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REVIEW

Basic Techniques and Technical Tips for Ultrasound-guided Needle Puncture

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Abstract:
Ultrasound-guided needle puncture is essential for both vascular and nonvascular interventions. Ultrasound is widely available in various clinical settings, requires no ionizing radiation, offers color Doppler imaging, and enables real-time visualization of the needle position during puncture. However, ultrasound imaging has some limitations, such as signal attenuation in deeper tissues and the inability to penetrate bone or air, and it is a heavily operator-dependent modality. Here, we outline the basic techniques and technical tips for ultrasound-guided needle puncture.

Keywords:
ultrasound, vascular access, biopsy, drainage, ablation

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Introduction

Interventional radiology procedures can use various imaging methods, such as fluoroscopy, ultrasound (US), Computed tomography (CT), and magnetic resonance imaging.

Among these, US is preferred because of its wide availability in different clinical settings, lack of ionizing radiation, provision of color and power Doppler imaging, and real-time visualization of the needle position during puncture [1-3]. However, US imaging has limitations, including signal attenuation in deeper tissues and the inability to penetrate bone or air, restricting its use in skeletal or lung interventions [1, 2]. Additionally, US heavily relies on the operator's skills [1].

Despite these constraints, US-guided needle puncture remains essential for both vascular and nonvascular interventions, encompassing procedures like vascular access, biopsy, and drainage [3]. Here, we detail the basic techniques and technical tips for US-guided needle puncture.

US-Guided Needle Puncture: Basic Points

US probe frequency is a key factor in image resolution. Higher-frequency US provides a vivid image; however, signals are significantly attenuated in deep soft tissues [1]. In general, ideal transducers for interventions in superficial tissues are linear and have high resolution (8-15 MHz), whereas for deeper lesions, 5-3.5 MHz probes are often necessary.

Local anesthesia should be administered cautiously to avoid inadvertently injecting air microbubbles, which can compromise puncture needle visibility [1, 3]. Accurate US-guided needle puncture requires appropriate local anesthesia to prevent body motion due to pain during needle puncture.

Needle puncture can be performed using a "freehand technique" or a needle guide designed to fit the transducer [1]. The "freehand" technique allows for a flexible angle and subtle trajectory changes during puncture. Needle guides fix the needle in a predetermined trajectory, while the software displays the expected trajectory in real time. Generally, the "freehand technique" is used for target lesions in superficial tissues, such as superficial lymph nodes and the jugular and brachial veins, whereas the needle guide is used for target lesions in deep tissues, such as the liver and kidney [1].

Some manufacturers offer needles with echogenic tips, which enhance visualization during procedures [3]. Additionally, moving the needle slightly back and forth aids in confirming the needle tip during puncture. A recent advancement, the biopsy needle enhancement mode (Canon

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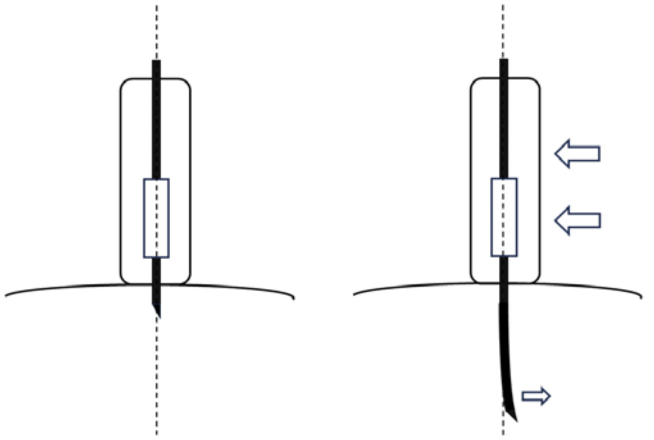

Figure 1.
If the position of the ultrasound probe is adjusted after fixing the needle via the incision with a needle guide, the probe may curve the needle slightly. As a result, the needle trajectory is out of the scan plane.

Medical Systems' Biopsy Enhancement Auto Mode), provides clearer visualization of needles [4].

When using a needle guide for puncture, the incision should be accurate. Adjusting the position of the US probe after fixing the needle with the guide may cause the needle trajectory to deviate from the scan plane (**Fig. 1**) [3].

