Techniques in Laparoscopic and Intraoperative Ultrasound Guidance

16

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Introduction

The use of intraoperative ultrasound is beneficial for many abdominal surgical procedures. While used for other purposes, intraoperative ultrasound is an essential tool for the hepatobiliary surgeon to localize tumors and define vascular anatomy in the liver and pancreas. It is useful during resection and is essential for all but the most superficial liver tumor ablations [1–4]. Ablation and biopsy of tumors requires facile use of intraoperative ultrasound guidance techniques to achieve reproducible and effective ablations with minimal chance of incomplete ablation and local tumor recurrence. Ultrasound can be utilized in both open and laparoscopic surgery with the use of a variety of transducers.

A disciplined and comprehensive ultrasound of the organ of interest is paramount to a successful operation. Primarily, intraoperative ultrasound localizes lesions found on preoperative imaging. It can also find previously undetected lesions [3, 5]. It is therefore essential that the chosen ultrasound scanning technique provide a thorough examination of all parenchyma.

Identified lesions can be targeted for needle biopsy/ablation or avoided during resection in order to achieve negative margins. Ultrasound guidance of biopsy needles, ablation electrodes, or antennae require the operator to perform a maneuver in three dimensions while referencing a two-dimensional ultrasound image. This can be technically challenging, even when the lesion is well visualized by the ultrasound transducer. Multiple errant attempts may result in unnecessary trauma so correct technique is helpful in reducing these errant attempts [6, 7]. This chapter discusses techniques in ultrasound surveillance as well as advanced techniques of biopsy and ablation device guidance for both laparoscopic and open surgery.

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Transducer Selection/Positioning

Transducer Selection

The image produced by an ultrasound transducer is affected by the configuration of the piezoelectric crystals that make up the transducer surface as well as the frequency they transmit. Higher-frequency ultrasound waves create sharper, higher-resolution images at the expense of penetration depth. High-frequency ultrasound waves attenuate very quickly in the tissue, and imaging of deep tissues with high-frequency transducers is poor. One of the benefits of operative ultrasound is that high-frequency probes that do not give good transabdominal images can be used directly on the organ of interest. This results in much more detailed images than would be available outside the operating room. In our practice we use frequencies of 5–10 MHz when imaging the liver to a depth up to 9 cm. For the pancreas we use 10 MHz and a depth up to 4 cm. For high-resolution vascular imaging, we use 15 MHz with a depth of 3 cm.

The shape of the transducer also affects the shape of the plane of tissue imaged. Curvilinear probes create a fan-shaped image with a larger amount of deep tissue visualized, whereas linear probes produce rectangular images of tissue directly beneath the transducer. We use both linear and curved arrays in open surgery, and the laparoscopic ultrasound probes are curved arrays in line with the shaft of the instrument (Fig. 16.1).

Transducer Orientation

The ultrasound transducer produces an image of the narrow plane of tissue beneath it. The transducer of most open ultrasound probes is perpendicular to the cord and handle and is

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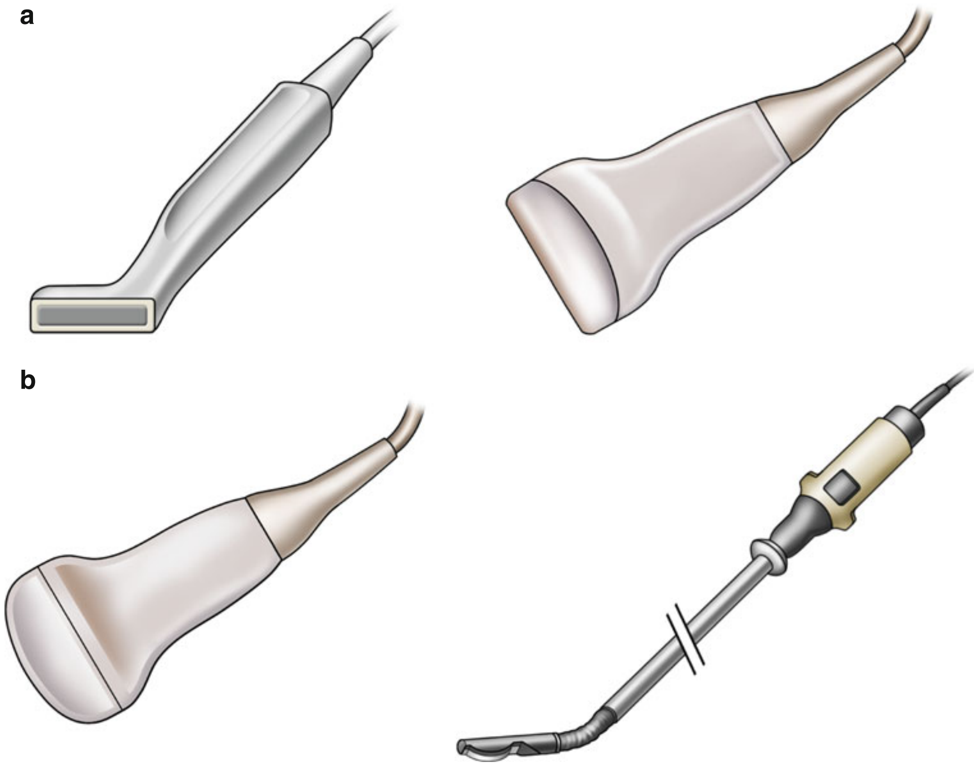

