

EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part I

General Aspects (long Version)

EFSUMB Leitlinien Interventioneller Ultraschall (INVUS), Teil I Allgemeine Aspekte (Langversion)

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Key words

- guideline
- ultrasound guidance
- hygiene
- microbiology
- safety

Abstract

▼ This is the first part of the Guidelines on Interventional Ultrasound of the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) and covers all general aspects of ultrasound-guided procedures (long version).

Zusammenfassung

▼ Der erste Teil der Leitlinien „interventionelle Sonografie“ der European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) erörtert die allgemeinen Aspekte sonografisch gestützter und assistierter diagnostischer und therapeutischer Interventionen im Abdomen (Langversion).

Introduction

▼ Ultrasound (US), both as a diagnostic modality as well as a guidance technique for interventional procedures, has developed into an invaluable tool in virtually all medical specialties. The real-time nature of US combined with low cost and high availability, has allowed US to become the modality of first choice for guidance of a broad variety of interventional procedures.

The history of interventional US (INVUS) goes back to the 1960s, when reports on the utility of US to guide renal biopsies, pleural fluid aspiration, and A-mode US-guided amniocentesis were published [1]. A milestone in early INVUS was the development of a special A-mode transducer with a central hole to enable amniocentesis and other punctures to be performed safely. In the 1970s and 1980s, the technological development of US systems and transducers was significant, and US systems with real-time grayscale imaging (B-mode) and Doppler mode became commercially available and widely distributed. During these two decades, the classic INVUS techniques of biopsy and drainage/puncture were further refined to become established techniques. First reports of US-guided tissue ablation appeared in the 1980s, but the different ablation techniques did not become established and clinically implemented until the 1990s [2].

Interventional ultrasound (INVUS) consists of a variety of diagnostic as well as therapeutic procedures, and may be performed with a variety of

equipment and different types of transducers. INVUS is now an integrated part of transcutaneous abdominal and superficial (small part) US. Furthermore, INVUS is a natural component of various endoluminal US exams such as transrectal, transvaginal, transbronchial and transgastric (endoscopic) US. Finally, INVUS is also feasible during intra-operative and laparoscopic US. Performing a competent INVUS procedure involves the successful combination of theoretical knowledge and practical skills at a high level:

- ▶ Knowledge of normal and pathologic US anatomy including pitfalls and artifacts
- ▶ Knowledge of the puncture principle and auxiliary US techniques such as Doppler and CEUS
- ▶ Knowledge of the INVUS apparatus used including all potential complications
- ▶ Dexterity and stereotactic skills. Part I of the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) Guidelines on interventional ultrasound addresses general aspects of US-guided interventions. The methods of guideline development are described in the introduction to the EFSUMB Guidelines on Interventional Ultrasound [3]. Levels of evidence (LoE) and Grades of Recommendations (GoR) have been assigned according to the Oxford Centre for Evidence-based Medicine criteria (March 2009 edition) [http://www.cebm.net/oxford-centre-evidence-based-medicine-levels-evidence-march-2009] [3].

Bibliography

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Imaging and INVUS



Ultrasound guidance for interventional procedures is utilized on different levels ranging from a “courtesy” look with the transducer prior to placing a pleural or ascitic drainage catheter to using sophisticated techniques of contrast-enhanced ultrasound (CEUS) fusion imaging with CT or MR imaging [4].

B-mode imaging

In preparation for a US-guided procedure, it is important to choose the appropriate transducer and imaging program (presetting/ap-plication) and to select the correct interventional apparatus. For abdominal or thoracic interventions, a curved or phased array transducer with a frequency of 3.5–6 MHz should be chosen. For a superficial lesion, a linear high-frequency transducer with a frequency of 7.5–15 MHz should be selected. Optimal and clear visualization of the puncture target and the puncture route is of utmost importance. A high-contrast image with a low dynamic range, which appears somewhat crispy or “hard” compared to the normal diagnostic US image is preferable. This enables better visualization of needles and other devices used in US-guided procedures. Use of “crossbeam” and other imaging improvement features may reduce reflections from the needle and blur the outline of the needle tip. Further adjustments of image size, field of view, gain, time gain compensation (TGC), depth and number of focal zones may often be necessary to obtain the best visualization of the target and puncture device. Whenever US visibility is an issue, CEUS or fusion imaging should be considered.

Recommendation 1

Ultrasound is safe and effective for selecting punctures site and subsequent guidance. (LoE 4, GoR C). Strong consensus (100%).

Doppler imaging

The use of Doppler in interventional US might be helpful in some circumstances as color Doppler may be used to map the relationship between the target and any vessel that needs to be avoided during puncture [5]. However, vascular structures are occasionally impossible to avoid and the procedural strategy must be directed towards the best approach dictated by the prevailing circumstances [6].

If any doubt exists as to whether the lesion is vascular or avascular, color Doppler should be applied. If this still does not solve the ambiguity, CEUS should be considered.

Recommendation 2

Ultrasound color Doppler can be helpful to avoid inadvertent puncture of vascular structures. (LoE 4, GoR C). Strong consensus (100%).

CEUS

A CEUS-guided intervention can be performed in much the same way as any routine US-guided procedure. Often two injections of contrast may be required: a preliminary injection to identify the lesion and plan the intervention strategy and a second injection to perform the procedure. A continuous contrast infusion through-

out the entire procedure may be used. CEUS is indicated in several situations and aspects of interventional US.

Biopsy from viable areas

With CEUS, the viability of tumor tissue, signified by the presence of vascularity, can be reliably evaluated, and CEUS-guided biopsy increases the diagnostic yield by 10% and decreases the false negative rate especially in large tumors with areas of necrosis [7, 8].