Interventional Procedures

Vascular access

According to recent central venous catheterization (CVC) guidelines, US-guided needle puncture is recommended for vascular access to enhance accuracy and reduce complications [5, 6]. Typically, venous puncture uses needles ranging from 18 to 21 gauge.

For vascular access, US-guided needle puncture offers both longitudinal and transverse approaches [1, 5, 6]. The transverse approach is commonly used for accessing almost any vessel and accurately depicts the positional relationship between the target vessel and surrounding structures [6]. Visualizing the needle tip involves slightly swinging the US probe during needle access. However, in deeper vessels, the needle tip may be lost out of the plane (**Fig. 2a**). Conversely, the longitudinal approach allows visualization of the entire needle length during access (**Fig. 2b**) [6]. However, in small vessels, approximately ≤2 mm in diameter, the spatial resolution of US may limit accuracy because of slice thickness artifacts [7]. Although the needle may appear intraluminal in one plane on a longitudinal view, adjusting the plane may reveal the needle lateral or medial to the vessel wall [1].

At our institution, US-guided needle puncture is the standard for vascular access in various procedures, including CVC, CV port placement, and peripherally inserted central catheter. The transverse approach is typically used for jugular and brachial vein access. However, for subclavian vein access, both longitudinal and transverse approaches are used on the basis of operator preference.

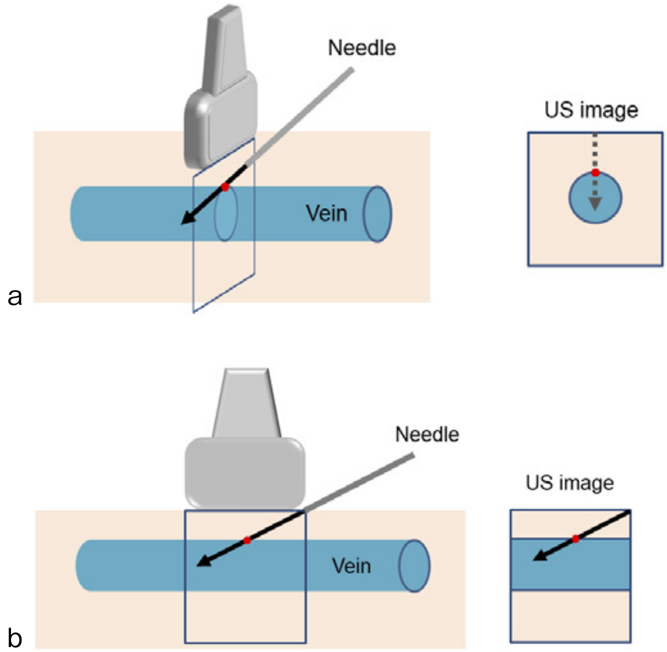

Figure 2. Schema of the transverse or longitudinal approach.
2a. The transverse approach demonstrates the positional relationship between the target vessel and surrounding structures.
2b. The longitudinal approach allows visualization of the entire length of the needle during needle access.

Image-Guided Biopsy

In the field of oncology, image-guided biopsy is a widely used procedure [8]. US-guided biopsy applies to all body parts except the central nervous system [1]. When US cannot visualize the target because of air or deeper tissue, CT-guided biopsy is performed [2].

Typically, semiautomatic or fully automatic cutting biopsy needles ranging from 18 to 20 gauge are used [8]. For relatively small target lesions (<2 cm), a semiautomatic cutting biopsy needle is recommended, allowing manual advancement of the inner "notched" stylet with care. In contrast, fully automatic cutting biopsy needles yield sharper specimens.

The freehand technique with a high-resolution linear probe is preferred for target lesions in superficial tissues, such as superficial lymph nodes [9]. For target lesions in deep tissues, like liver tumors, a needle guide with a 3.5-MHz convex probe is commonly used [10]. US-guided biopsy with color Doppler can be performed to avoid vascular injury, even when the target lesion is located in the pelvis (**Fig. 3**) [11, 12]. Complications after biopsy, such as bleeding and hemorrhage, can be monitored using US imaging.

If multiple specimens (>3-4) are required, biopsy using a coaxial needle without repeated puncture is also useful [8].