Fig. 16.1 Ultrasound probes are designed with both ergonomics and imaging characteristics in mind. Handpieces can be shaped for a particular use, and straight and curved arrays provide different imaging qualities. (**a**) Linear transducers in two ergonomic configurations. (**b**) Curved array transducers in both open and laparoscopic varieties

therefore described as having a "left" and "right" side (Fig. 16.2). The laparoscopic probe is oriented such that the transducer is in line with the shaft. The distal tip of the device is termed the "toe" and the proximal end of the transducer the "heel" (Fig. 16.3). The image on the ultrasound screen can be manipulated in regard to the "left-right" orientation viewed on the screen. Thus, the toe portion of the image can be on the right-hand side of the screen or on the left. This applies in a similar manner to an open probe. It is at the operator's discretion as to which orientation to choose, and the preferred view will depend on how each individual visually processes the spatial relationship seen on the screen [8]. Either orientation is acceptable, but it is critically important to know the orientation prior to beginning a scan for accurate planning and execution of biopsy or ablation. The recommended technique for determining orientation of the probe is to place only the tip of the laparoscopic probe, or one side of the open probe, in contact with the tissue and then look at the screen to determine which side of the tissue is being projected (Fig. 16.4a, b). The orientation is now known and the image can then be reversed as needed.

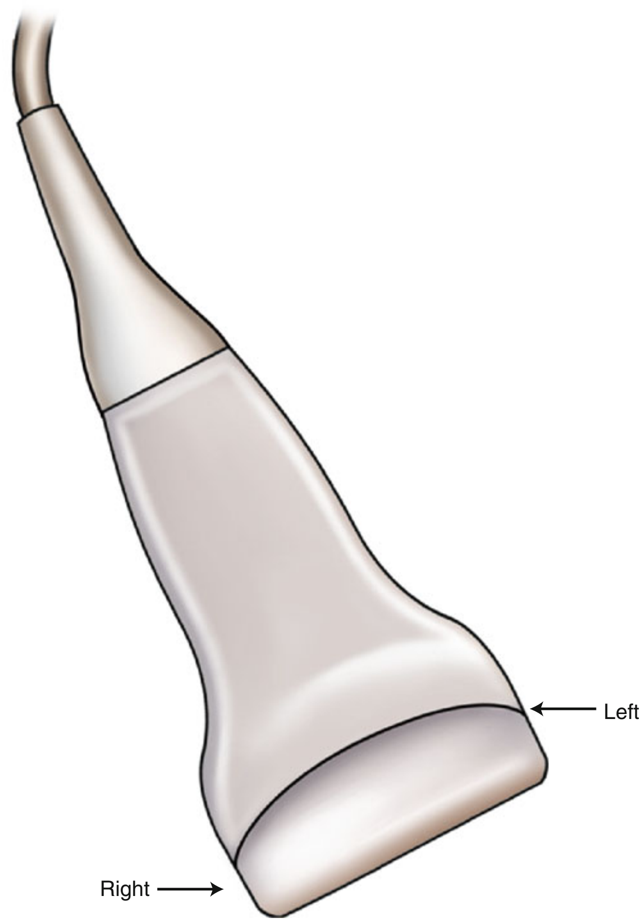

Fig. 16.2 Handheld ultrasound transducer marked left and right. The image on-screen can be flipped so that the right edge of the transducer corresponds to either the right or left edge of the screen to fit the user's spatial orientation preference

Transducer Head Position

The laparoscopic transducer can be flexed up and down as well as left to right. This allows for great flexibility in scanning an organ's contour. Rigid laparoscopic ultrasound devices are available, but the limitations of movement make them inadequate for full hepatic ultrasound. A common pitfall is to place the transducer in contact with the tissue and then rotate the transducer head while stationary in order to scan the tissue. This results in large amounts of deep tissue scanned, but very little tissue scanned on the surface. Figure 16.5 shows the result of rotating the transducer head without moving across the tissue (Fig. 16.5). When this maneuver is performed sequentially at different positions along a path, it is very easy to think that all tissue along the path has been scanned. However, in reality this is not the case. Figure 16.6 illustrates how a superficial lesion can be missed entirely by placing the transducer in two positions and rotating while remaining in place (Fig. 16.6). Therefore, the recommended technique for scanning is to move the transducer over the tissue while keeping it parallel to the tissue. In this way, an equal amount of deep and superficial tissue will be visualized, reducing the chance of missed lesions at any depth (Fig. 16.7). With an open ultrasound probe, this error is easier to avoid by keeping the ultrasound probe flat on the tissue of interest.

There are circumstances when moving an ultrasound probe smoothly over the surface of an organ is not possible. For example, a cirrhotic liver is very challenging to transduce accurately because it is difficult to get all points of the transducer touching the surface at one time. This can be overcome with a "standoff" technique where saline solution is used to submerge the liver (Figs. 16.8 and 16.9). The ultrasound transducer can then be positioned above the surface without the loss of image quality that would result from transmission through air. This can also be very useful for superficial lesions located around corners. Figure 16.10 demonstrates the standoff technique allowing visualization of a lesion that would be difficult to access with a flexed ultrasound transducer (Fig. 16.10)