Biopsy of “invisible” or poorly visualized/delineated lesions

When previous CT, MR or PET-CT imaging has demonstrated a suspicious lesion and a biopsy for a definitive diagnosis is required but the lesion is not seen or is poorly visualized with US, CEUS may be helpful in two ways: 1) The target lesion may become “clearly visualized” on CEUS, or 2) Additional lesions that potentially render themselves more accessible to biopsy become evident and can then be biopsied under CEUS guidance [9–11].

Guidance, monitoring and follow-up in percutaneous thermal ablation of abdominal tumors

The ablation volume may be of a similar texture to the surrounding normal tissue on B-mode US, however, the clarity achieved with CEUS is playing an increasingly important role in monitoring post-ablation local recurrence and ablation volume viability, as well as demonstrating new lesions [12–16].

Emerging applications

Besides the indications for CEUS in interventional US described above, a number of other uses may serve as alternatives to existing techniques or offer a possible alternative where no current technique is available. Examples of indications include but are not limited to: A) replacement for a conventional X-ray contrast study, i.e., fistulography (including CEUS via nephrostomy catheter), B) diagnosis and monitoring of all stages of post-procedure bleeding, C) improved visualization of all types of fluid collections other than blood.

Avoidance of interventional procedures

CEUS may prevent patients from undergoing an interventional procedure with the associated morbidity e.g. liver biopsy if CEUS can allow for a definitive diagnosis of a malignant or benign abnormality.

Recommendation 3

CEUS can be helpful to avoid necrotic areas in percutaneous biopsy of intra-abdominal tumors. (LoE 4, GoR C). Strong consensus (100%).

Recommendation 4

CEUS can be helpful in identifying biopsy targets poorly or not visualized with fundamental B-mode. (LoE 4, GoR C). Strong consensus (100%).

Recommendation 5

CEUS is safe, effective and comparable to CT and MRI in percutaneous ablation for guidance and procedural monitoring. (LoE 4, GoR C). Strong consensus (97%).

Guiding techniques

▼
The fundamental technique of INVUS (the puncture principle) is an alignment of two planes, namely the “scan plane” that shows the target pathology on the US screen and the “needle plane” containing the needle (or other INVUS device) approaching the target. Real-time visualization of the needle tip is possible using US due to the reflection from the metal in the needle [17]. The intensity of the display of echoes from the “needle plane” will depend on the needle size, the scanning depth, angulation and the US system. [4].

Needle guiding devices versus free-hand technique

The needle may be inserted parallel to the transducer in the “scan plane” or perpendicular to the transducer, “off the scan plane”. Insertions parallel to the transducer may be performed using a steering device or using a free-hand technique, whereas insertions perpendicular to the scan plane may only be performed using the free hand technique. To become familiar with the principle of US-guided puncture, it is recommended to use a steering device. A steering device is a plastic or metal device attached to the transducer, with a channel for the needle, which may be positioned at different angles (dependent on the US system). The path of the needle is shown on the US machine screen, but misalignment between the scan plane and the needle plane may occur if pressure/torque is applied to the transducer or the needle during the procedure or by patient movement. Prior to the interventional procedure, the target is imaged and a position where the puncture line crosses the target without crossing vital structures such as large vessels is marked on the skin. The steering device usually gives more confidence when inserting the needle, but is compromised by fewer degrees of freedom for needle manipulation during insertion.

In three studies these two techniques were evaluated in US phantoms. The two techniques had the same quality of biopsy specimen in one study, but the guided technique was faster than the free-hand technique (23 seconds versus 32 seconds) especially for less experienced evaluators [18–20]. One study evaluated the effect of training in US-guided biopsies by self-assessment questionnaires and found that training had a significant positive effect [21].

Transducers

If a needle guide is required, a limited number of transducers have this capability and this is vendor-dependent. Transrectal and transvaginal ultrasound-guided interventions may be performed, most often with a needle guiding device attached to the transducer [22].

Fusion imaging

New methods of image fusion and electromagnetic needle tracking enable puncture of targets that are difficult to visualize with US, or of targets located in areas with poor access, for instance in the retroperitoneum or between loops of the bowel. When using image fusion, a previously recorded data set from CT, MR or PET imaging is displayed simultaneously with the real-time US images on the screen in the same plane as the US scanning plane. The images may be shown side by side or with a semi-transparent overlay. Image fusion and electromagnetic needle tracking work by means of an electromagnetic positioning system based on a magnetic transmitter (coil) placed beside the patient and magnetic sensors attached to the transducer and located in the

needle tip of special needles. Before the procedure, a previously recorded data set is uploaded to the system, and a co-registration (alignment) is performed by matching/pairing anatomical points or planes in the data set and the real-time US images [23]. Using electromagnetic needle tracking, the route of puncture is marked electronically on the screen. The needle tip is also specifically marked and when not in the scan plane, alters color and size according to the distance from the scan plane. The method has been used for small lesions in the retroperitoneum and pelvis, where visualization of the needle tip is particularly difficult. Fusion imaging has been successfully evaluated in several studies on focal liver lesions undetectable or difficult to visualize using conventional US, but visible on CT or MR imaging. In one study of 295 lesions undetectable on routine US, 96.5 % were correctly targeted and 90.2 % were successfully ablated [24].

Both in phantom and clinical studies, the rate of success increased when measured by the rate of obtaining an adequate sample [25, 26].

Recommendation 6

A needle guiding device is recommended for deeply located lesions, especially for less experienced users. The biopsy technique to use depends on the examiner's skills and the accessibility of the target. (LoE 4, GoR C). Strong consensus (100 %).