Image-Guided Drainage

Image-guided drainage of fluid collections or abscess cavities is a common procedure [2, 13, 14]. A CT image

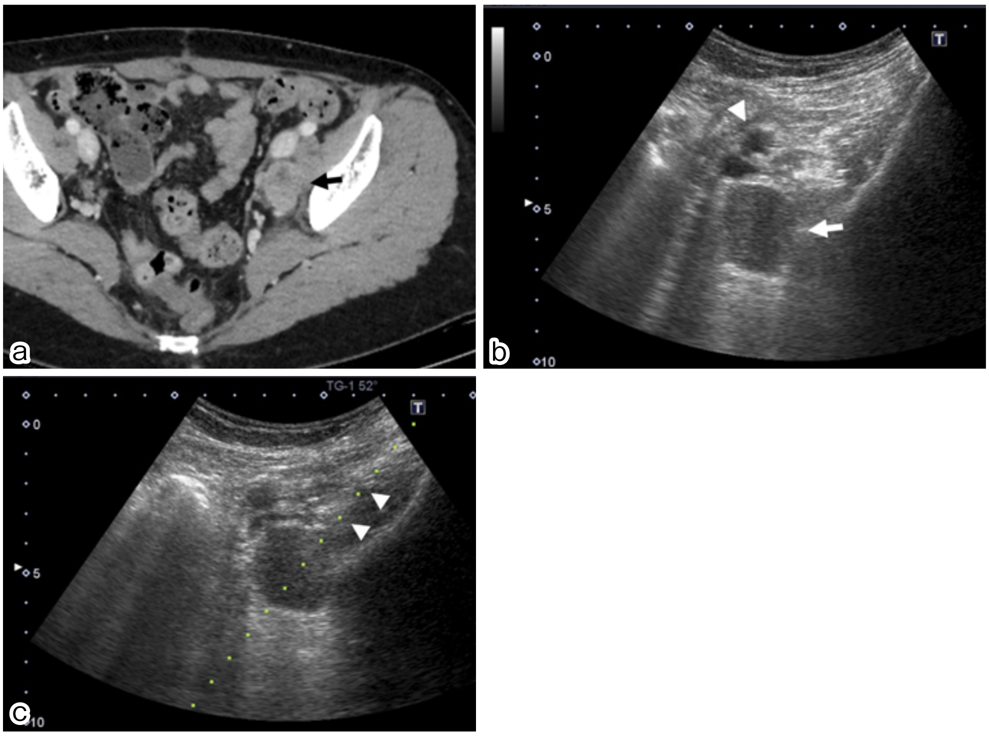

Figure 3. Biopsy for obturator lymphadenopathy.
3a. Computed tomography showing the obturator lymphadenopathy (arrow).
3b. Ultrasound (US) showing obturator lymphadenopathy (arrow) and external iliac artery (arrowhead).
3c. US-guided biopsy with needle guides (arrow heads) was performed.

typically shows the fluid collection as a homogeneous low-density area, whereas US may reveal it as a heterogeneous cavity with septal walls. Detailed properties of the target lesion can be assessed using US imaging before the drainage procedure. When the target lesion is visible via US, needle puncture is generally performed under US guidance, and the drainage catheter is inserted along with a guide wire under fluoroscopic guidance [14]. The position of the drainage catheter can also be confirmed using US imaging during the procedure.

For relatively large cavities, drainage catheter insertion with a smaller-diameter catheter (6-8 F) can be performed solely under US guidance using the trocar technique [15]. If the abscess cavity has complex spreading, it is sometimes difficult to confirm the guidewire position using US imaging during the procedure; therefore, CT-guided drainage may be useful in such cases.

Typically, needle puncture uses an 18-gauge needle [14]. In cases of small puncture points or cavities with vascular structures on the puncture route, drainage catheter insertion using a two-step method with a 21-gauge needle is an alternative procedure.

For target lesions in deep tissues like the liver and pelvic abscess, a 3.5-MHz convex probe with a needle guide is commonly used [3]. The operator should be vigilant about potential injury to the iliac arteries and veins, detectable using a 3.5-MHz convex probe, particularly during pelvic abscess drainage (**Fig. 4**). When the abscess cavity is just below the abdominal wall, a higher-frequency linear probe provides a vivid image, allowing the confirmation of fine vessels in the abdominal wall (**Fig. 5**) and preventing vascular injury. A higher-frequency linear probe with a needle guide also enables puncturing small spaces between the gastrointestinal tract (**Fig. 6**). US imaging provides a clear visualization of the residual tract after surgical drain removal, and needle puncture of the residual tract can be performed under US guidance (**Fig. 7**) [16].