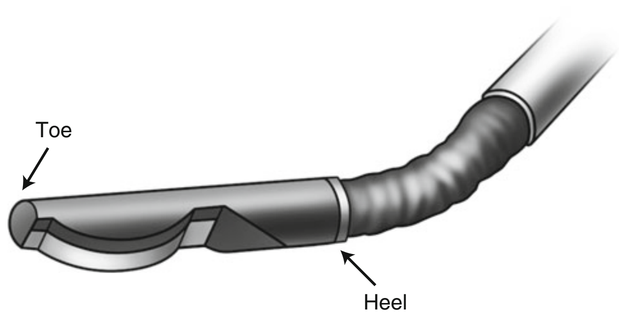

Fig. 16.3 Laparoscopic transducer head shown in flexed position marked with heel and toe. The image on-screen can be flipped to fit the user's preference

Scanning Techniques

Regardless of the tissue scanning method employed, it is important that it be methodical and complete. With any organ, a scanning technique can follow anatomic landmarks within the tissue, such as vasculature, or can be performed in a standardized fashion along the surface of the organ. For liver ultrasound, two different approaches are recommended. The portal vasculature can be followed in a "pedicle" technique, or the surface of the liver can be followed in a "lawnmower" fashion. These techniques will be described for the liver in this section, but other organs in the abdomen can be scanned with similar techniques requiring only small modifications for anatomy.

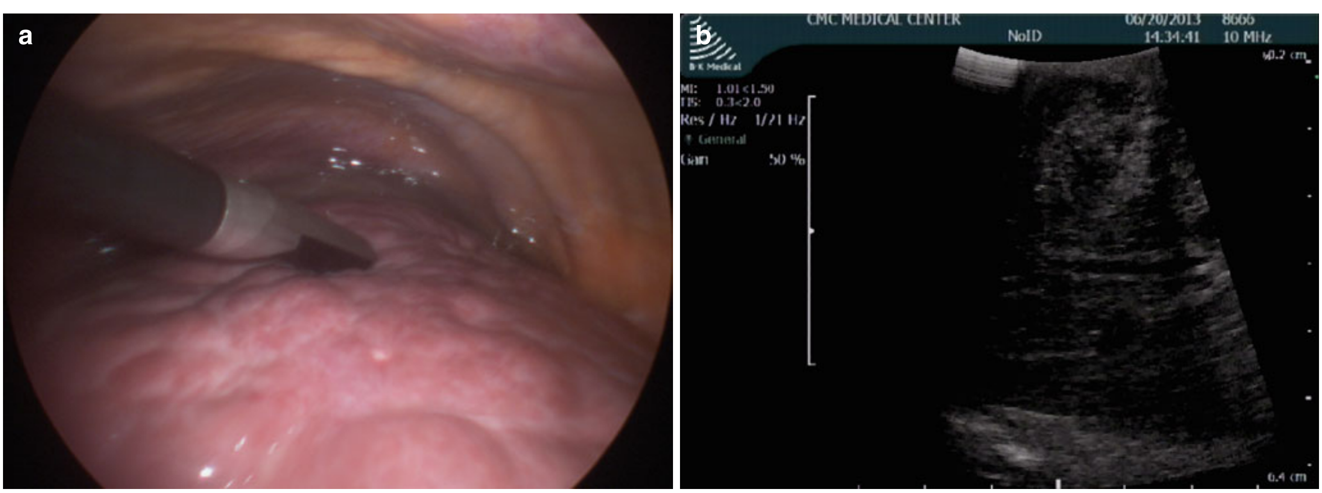

Fig. 16.4 (**a**) Intraoperative image of ultrasound toe touching the tissue. (**b**) A corresponding ultrasound image showing half of field with visible tissue, orienting the toe of the probe to the right of the screen

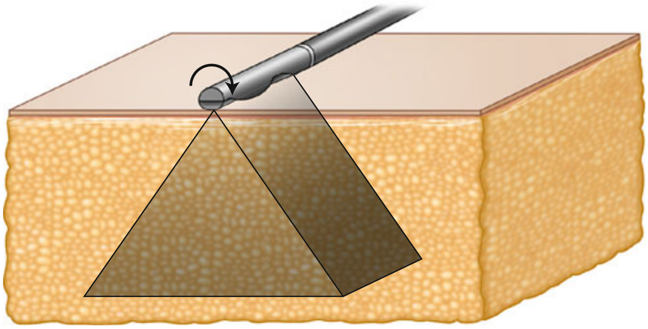

Fig. 16.5 The tissue is visualized perpendicular to the transducer. Rotation of the laparoscopic transducer without linear movement along the tissue visualizes a large amount of deep tissue with relatively little superficial tissue visualized

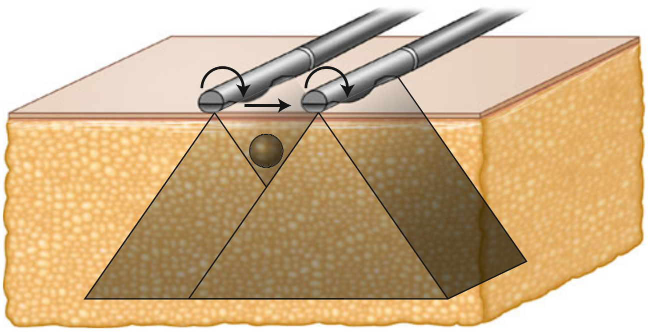

Fig. 16.6 When two sequential positions are used for transducer rotation, superficial lesions can be missed even though complete visualization is assumed. In this figure the laparoscopic transducer is rolled on the surface, moved laterally, and rolled in position again. A superficial mass is not imaged by either rolling motion, and if not picked up during the lateral movement of the probe, it will be missed entirely