Recommendation 7

Use of an electromagnetic needle tracking device with a free-hand technique has the same success rate as biopsy using a needle guiding device. (LoE 4, GoR C). Strong consensus (100 %).

Recommendation 8

Image fusion with CT or MR may be helpful for ultrasound-guided biopsy in lesions difficult to visualize on ultrasound. (LoE 4, GoR C). Strong consensus (100 %).

Patient information, informed consent, and procedure documentation

Patient information

Patients should be informed about the objective of the planned procedure, the possible complications and alternative procedures that may arise. Written information should be phrased in layman's terms, assuming little knowledge of medical procedures. It should include particulars about the aim, necessity, procedure, possible risks, side effects or complications as well as benefits of the proposed procedure, and information about possible alternatives. Information should be given at an appropriate time to help patients make a decision without any pressure. Written information does not replace the need for oral information, ensuring that the patient has understood the content of the written information and has the opportunity to ask questions. In some cases physical disability, illiteracy or inadequate knowledge and language issues, make oral information the only way of providing individualized information. Professional interpreters should be used when patients are not proficient in a language used by the health care providers. We en-

courage the provision of information leaflets for all minimally invasive procedures and make them available to patients in advance of the procedure. This allows patients to be properly prepared, giving them confidence and helping them to ask related questions prior to signing the consent form.

The European Society for Cardiovascular and Interventional Radiology (CIRSE) and the Society of Interventional Radiology (SIR) provide information on many interventional radiology procedures on their websites [www.cirse.org]. The Royal College of Radiologists (RCR, UK) and the British Society of Interventional Radiology (BSIR) have similar information available for download from the RCR website [www.rcr.org].

Informed consent

Informed consent should be obtained when the planned procedure is complex and involves significant risk and/or side effects and when there may be consequences for the patient's employment or social or personal life. Consent might be given in writing or orally depending on the national legislation, and should always be documented in the patient record. It is important to establish that the patient has sufficient information to make an informed decision to proceed with the procedure and there should be a detailed face-to-face discussion with the patient.

Consent must be given freely, without pressure from any person, which would invalidate the consent process. Patients should be advised honestly, accurately and clearly, based on the best interest of the patient with due acknowledgement of the risks and benefits involved. Consent should always be obtained before sedation is given. CIRSE has published recommendations on informed consent stating the details of the proposed treatment. It requires the disclosure of all significant risks or substantial risks of grave adverse consequences [www.cirse.org].

Legal aspects

Informed patient consent provides the lawful justification for carrying out an interventional procedure. There is no legal requirement for consent to be written, or be in a particular form. However, a signed written consent form provides documentary evidence of consent and is recommended for any intervention carrying risks. Standardized consent forms are usually provided in all hospitals. In order for consent to be valid, it must be: 1) given by someone who is competent (has legal capacity), 2) sufficiently informed and 3) freely given. Consent may be withdrawn at any time, even after the form has been signed, and should lead to immediate discontinuation of a procedure.

A patient is deemed capable of consenting or refusing the procedure irrespective of legal age if he/she can: 1) understand the information relevant to the decision, 2) retain the information long enough to make a decision, 3) weigh the information and make a choice and 4) communicate the decision. It is the responsibility of the doctor to be aware of the valid legislation and ethical guidelines in their region. If procedures are performed as part of a clinical research study, formal written consent to participate in the study is used, and the written patient information and consent form should be approved by the institutional committee for ethics in research.

Procedure documentation

The informed consent should be documented and preserved in the patient record as an important legal document. The operator who is to perform the procedure should obtain the patient's consent, but this may be delegated to a suitably trained and qualified

physician who has sufficient knowledge of the proposed procedure and understands its risks.

Recommendation 9

Information about the INVUS procedures must be given to the patient or their representative. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 10

Informed consent is mandatory prior to all INVUS procedures and should be documented in the patient record. (LoE 5, GoR D). Strong consensus (100%).

Patient preparation



Preparation of the patient who is undergoing any US-guided intervention depends on the type of procedure and the status of the patient. The preparation includes patient information and consent and precautions to minimize procedure-related complications. There are substantial national variations in patient preparation and the conducting of INVUS procedures.

Precautions to minimize hazards

The INVUS procedure should be performed in a calm atmosphere of competence and trust. The planned procedure should have a clear indication, and the result should either be therapeutic or diagnostic. For diagnostic procedures, the result should have an impact to alter the treatment plan for the patient. Written protocol instructions for the INVUS procedure increase patient safety, and secure a more uniform procedure. Some departments also apply checklists to ensure that the patient is completely prepared and all equipment is present. Application of local anesthetics, potentially combined with sedation should be considered part of every INVUS procedure. Some INVUS procedures with fine needles are performed on an outpatient basis, while others require hospitalization. Patients should be dressed accordingly.

Relevant blood tests including coagulation status plus enquiring about anticoagulative medication is mandatory and the results should be available before every interventional procedure.

Fasting is beneficial with regards to possible complications regarding general anesthesia. However, fasting status does not substantially influence visualization during the procedure [27]. The use of water, laxatives and anti-flatulent medication may improve the visualization of the retroperitoneal area in some patients [28].

For most INVUS procedures the risk is low for contamination if a procedure is performed under sterile conditions. A single dose of antibiotic prophylaxis is recommended at many centers for procedures in which sterile cysts are traversed and after endoluminal interventional procedures such as transrectal or transvaginal biopsies.

Post-interventional observation

Clinical observation is needed for at least two hours, when most complications tend to arise. In uncertain cases a repeat US examination should be performed prior to discharge. The timing of discharge is dependent on the invasiveness of the procedure, and hospitalization is recommended in the case of postprocedural complications.