Ablation

Ablation therapy, including radiofrequency ablation (RFA), microwave ablation, and cryoablation, is commonly performed under US guidance. Real-time visualization of intraorgan vessels, absence of radiation exposure, and control over the electrode insertion angle are potential advantages of US-guided RFA. However, the tip of the electrode is poorly visualized because of bubble formation during RFA. Despite being a common procedure, Rhim et al. reported that approximately 45% of small HCCs referred for possible percutaneous RFA were not clearly visible with US, which is the most common guidance tool for liver RFA [17]. Dynamic contrast-enhanced US overcomes this limitation and facilitates RFA electrode placement in hypervascular HCCs, which are poorly depicted with B-mode US [18]. Dynamic contrast-enhanced US also reveals residual tumors with vascularity after ablation therapy, enabling accurate additional ablation under dynamic contrast-enhanced US guidance [19].

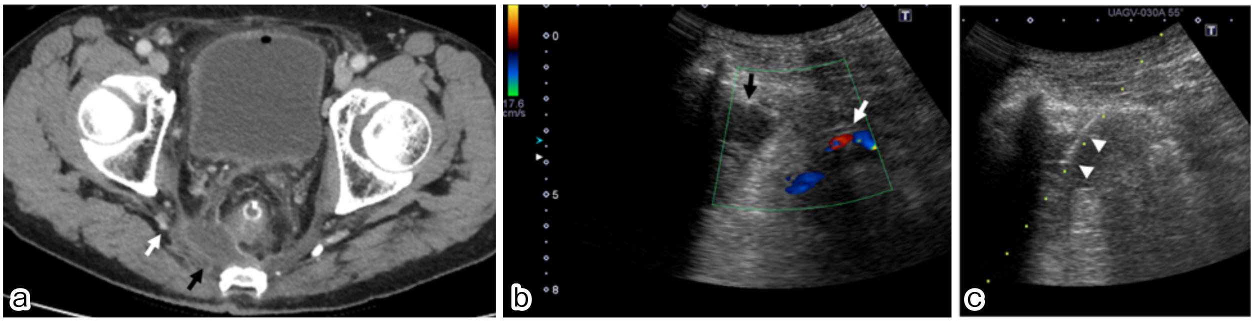

Figure 4. Pelvic abscess drainage after surgery for rectal cancer.

4a. Computed tomography showing the abscess cavity (black arrow) and inferior gluteal artery (white arrow) in the pelvis.

4b. Ultrasound (US) showing the abscess cavity (black arrow) and inferior gluteal artery (white arrow) in the prone position.

4c. US-guided puncture with a needle guide was performed using an 18-gauge needle (arrowheads).

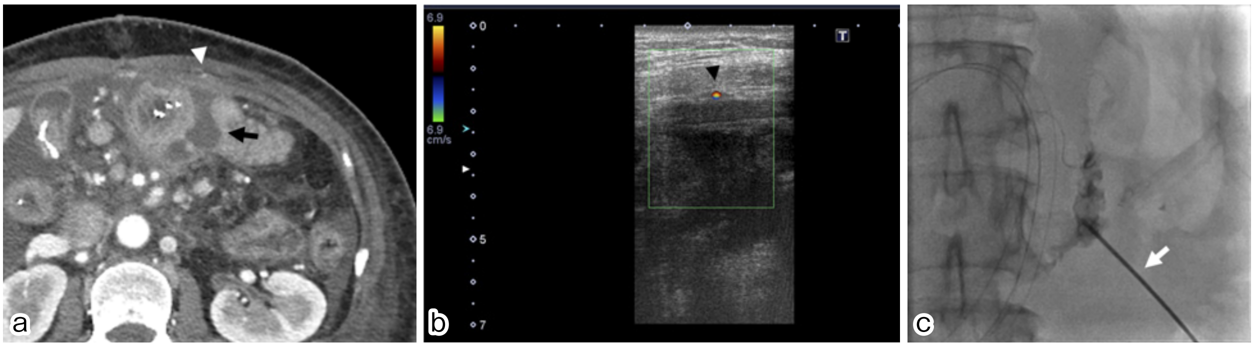

Figure 5. Abdominal abscess drainage after surgery for pancreatic cancer.