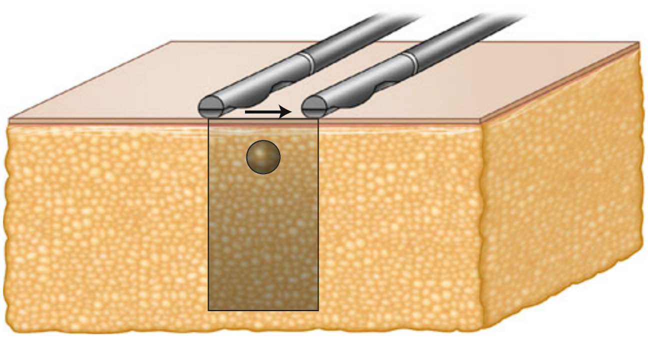

Fig. 16.7 By moving the transducer linearly along the tissue while maintaining perpendicular position relative to the tissue surface, an equal amount of superficial and deep tissue is visualized, and a superficial lesion is located

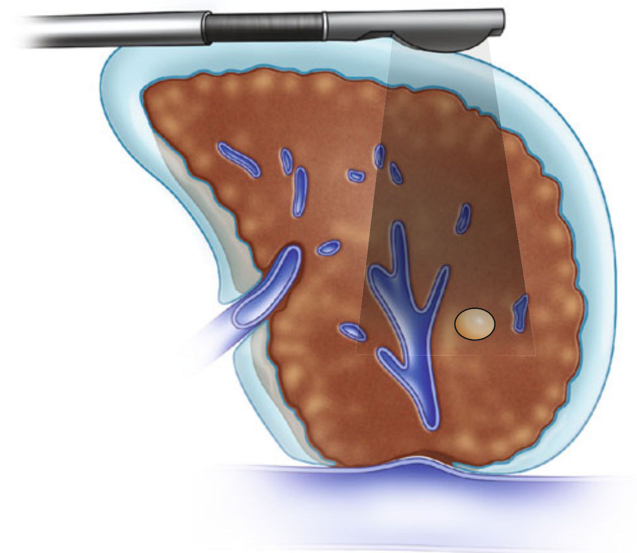

Fig. 16.8 The standoff technique used for a nodular cirrhotic liver using saline as an acoustic window. Ultrasound waves pass through the water layer and into the tissue seamlessly, providing a superior image

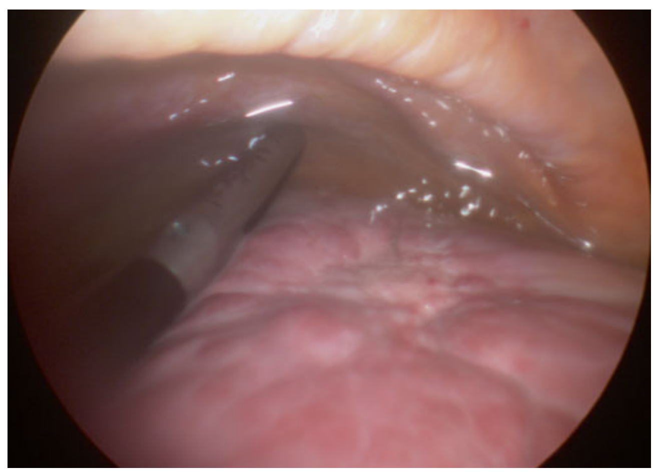

Fig. 16.9 A laparoscopic view of the standoff technique in use. Note the nodular appearance of the liver and the saline surrounding it. The transducer is submerged in saline in order to visualize pathology close to the surface of the liver

Lawnmower Technique

The "lawnmower" technique is used to scan the liver irrespective of intrahepatic anatomical landmarks. The entire surface is scanned by moving the transducer back and forth in narrow stripes beginning away from and moving toward the operator. Figure 16.11 shows the pattern used for this technique (Fig. 16.11). We perform this technique beginning in the right lobe and use the following pattern every time for consistency: segments VII–VI, VIII–V, IVa–IVb, II–III, and lastly I. Stripes should overlap so that no tissue is missed. The transducer should be moved slowly over the liver while the operator maintains constant attention to the ultrasound image. Recall that the laparoscopic transducer can be flexed to facilitate imaging over the dome of the liver. In an open approach the transducer motion can be modified to overlap stripes formed in a forward-and-back motion without

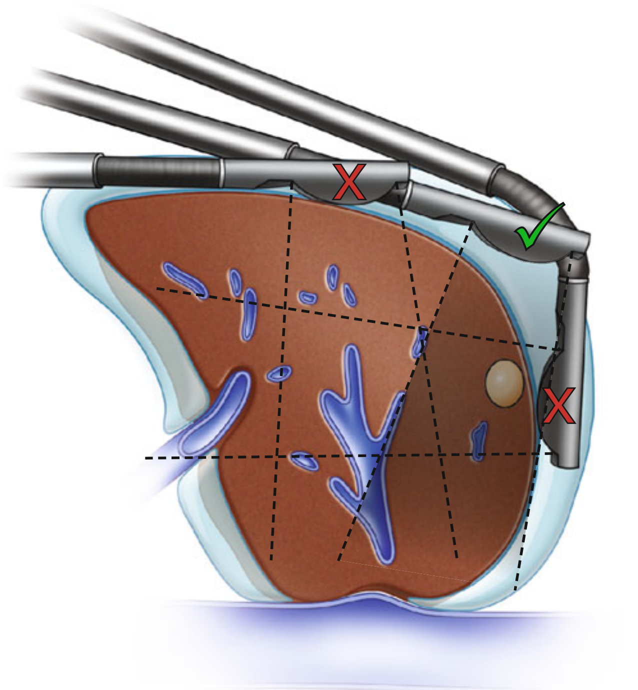

Fig. 16.10 The standoff technique used to visualize a superficial lesion high on the dome of the liver, which would be difficult to access directly with the ultrasound probe. This allows the lesion to be visualized through both the liver tissue and water layer with a clear image on-screen. The inferior (*red X*, *top*) probe position is the farthest a straight probe can achieve while maintaining contact directly with the liver tissue. The lesion is missed. The superior (*red X*, *right*) probe position requires the probe to be flexed around the edge of the liver to visualize the tumor, making targeting extremely difficult. The middle (*green check mark*) probe position allows the surgeon to visualize the tumor with a straight probe, making targeting for ablation most straightforward