Recommendation 11

Patient preparation should include procedure information, informed consent, relevant medical history and laboratory data. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 12

An INVUS procedure should have an indication, and the results should influence patient management. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 13

Antibiotic prophylaxis is not recommended, but should be considered on an individual basis. (LoE 5, GoR D). Strong consensus (100%).

Local anesthesia and sedation

Many of the INVUS procedures are relatively rapid to perform and have a low to moderate pain level so that they are ideally suited to be conducted solely under local anesthesia.

Local anesthesia technique

A good anesthetic technique is important since effective local anesthesia may eliminate the need for sedation. The site of injection should be prepared/sterilized with antiseptic or alcohol to reduce infection. Alcohol wipes have been shown to be as effective as chlorhexidine or iodine. Shaving the puncture area might be necessary to obtain full skin sterility. After the preparation of the skin a local anesthetic agent is administered using the thinnest possible (22-gauge or 25-gauge) needle. Typically 10 ml of 1% lidocaine is an appropriate dose. However, the dose depends on the location and depth of the intended target. Local anesthetic administration commences with the subdermal injection of a sufficient volume of anesthetic solution to raise the skin followed by a subcutaneous injection/infiltration. The needle is then further advanced into the abdominal or intercostal muscle and eventually to the organ capsule (liver or kidney). For liver biopsies, when approaching the liver capsule, local anesthetic should be instilled during a short breath-hold to avoid injuries to the capsule [29]. To avoid intravascular injection, aspiration should be performed before the local anesthetic solution is injected and the needle repositioned until no return of blood is elicited by aspiration. Importantly the absence of blood in the syringe on aspiration does not guarantee that intravascular injection has been avoided. Some interventionalists prefer to administer local anesthesia under US guidance to ensure adequate analgesia along the planned puncture tract. Vasoconstrictors (e.g. epinephrine) are used to reduce absorption of local anesthetics into the systemic circulation [30]. Adding epinephrine to lidocaine solutions causes local vasoconstriction and increases the duration of analgesia and may also reduce post-procedural bleeding from the puncture site [31].

For patients with a particular aversion to percutaneous puncture, a topical local anesthetic cream can be used prior to the procedure. INVUS procedures using very thin needles may be performed without any anesthesia.

Some INVUS procedures are empirically painful (and often protracted) and therefore require sedation in addition to the local anesthesia. Examples of these include nephrostomy, ablation, and transrectal or transvaginal drainage. Furthermore, anxious or confused patients may benefit from sedation. Almost all ablations and all INVUS procedures in children are performed under general anesthesia.

Sedation comprises a continuum of drug-induced states ranging from minimal sedation (anxiolysis) to general anesthesia. Drugs that are used are: anxiolytics, benzodiazepines, sedative-hypnotics, antihistamines and narcotics. Drugs may be administered orally or by a non-oral route.

Minimal sedation or anxiolysis is a state during which the patient responds normally to verbal commands. Although cognitive function and coordination may be impaired, ventilatory and cardiovascular functions are unaffected.

Moderate sedation (usually referred to as "conscious sedation") is a minimally depressed level of consciousness in which the patient retains continuous and independent ability to maintain protective reflexes and a patent airway and to be aroused by physical or verbal stimulation.

Deep sedation is a depression of consciousness during which the patient cannot be easily aroused but responds to repeated or painful stimulation. Independent ventilatory function may be impaired and the patient may require assistance in maintaining a patent airway.

General anesthesia is a controlled state of unconsciousness in which there is a complete loss of protective reflexes, including the ability to maintain a patent airway independently and to respond appropriately to painful stimulation. The procedure is performed under the responsibility of an anesthetist.

Administration of moderate and deep sedation is a complex procedure with several potential complications and should only be done under the responsibility of a person with documented knowledge and experience regarding the pharmacology, indications and contraindications for the use of sedative agents, as well as the role of pharmacologic antagonists. The type of anesthetic used and the degree of sedation should always be evident in the medical records.

Recommendation 14

Administration of local anesthesia and sedation may be beneficial in terms of patient comfort and safety and should be considered for INVUS procedures. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 15

Administration of drugs for sedation should be reserved for personnel with knowledge and experience according to national legal regulations (LoE 5, GoR D). Strong consensus (97%).

Hygiene management in INVUS**General hygienic requirements**

Hygienic requirements have to be tailored to the specific diagnostic procedure being performed.

Personal protective equipment and coverings

There is a differentiation between major and minor invasive procedures with or without an increased risk of infection. For minor invasive procedures that are not associated with an increased risk of infection, it is sufficient to perform a hygienic hand wash, wear a protective decontaminated or disposable gown and sterile gloves. Major procedures or minor invasive procedures that are associated with an increased risk of infection or body fluid splashes additionally require a surgical cap, surgical mask, sterile protective surgical gown and sterile gloves [32]. Sterile gloves are donned over the air-dried or sterile towel-dried hands following surgical hand antisepsis (surgical scrub). It is thought that surgical masks prevent contamination of medical personnel and can also protect patients, especially immunocompromised patients, although there is little evidence to support this. Further research is needed [33].

Disposable transducer covers

Only sterile, disposable transducer covers should be used in interventional procedures [34]. Sterile transducer covers do not eliminate the need for transducer decontamination [35–37]. Sterilization of the transducer after use is necessary in procedures with a high risk of contamination.

Ultrasound gel

The ultrasound gel used in interventional ultrasound procedures should be sterile and a new sachet should be used for each patient [38–46].