5a. Computed tomography showing fluid collection due to pancreatic fistula in the abdomen (arrow) and fine artery in the abdominal wall (arrowhead).

5b. Ultrasound (US) clearly showing the fine artery in the abdominal wall (arrowhead).

5c. US-guided puncture with the freehand technique was performed using an 18-gauge needle (arrow).

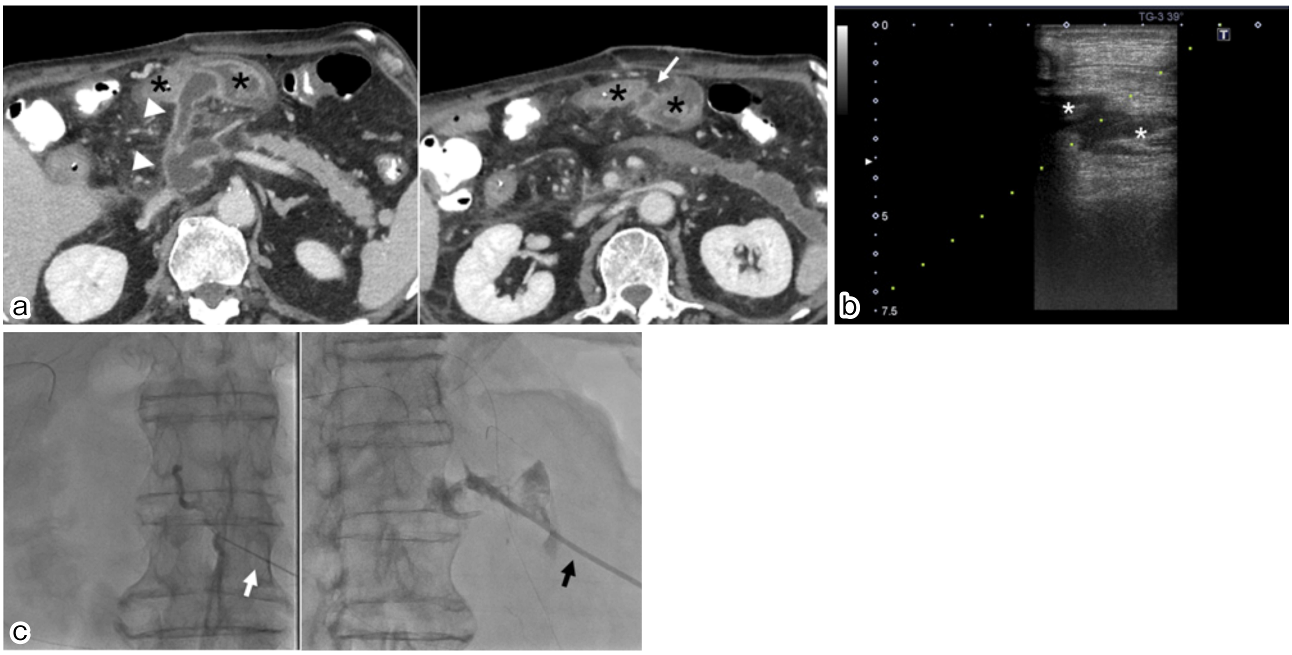

Figure 6. Abdominal abscess drainage after surgery for pancreatic cancer.

6a. Computed tomography showing fluid collection due to pancreatic fistula in the abdomen (arrowheads) and small space (arrow) between the gastrointestinal tracts (asterisk).

6b. Ultrasound (US) showing the small space between the gastrointestinal tracts (asterisk). US-guided puncture with a needle guide was performed using a 21-gauge needle.

6c. A small amount of contrast medium was injected using a 21-gauge needle (white arrow), and an 8-Fr drainage (black arrow) catheter was inserted.