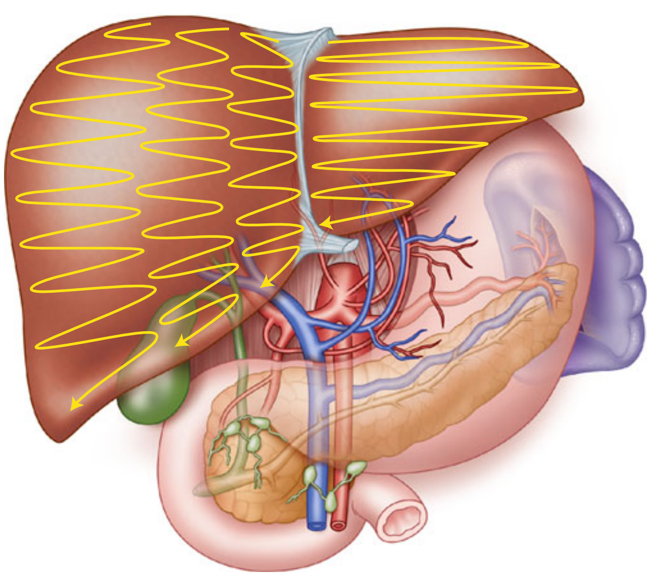

Fig. 16.11 The lawnmower technique. The probe is moved side to side in small stripes beginning away and moving toward the surgeon. The entire liver is visualized without regard to intrahepatic anatomy

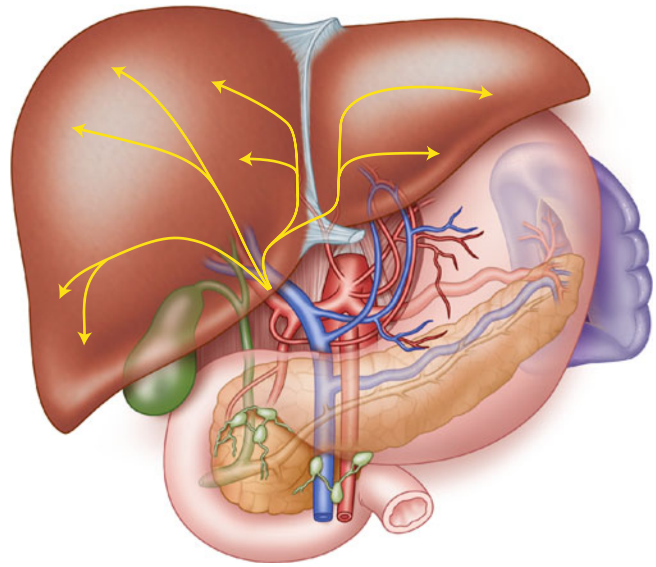

Fig. 16.12 The pedicle technique. Beginning at the porta hepatis, the portal pedicles are traced systematically. We begin with the right portal vein and move along the anterior, posterior, and segmental branches to the periphery of each segment. The left portal vein is traced in similar fashion, followed by the caudate lobe. This technique is especially useful to help identify lesions known to be in proximity to specific pedicles seen on preoperative imaging

side-to-side motions within stripes. This technique is especially useful when the surgeon is not looking for specific lesions based on preoperative imaging, but rather scanning for potential lesions.

Pedicle Technique

The basis of the "pedicle" technique is to use the liver anatomy as a guide. The surface of the liver is scanned in the direction of the portal pedicles (Fig. 16.12). Beginning with the portal vein, the right portal vein is followed along its anterior, followed by posterior segmental branches to the periphery of each segment. The left portal vein is scanned along the branches of IVa and IVb followed by the branches of II/III. Segment I is scanned last. During this technique we find it more natural to flip the left-right orientation of the screen when moving from the right to the left portal pedicles. When all pedicles are traced to their periphery, the liver is considered to be effectively visualized in its entirety. When preoperative cross-sectional imaging demonstrates lesions with nearby vasculature, the pedicle technique allows the surgeon to follow vessels to or near the lesion. This technique can be performed by itself or as a localizing technique for specific lesions followed by a lawnmower scan to evaluate the entire liver for additional lesions.