Hand and skin disinfection

Hand antisepsis is the most important measure for protecting both staff and patients in everyday practice. Fingernails should be trimmed short and round. Nail polish and artificial nails should not be used, as these shield microorganisms from the effects of hand antiseptics. Hands should be free of injuries, especially in the nail bed, and free of inflammatory processes. Watches, jewelry, and rings should not be worn. Hygienic hand disinfection is always performed before and after patient contact, regardless of whether protective gloves will be or have been used. Contact time of disinfectant varies with the agent, the infection risk of the procedure and the type of skin [47, 48]. In interventional US procedures such as percutaneous liver biopsy or the percutaneous aspiration of ascites, hygienic hand antisepsis is considered sufficient. In other procedures such as PTCd, nephrostomy, or tumor therapies that are classified as an operative or minor invasive procedure with an increased risk of infection, an aseptic technique is essential [49–51]. The skin preparation begins with thorough cleansing of the skin with sterile sponges held on (Kocher) forceps. The boundaries of the skin prep should be wide enough to allow for possible adjustment of the entry site, and therefore of the sterile drapes, without contaminating the puncture needle.

Decontamination of ultrasound transducers

Ultrasound transducers used in image-guided interventional procedures are generally classified as semi-critical items (objects that come into contact with mucous membranes or skin that is not intact). Direct transducer contact with critical medical products should be avoided during the procedure despite the use of sterile, disposable transducer covers. Critical medical products, which include ultrasound transducers that are used intraoperatively, or through which a needle will be introduced (e.g. for abscess drainage or PTCd) must be sterilized. After every exami-

nation, residual US gel should be carefully removed with a disposable towel and the transducer cord wiped with a towel moistened with cleanser, followed by disinfection with a virucidal agent [52, 53]. The sterilization process should always conform to standard operating procedures.

Decontamination of ultrasound accessories

Whenever available, the biopsy instruments such as cannulae, hollow needles, etc. should be disposable, single-use items [54]. Otherwise, the biopsy instruments should be submitted to machine decontamination (cleaning and disinfection) followed by sterilization. All steps require detailed standard operating instructions.

Recommendation 16

A hygiene plan should be established in every department. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 17

Hand hygiene is the most important measure for preventing infection. (LoE 2a, GoR B). Strong consensus (100%).

Recommendation 18

A limited hygiene program is sufficient when there is a low risk of infection. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 19

A strict hygiene program is required for procedures with a high risk of infection. (LoE 5, GoR D). Broad agreement (93%).

Recommendation 20

A sterile ultrasound transducer or a sterile disposable transducer cover must be utilized if in contact with a needle. (LoE 5, GoR D). Broad agreement (93%).

Recommendation 21

The ultrasound transducer should be adequately cleaned after every examination and procedure. (LoE 4, GoR: C). Strong consensus (97%).

Puncture routes and accessing techniques

There is a lack of evidence in the literature in this area.

Choice of puncture route

One of the most important points for a successful US-guided intervention is choosing the best path for the target lesion. Although not always possible, the shortest route should be preferred. If any “risky” structure is present on the anticipated pathway, then a longer but still safe route may be chosen. The shortest route may not be possible for other reasons e.g. natural bony structures (costal cartilage, iliac bone, etc.), subcutaneous

emphysema, overlying blood vessels or bowel gas, skin lesions or fixed cutaneous devices.

The distance from the skin puncture site to the target should be measured using the US machine, so that the correct needle length can be selected. Furthermore, although not always practical, an estimate of the route angle may be calculated to aid puncture.

The stomach and small bowel can be traversed usually without any consequences, particularly with fine needles, but colon puncture should be avoided because of the infection risk. Transcolonic needle aspiration of an abscess might in rare cases be the only treatment option.

Puncture routes for specific procedures may vary. For biliary drainage, a right intercostal puncture is usually preferred. However, a subxiphoid puncture route is necessary for left biliary duct drainage. Nephrostomy is usually performed from a postero-caudal route, targeting a lower pole calyx. The renal pelvis should be outside the puncture route to avoid damage to the hilar vessels. When puncturing an abdominal hydatid cyst, needle entry into the cyst should traverse the organ parenchyma to prevent subcapsular cyst fluid leakage.

Penetrating organs in INVUS

Puncture should be rapid and during breath-hold so that the capsule (liver, kidney and spleen) is minimally traumatized and bleeding is potentially avoided. In uncooperative patients, breathing movement during capsular penetration may cause misalignment of the needle and the transducer with subsequent impaired needle visualization.

Hazardous organs on INVUS

Traditionally the spleen has been considered a hazardous organ for puncture, primarily because of the risk of bleeding. However, there is evidence that the risk of splenic bleeding is not significantly higher than liver or kidney bleeding after puncture [55].

Recommendation 22

The safest access route with the best visibility on US should be used in interventional procedures. (LoE 5, GoR D). Strong consensus (97%).

Avoidance of complications

Generally US-guided interventions have a low complication rate. General complications include bleeding, infection and unintentional organ injury. Complications may be specific to the target and type of intervention as well as patient comorbidity and comedication. Periinterventional patient monitoring is crucial for the management of complications.

Classification of complications into minor and major is based on clinical outcome in accordance with the guidelines of the Society of Interventional Radiology (Table 1) [56]. Large retrospective surveys indicate that US-guided fine-needle biopsy (needle diameter up to 1.0 mm) has a complication rate ranging between 0.51% and 0.81%, including a major complication rate of between 0.06% and 0.095% [57, 58]. The mortality rate ranges from 0.0011 to 0.018% [58, 59]. Retrospective and prospective single-center studies of liver and abdominal organ biopsies with large numbers using a needle diameter > 1.0 mm have shown higher complication rates from 0.4% to 2.5% [60–64]. In a recent prospective Ger-

man multicenter study, deaths occurred in 0.05% of percutaneous US-guided intraabdominal interventions performed under continuous US guidance [65].

