8.5 % 10.9 mo 9.9 mo	• Laparoscopic only • HCC only
Tinguely [3]	2017 (2013–2015)	CRLM, HCC, NET (51, 346)	1.9 % 28 % 4 % Clavien-Dindo gr. 3 or 4	NR LR: 9 % at 9 days NR NR	• Used stereotactic image guidance
Leung [15]	2015 (2008–2013)	HCC, CRLM, iCC, other (176, 416)	0 % 25.6 % 13.6 % Clavien-Dindo gr. 3 or 4	NR 7.9 % per lesion 17.6 % per patient 20.5 mo 7 mo	• Some pts. underwent resection + ablation. • 8.3 % developed complications for ablation alone vs. 30 % who underwent resection + ablation
Eng [13]	2015 (2009–2013)	CRLM (33, 49)	0 % 54 % 24 % Clavien-Dindo gr. 3 or 4	NR NR 17 mo 12 mo	• 85 % had concomitant hepatic resection • All patients with major complication had concomitant resection • Local recurrence defined as any intrahepatic recurrence
Zaidi [21]	2015 (2014–2015)	CRLM, NET, HCC, other (53, 149)	0 % 11 %	IA: 0.7 % LR: 0.7 % 4.5 mo 3 mo	• Median tumor size: 1.5 cm • Median tumors/patient: 3
Groeschl	2014 (2003–2011)	CRLM, HCC, NET, other (450, 865)	1.5 % 18.4 %	IA: 3 % LR: 6 % Median fu 18 mo	• Concomitant hepatectomy: 38 % • 51 % open, 39 % lap, 10 % perc.
Correa-Gallego [12]	2014 (2008–2011)	CRLM (134, 254)	0 % 27 % (MWA cohort)	NR LR: 6 % 18 mo NR	• Comparison of MWA and RFA, matched • 91 % concomitant hepatectomy
Swan [18]	2013 (2007–2011)	HCC (54, 73)	0 % 28.9 % 11 % Clavien-Dindo gr. 3	IA: 5.9 % LR: 2.9 % 9 mo NR	• Median tumor size 2.6 cm • 95 % laparoscopic
Takami [20]	2012 (1994–2010)	HCC (719, 1804)	0 % 7 %	IA: 0 % LR: 1.9, 4.8 and 5.9 % at 1, 3, and 5 years	• Mix of open, laparoscopic, transdiaphragmatic
Martin [16]	2010	CRLM, HCC, NET, other (100, 271)	0 % 29 % Median Clavien-Dindo grade: 2	IA: 5 % LR: 2 % 36 months NR	• 68 % open, 32 % laparoscopic • 30 % concomitant hepatectomy

IA: incomplete ablation. LR: local recurrence. CRLM: colorectal liver metastasis. HCC: hepatocellular carcinoma. NET: neuroendocrine tumor. RF: risk factor. OS: overall survival. RFS: recurrence-free survival.

Declaration of competing interest

David A. Iannitti is a consultant with AngioDynamics, Johnson & Johnson, and Medtronic.

Matthew Strand has no conflicts of interest to declare.

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