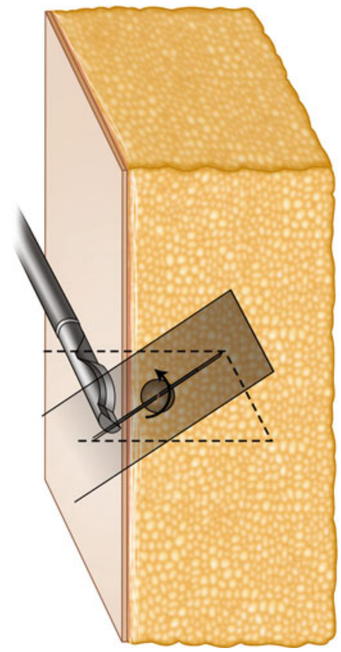

Fig. 16.13 If the transducer head is rotated without being recognized, an identified lesion will be mistakenly thought to be beneath the probe, when in fact it is perpendicular to the probe off to one side. This leads to errant passes and unneeded tissue trauma

Guidance Techniques

After lesion identification with ultrasound, targeting for biopsy or ablation can be performed under ultrasound guidance. Needle guidance can be performed either "in plane" with the transducer or "out of plane." Prior to any attempt at needle insertion, it is essential to have the transducer correctly positioned. Again, the ultrasound image presented on-screen is a thin plane of the tissue directly beneath, and in line with, the transducer head. Therefore, only objects passed directly underneath the transducer head will be imaged, including the needle and the lesion itself. It is important that the laparoscopic or open transducer head be flat against the tissue to provide a clear image along the entire length of the probe. It is also imperative to avoid rotating the transducer head as previously discussed. When a lesion has been identified with a rotated transducer head, the temptation is to assume the lesion is perpendicular to the tissue surface under the transducer. However, the image is actually of the tissue perpendicular to the transducer head. So if the transducer is rotated, the lesion will not be directly beneath the transducer, but rather off to the side. Figure 16.13 demonstrates the position of a lesion relative to the ultrasound probe when rotated

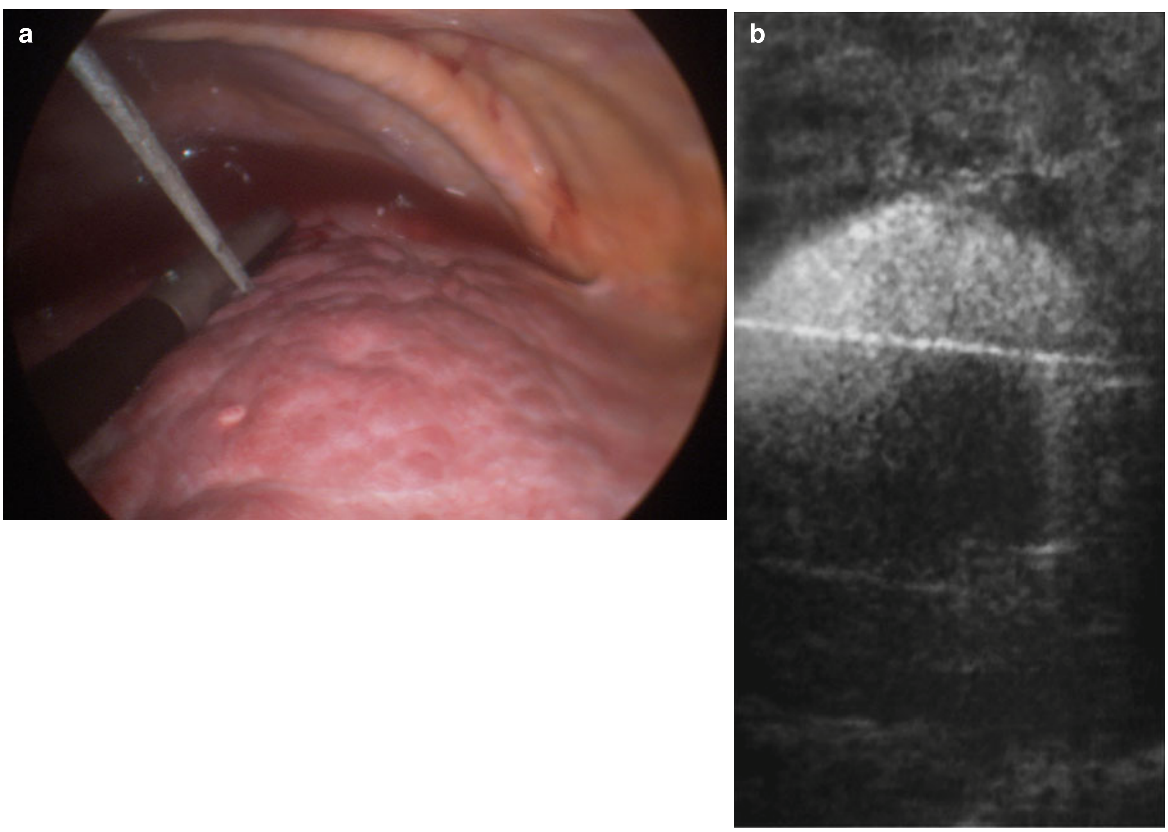

Fig. 16.14 (**a**) A microwave antenna is advanced in plane with the lesion. The antenna is visualized throughout its course, with the lesion still in view on-screen (**b**). Adjustments can be made quickly to minimize unnecessary errant attempts