Minor complications like pain occur in 5–10% of US-guided interventions [62, 66, 67]. However, in these retrospective studies, pain assessment is based on medical records. In a retrospective single-center analysis of 1923 diagnostic and therapeutic punctures in the liver and pancreas, postinterventional pain treatment was reported by 10.5% patients [62]. Vasovagal reactions range from minor symptoms associated with pain in 0.13% liver biopsies to severe vasovagal reactions in 2.8% of patients undergoing prostatic biopsy [68–70].

The relative frequency of organ-specific major complications (pancreatitis, pneumothorax, bile leakage) relates to the inclusion of various targeted sites in the statistical data. Retrospective and prospective single-center studies with large numbers reporting on liver and other abdominal organ biopsy with needle diameters > 1.0 mm have shown higher complication rates ranging from < 0.4% to 2.5% [61–64]. In the UK national audit evaluating liver biopsy including 3486 patients, the rate of major complications was 0.43% and 4 hemorrhage-related deaths occurred (0.11%) [71]. In a prospective study in France, 2082 liver biopsies were performed by senior physicians in 76% of cases, by junior physicians in 24% of cases, by hepato-gastroenterologists in 89%, and by radiologists in 11% [72]. In this study, the rate of severe complications was 0.57% and increased with the number of needle passes and decreased with the experience of the operator, use of atropine, and US guidance. US guidance was used in 56% of biopsies and sedation was given in 0.46% of patients. In an Italian study of 203 percutaneous liver biopsies in hepatitis C patients, the rate of major bleeding was 0.4% [73]. In the prospective German multicenter study including 8172 intraabdominal interventions, the rate of major bleeding was 0.43% [65].

Needle tract seeding

In three large surveys the range of needle tract seeding was 0.003% (2/66 397 fine-needle biopsies), 0.0063% (6/95 070 fine-needle biopsies), and 0.009% (1/10 766) [58, 59, 74]. However, these data are likely to understate the true incidence as tumor seeding generally presents after a latency period of several months to as long as 25 months after needle biopsy [74–77]. More recent studies indicate a higher risk of malignant needle tract seeding after both diagnostic and therapeutic US-guided interventions for malignant tumors. The risk for tumor seeding differs between specific targets sites and tumor entities [78].

Pain

In the UK national audit on image-guided or image-assisted liver biopsy, the frequency of pain ranged from minor pain (< 30%) to major pain (< 3%) based on patients records [71]. Pain is defined as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage” [79]. For the assessment of pain, numeric rating scales are a standard method to evaluate individual pain [80]. A numeric rating scale is a scale ranging from “0” to “10” in whole numbers. “0” means no pain, “10” is the worst pain conceivable. The severity of pain can differ strikingly between individuals undergoing the same interventional procedure. Prospective pain assessment during US intervention is rarely addressed in published data. In a prospective French survey with more than 2000 liver parenchyma biopsies, the level of pain was 2.8 ± 2.6 [72]. Levels of pain were higher in women and patients with hepatitis C.

Table 1 Classification of complications based on SIR [Society of interventional Radiology Standards] [101].

minor complications	
A	no therapy, no consequence
B	nominal therapy, no consequence; includes overnight admission for observation only
major complications	
C	require therapy, brief hospitalization (<48 hours)
D	require major therapy, unplanned increased level of care, prolonged hospitalization (>48 hours)
E	permanent sequela
F	death

Pain levels decreased when the biopsy was performed by experienced physicians (>150 liver biopsies). In a small prospective 1-year study, the pain of 223 patients undergoing US-guided predominantly diagnostic punctures of the liver and pancreas was assessed using numeric rating scales immediately after the intervention (<10 min), one hour after puncture and four hours after puncture [81]. The average level of pain was 2.98 at puncture. The pain was of short duration, and decreased to almost normal after 4 hours. Women experienced significantly higher pain levels than men. Younger patients (<50y) experienced more pain than older patients. Individual pain perception of patients was significantly lower when the intervention was performed by an experienced operator (>500 biopsies). In this study 13.9% of patients received analgesic medication. In liver parenchyma biopsy, US guidance can significantly reduce pain compared to no US guidance based on pain questionnaires 2 weeks after biopsy [82].

Risk factors for major bleeding complications

Center volume and operator experience

There is limited data available for the assessment of bleeding complications in relation to the number of procedures performed; "center volume". In a prospective study conducted in 30 centers, the overall rate of major bleeding complications ranged from 0–1.48%. The frequency of major complications in four high-volume centers (defined as >500 interventions in 2 years) was slightly lower than in low-volume centers. Information on the relation of complication rates to operator experience is based almost exclusively on percutaneous liver biopsies. In a Swiss survey evaluating 3501 liver biopsies (32.3% ultrasound-guided), the complication rate among internists performing <12 biopsies per year (1.68%) was higher than that of physicians performing >50 liver biopsies per year (0%). Gastroenterologists had lower complication rates (0.11%) than internists (0.55%) [83]. Similar results were reported in a British survey and in a retrospective analysis of percutaneous liver and renal biopsies from two U.S. centers [84, 85]. In one retrospective study on liver biopsies, the complication rate was 0.7% for inexperienced operators (<150 liver biopsies) compared to 2.0% for experienced operators (≥150 liver biopsies) [68]. In two prospective and two retrospective studies exclusively with liver biopsies, the complication rate of major bleeding was not influenced by the physician's experience [69, 86–88]. A prospective French study analyzed 600 US-guided liver biopsies and found no significant difference in complication rates between experienced operators (>150 liver biopsies) and inexperienced operators (<15 liver biopsies). This series included only one major complication and inexperienced operators performed only 25% of the biopsies [69]. A prospective

study in the Netherlands analyzed 464 US-assisted liver biopsies (US used solely to locate the biopsy site) and found no significant difference in complication rates between experienced operators (>50 liver biopsies) and inexperienced operators (<50 liver biopsies). The overall incidence of major complications in this study was 0.6% (3/464) [87].