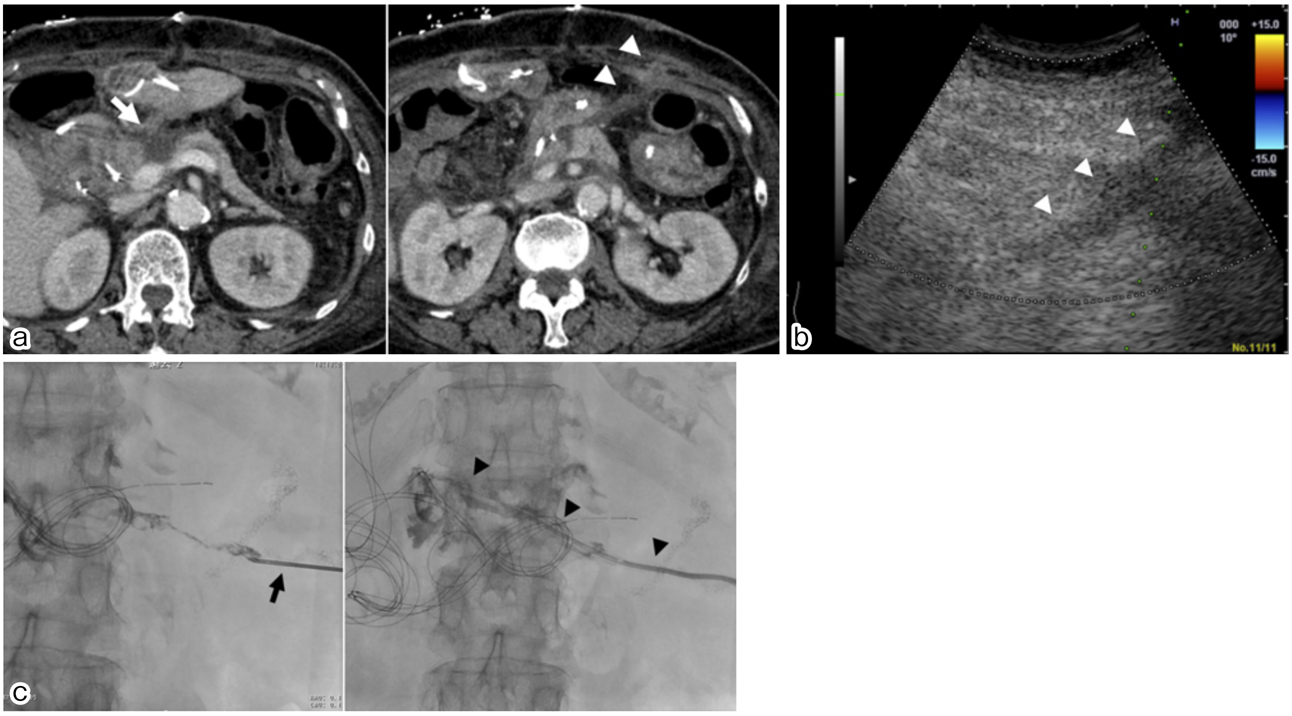

Figure 7. Abdominal abscess drainage after surgery for biliary cancer (courtesy of Dr. Daisuke Abo).
7a. Computed tomography showing fluid collection due to pancreatic fistula in the abdomen (arrow) and residual tract after surgical drain removal (arrowheads).
7b. Ultrasound (US) clearly showing the residual tract (arrowheads); US-guided puncture with a needle guide was performd using a 21-gauge needle.
7c. A small amount of contrast medium was injected using a 21-gauge needle (black arrow), and a 10-Fr drainage (arrow heads) catheter was inserted.

Advanced Technique

Hydrodissection is a well-established thermoprotective technique that involves the injection of fluid to separate the tumor from nearby structures [20, 21]. The utility of ablation therapy with hydrodissection under CT guidance has been previously reported, and this technique can be applied to US-guided puncture. Injecting saline or a local anesthetic solution can displace critical organs such as the gastrointestinal tract and vessels along the needle puncture route, thereby enhancing the safety of needle puncture [22].

Another valuable technique for abdominal target lesions is compression with a US probe. Applying compression to the gastrointestinal tract just below the abdominal wall can displace it, allowing for safer needle puncture under compression [23].

Conclusions

US is a versatile imaging technique that can be applied in various interventional procedures. However, the US is heavily user dependent. Depending on the location of the target lesions, appropriate US probes and puncture techniques should be selected. Hence, interventional radiologists should have adequate knowledge of US imaging features and proper technical tips for US-guided interventions.

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