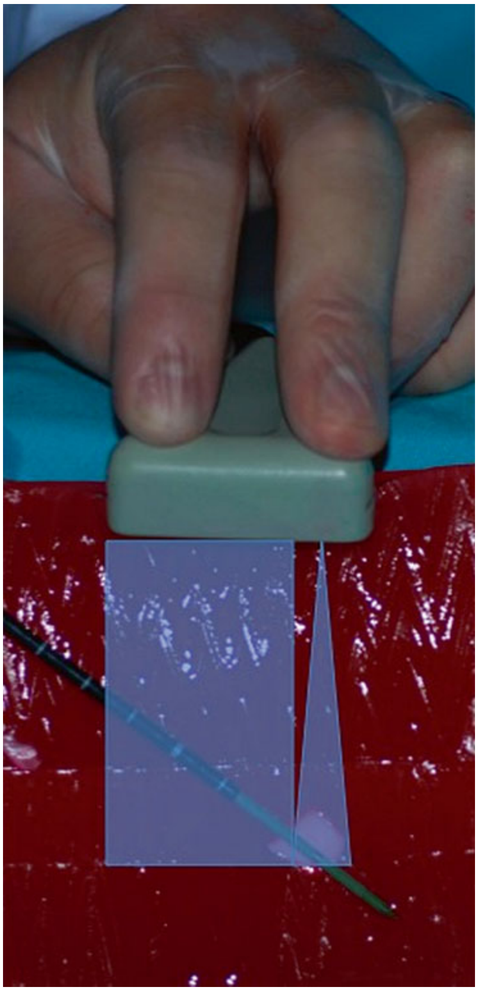

Fig. 16.15 Placing the lesion of interest at the far edge of the probe allows an "in-plane" antenna to be visualized traversing the entire screen. Adjustments are easier, and no screen space is wasted on the tissue not to be traversed

(Fig. 16.13). This makes targeting much more difficult and should be avoided.

In-Plane Targeting

In-plane targeting refers to passing the biopsy/ablation needle through the tissue parallel to and directly beneath the ultrasound transducer. This allows the surgeon to monitor the track of the needle throughout insertion. Figure 16.14a, b shows an image of an in-plane technique with a representative ultrasound image (Fig. 16.14a, b). When possible, placement of the lesion at the ultrasound probe toe laparoscopically, or at the edge opposite from needle entry of an open probe, as seen in Fig. 16.15 is recommended (Fig. 16.15). This allows for the greatest amount of needle track to be visualized and affords the opportunity to make angle adjustments early in the course of the maneuver. This must be done with care and attention to the tip of the needle, however, as it will travel the most during an angle adjustment and structures near the tip can be lacerated.

Open surgery affords great flexibility of motion in the absence of abdominal wall interference, making an in-plane approach feasible most of the time. In-plane targeting laparoscopically is more challenging not only because of the additional abdominal layer but also because all maneuvers are performed referencing the two-dimensional image produced by the laparoscope. Laparoscopic ultrasound probe shafts are in line with the transducer. It is ideal if the needle can be advanced from the heel of the probe directly beneath the transducer head. This should be kept in mind when determining where and at what angle to insert the needle through the skin.

Some laparoscopic ultrasound devices have built-in biopsy channels or attachment needle guides that can be placed on the tip of the transducer. Tracking guides can then be displayed on the screen in the path of a needle passed through the guide. This allows the surgeon to visualize the path of the needle before insertion and can reduce the number of errant passes. It is not always possible to orient the ultrasound device and needle to use the channel guide, and some large diameter devices do not fit through the channels. However, it is a useful adjunct when available. It is often necessary, as well as advantageous, to flex the ultrasound probe left or right in order to bring the heel into better position for needle insertion. When it is not feasible to use a needle guide or to pass under the probe from directly behind the heel, it is recommended to insert the needle alongside the transducer head at no greater than a 30° angle. This will bring the majority of the needle's path within the ultrasound image.

Once the transducer has been positioned appropriately for an in-plane technique, the surgeon must assess the lesion's depth by ultrasound and mentally determine the entry point and angle of approach to intersect with the lesion at the correct depth. During laparoscopy, this determines the entry and passage through both the abdominal wall as well as liver tissue. This determination is more difficult for deep lesions. However, when using the in-plane technique, error in angle of insertion can be ascertained quickly and adjustments made without making multiple full-depth passes through the tissue.

There are many benefits to utilizing the in-plane technique. The ability to rapidly assess needle angle helps avoid additional unnecessary tissue trauma. Adjustments in needle position are more difficult once the abdominal wall has been traversed. It may be necessary to entirely withdraw and replace the needle. The preferred approach is set up so that the needle passes through the abdominal wall at the same angle as through the intra-abdominal tissue. In thin patients adjustments can more easily be made without requiring great effort or strain on the needle. Obese patients will often