Technical aspects

Needle diameter, needle type, needle passes

Data from surveys with high case numbers have yielded controversial results on the diameters and types of biopsy needle used [58, 83]. Retrospective analyses of parenchymal liver biopsies and biopsies of focal liver lesions have consistently shown higher complication rates associated with the use of cutting biopsy needles compared with aspiration needles [61, 68, 89]. Comparative studies do not support the perception that needle diameters between 18 gauge and 14 gauge (1.2–1.6 mm) are associated with a higher biopsy risk than fine needles [90–95]. In an experimental animal study on liver punctures at laparotomy using only Chiba-type needles, larger needle diameters generally produced more bleeding. However, the differences were statistically significant only when comparing 14- with 16-G needles and 16-G needles with the group of 18-, 20-, and 22-G needles [96]. A prospective study in France of 2082 liver biopsies showed the rate of severe complications was 0.57% and increased with the number of needle passes (26.6% with one pass vs. 68% with 2 and more passes ($p < 0.001$)) [72]. A prospective study in Germany of 8172 intraabdominal interventions showed most punctures were performed with a single needle pass (63.5%), with two needle passes occurring in 24.9% and >2 needle passes in 11.6%. There was no significant increase in major bleeding complications with 2 needle passes versus 1 needle pass and >2x needle passes versus 1 needle pass [64]. Other studies have also reported that the number of needle passes has no effect on the rate of post-biopsy complications [97, 98].

Patient-related risk factors

Liver cirrhosis and INR

Liver cirrhosis itself is not a risk factor for major bleeding complications as long as the INR and platelet values are within the normal range. In a study of 449 cirrhotic and 1474 non-cirrhotic patients, the rate of post-interventional major bleeding complications was 6.1% in cirrhotic patients with an INR >1.5 and 0.5% in cirrhotic patients with an INR ≤1.5 [62]. This finding is in good accordance with data from the prospective German multicenter study showing a nearly 10fold higher risk of major bleeding for patients with an INR >1.5 compared to a normal INR [65].

Inherited coagulation disorders

Abdominal INVUS in patients with inherited coagulation disorders and low clotting factor levels can cause life-threatening bleeding. Clotting factor levels must be assessed and treatment with factor concentrates prior to INVUS should be undertaken based on the individual levels of clotting factors. Percutaneous liver biopsy in patients with factor VIII deficiency can be safely performed using either bolus or continuous infusion of recombinant factor VIII [99, 100].

Anticoagulants and antiplatelet drugs

The risk for bleeding complications is higher in patients with a medication interfering with platelet function or plasma coagulation.

Warfarin (Coumadin) is a contraindication for intraabdominal INVUS. Warfarin should be withdrawn, and the procedure bridged with heparin until the INR ≤ 1.5 . If the patient is on low-molecular weight heparin (LMWH), withholding one dose prior to the percutaneous intraabdominal image-guided intervention is suggested. The bleeding risk associated with aspirin must be weighed against the important implications of aspirin withdrawal (e.g. the risk of coronary and cerebrovascular events). In a retrospective review of 15 181 image-guided percutaneous core biopsies, the rate of bleeding was not significantly increased in 3195 patients taking aspirin within 10 days prior to biopsy compared with 11 986 patients not taking aspirin (0.6% versus 0.4%; $p=0.34$) [60]. In the SIR guidelines for the periprocedural management of coagulation status and hemostasis risk in percutaneous image-guided interventions [101, 102], pre-interventional withholding of aspirin for five days is only recommended for procedures with significant bleeding risk like renal biopsy, biliary interventions, nephrostomy tube placement and complex radiofrequency ablation. For procedures with a moderate risk of bleeding like transabdominal liver biopsy or intraabdominal abscess puncture or drainage, the withholding of aspirin is not recommended.

Pre-interventional withdrawal of thienopyridines, glycoprotein IIb/IIIa inhibitors or direct thrombin inhibitors is currently recommended for percutaneous intraabdominal image-guided interventions as life-threatening hemorrhage has been reported [101, 102]. Patients with hemostatic disorders might be treated with K-vitamin, fresh frozen plasma, or platelet concentrates dependent on the type of disorder for optimizing the coagulation status prior to an interventional procedure.

Intervention in patients on long-time anticoagulative therapy (e.g. heart valve prosthesis, atrial fibrillation, or venous thromboembolism) is challenging as interrupting anticoagulation increases the risk of thromboembolism. Treatment with vitamin K antagonists can be temporarily replaced with low-molecular weight heparin. Weighing the bleeding risk, cardiovascular risk, and risk of thromboembolism should always be an interdisciplinary, case-by-case decision.

Management of bleeding complications

Timing

Bleeding complications after a US-guided procedure occur early, the majority within 24 hours, and rarely require invasive management [62]. Delayed complications, such as bleeding occurring after 24 hours, are extremely rare.

Assessment of bleeding risk

The assessment of bleeding risks before a percutaneous US-guided procedure is based mainly on the patient's history and clinical data. Routine determination of thromboplastin time (Quick value), INR, PTT, and platelet count is recommended before any elective intervention, both for legal reasons and for best practice. Global coagulation tests in themselves are inadequate for the assessment of bleeding risk [103 – 105]. Normal or only mildly reduced coagulation parameters do not prevent bleeding complications [61, 83, 106].