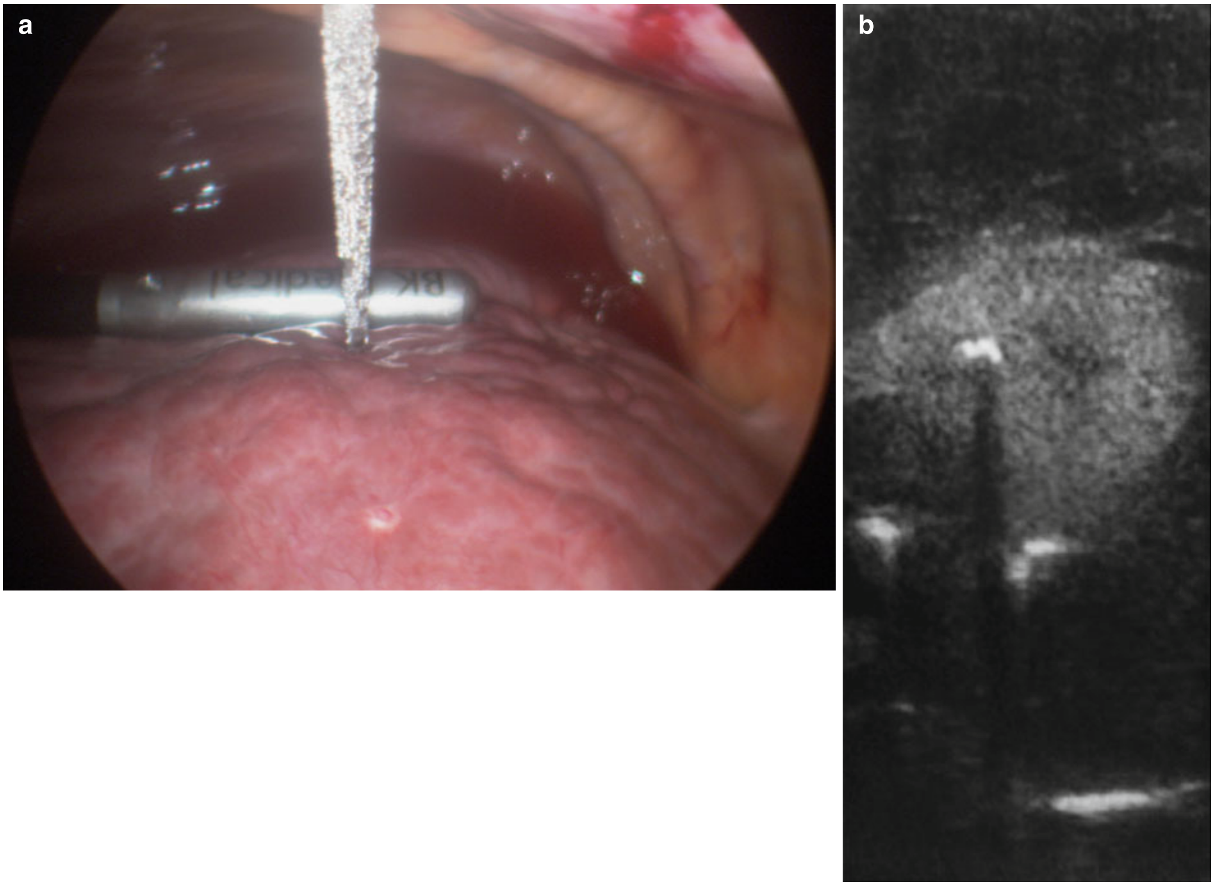

Fig. 16.16 (**a**) A microwave antenna is advanced out of plane with the lesion. The lesion and antenna are visualized on-screen together only in the single instance of the antenna crossing the plane of the ultrasound image (**b**). Adjustments are more difficult to make from an out-of-plane approach

require replacement of the needle if more than minor adjustments are required in the angle of the approach. An additional benefit to the in-plane technique is the ability to visualize in real time the needle traverse parenchyma prior to reaching the target. This allows the surgeon an approach that avoids large vessels during entry.

Out-of-Plane Targeting

It is common that an in-plane approach is not feasible for biopsy/ablation. This can occur when the approach through the abdominal wall is limited by port placement or when a lesion can only be viewed with the ultrasound probe in one position. When this occurs, an out-of-plane needle insertion is required. Figure 16.16a, b illustrates this technique with a corresponding ultrasound image (Fig. 16.16a, b). When a needle is inserted out of plane and the ultrasound transducer is held in a single position, the needle is only visible briefly as it breaks the plane of the visualized tissue. This can make it very technically difficult to assess needle trajectory and often results in full-depth passes being performed before the error in trajectory is recognized. The surgeon can move the ultrasound probe during the insertion to follow the needle, and it is important to do so to avoid injury to vessels, but this removes the lesion from the ultrasound image and the lesion must be reacquired during insertion. The combination of needle and lesion is only seen together on the ultrasound image when a correct placement results in the needle being within the lesion. A recent study looking at a novel 3D guidance system tested operators of varying experience in standard 2D targeting. The out-of-plane success rate in the hands of experts was 60 % [6]. When misses occur it is often difficult to correctly assess the cause of the miss in order to make adjustments for additional attempts. When a miss occurs it is recommended to leave the needle in position and pass the ultrasound between lesion and needle to assess the cause of the miss. In this situation, the probe can be rotated while in a single position, which will give the surgeon the ability to assess more of the needle track and extent of the lesion without needing to navigate around the needle. This will also lessen the chance of making a similar mistake on a second attempt. Patience is emphasized to avoid making similar errant passes repeatedly.

Future Directions

Innovations in ultrasound imaging and targeting are currently at various stages of development. Devices that provide a three-dimensional solution to lesion targeting are currently being developed and actively used, some within the confines of a prospective trial [6, 7, 9]. One of the most difficult and often frustrating parts of ultrasound guidance is performing a three-dimensional procedure using a two-dimensional image. The surgeon must simultaneously process the ultrasound image, the angle and flex of the ultrasound probe, and the position of the needle in three dimensions relative to the lesion and must mentally project the trajectory of the needle to intersect with the lesion. Newer technologies perform many of these tasks automatically by providing a three-dimensional view of the spatial relationships of instruments and the virtual path of the needle. Chapter 18 will discuss these evolving technologies in greater detail. These new devices will result in fewer errant attempts, more precise targeting, and ultimately more consistently complete tumor ablations.

Conclusions

Intraoperative ultrasound can be an incredibly useful tool for guidance of biopsy/ablation when used correctly. Consistent methods of surveillance will increase the ability to detect both known and unknown lesions. When possible, in-plane needle insertion is recommended. However, even out-of-plane targeting can be very successful when patience and proper technique are employed. Emerging technologies will further enhance the surgeon's ability to target lesions for biopsy and ablation with greater precision.

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