Postinterventional care and detection of bleeding complications

Every US-guided biopsy or therapeutic intervention should be followed by appropriate postinterventional care. Direct manual compression of the puncture site for 5 to 10 minutes prevents bleeding. For intraabdominal or vascular (arterial) interventions, additional

continued compression using adhesive compression bandages and sandbags, and bed rest (usually 4 hours) is recommended. The large majority of complications occur immediately or within 4–6 hours following intervention, more than 80% occur within 24 hours [60 – 62, 107 – 109]. In one retrospective study of 629 percutaneous liver biopsies, clinically overt bleeding complications were documented in the files of 10 patients (1.6%). In 7 out of 10 symptomatic patients, signs of bleeding complications after liver biopsy were not apparent before day 2 of bleeding [110].

After intraabdominal interventions, vital signs should be checked every 30–60 minutes (general status, pain or other symptoms, blood pressure, pulse) for up to 4–6 hours. If there are clinical signs suggestive of a complication (pain, discomfort, hemodynamic instability) or a significant hemoglobin decline (>2 points), the first investigation is US, which may be supplemented by other imaging studies (e.g. CT, angiography). In cooperative and mobile patients with no apparent risk factors, an observation period of several hours to 24 hours should be adequate after a US-guided intraabdominal biopsy. The discharge interview with the patient should note the possibility of late complications and describe their symptoms, and this information should be documented.

Ultrasound diagnosis of bleeding

In the prospective DEGUM INVUS study of 8172 US-guided intraabdominal interventions, free fluid within 24 hours after intervention (detected on US) was seen in 443 patients (5.42%). However, the rate of major bleeding was only 0.43%.

Postbiopsy Doppler: Visualization of flow along the needle tract in immediate postbiopsy Doppler ("patent tract sign" reported in 12% in one study on 352 US-guided liver biopsies) is self-limiting within 5 minutes in most cases [111]. A patent track that was demonstrable more than 5 minutes post-biopsy was associated with significant bleeding in 4/5 patients.

A perirenal hematoma detectable after percutaneous renal biopsy is a predictor of clinically significant bleeding complications (positive predictive value [PPV] 43%, negative predictive value [NPV] 95%) [112, 113].

Contrast-enhanced ultrasound: CEUS is an excellent and repeatable study for detecting persistent active bleeding or catheter malposition [114, 115].

Treatment of bleeding complications

In the event of complications, immediate treatment should be instituted and include basic stabilizing measures (usually intensive care management) plus any complication-specific interventions that are required. Pain without a clinically or radiologically apparent cause is managed with standard analgesics (e.g., novaminsulfon and/or pethidine, fentanyl, or piritramide). Infectious complications require appropriate antibiotic therapy, which should take into account any preinterventional antibiotic prophylaxis. If significant bleeding occurs, coagulation tests should be performed. Depending on the test results and known risk factors, replacement therapy or the early intravenous administration of tranexamic acid or desmopressin may be indicated. Hemostasis can usually be obtained with conservative measures. In the prospective DEGUM INVUS study, major bleeding complications with changes of vital signs, shock or intensive care management and the need of erythrocyte transfusion occurred in 19 patients (0.23%). Major bleeding complications with subsequent surgical bleeding control were observed in 8 patients (0.10%). Major bleeding complications with subsequent radiological embolization were observed in 4 patients (0.05%). The possibility of

a US-guided intervention should always be considered, such as the CEUS- or color-Doppler-guided injection of human thrombin solution, fibrin glue, cyanoacrylate, or hemocoagulase into a pseudoaneurysm or intraparenchymal bleeding site [116, 117].

Recommendation 23

Routine ultrasound examination after ultrasound-guided interventions is not necessary in asymptomatic patients. (LoE 5, GoR C). Strong consensus (97%).

Recommendation 24

The rate of bleeding complications is increased in patients with an INR > 1.5. (LoE 1b, GoR A). Strong consensus (100%).

Recommendation 25

The rate of bleeding complications is increased in patients with low platelets, although the threshold has not been definitively established (< 50 000 – 100 000/ul). (LoE 2b GoR B). Strong consensus (100%).

Recommendation 26

The rate of bleeding complications is increased in patients taking non-acetylsalicylic acid antiplatelet drugs or anticoagulants. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 27

Acetylsalicylic acid prescribed for secondary prevention need not be stopped in low risk procedures. (LoE 2b, GoR B). Broad agreement 88 %.

Recommendation 28

In patients on antiplatelets and/or anticoagulants, a risk assessment balancing thromboembolic events versus bleeding should be performed prior to INVUS. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 29

Decision on suspension of antiplatelet drugs and/or anticoagulants or delay of the procedure should be made based on an individual risk assessment. (LoE 5, GoR D). Strong consensus (100%).

Recommendation 30

Complications that arise in association with ultrasound-guided interventions should be documented. (LoE 5, GoR D). Strong consensus (97%).

Organization of INVUS



Training on biopsy phantoms and simulators

Technical improvements in image quality and haptic feedback have made digital simulators more realistic and relevant to achieve a level of competence in the course of performing INVUS. Studies indicate a shorter learning curve by adding simulator-based training to clinical practice [118 – 122]. Learning INVUS should always be based on knowledge with non-interventional US imaging of the area of interest. Competence training in INVUS should start on a phantom.

The aims of phantom or simulator training can be:

1. To provide skillfulness in mastering the equipment and to integrate imaging and intervention.
2. To increase skillfulness in hitting a target in a simulated environment (sensory-motor skills).
3. To develop and maintain skillfulness in new procedures and procedures not performed on a daily basis.

In order to meet levels 1 and 2, simple phantoms can be easily made with tofu, gelatin or agar with the addition of different scatterers. Targets of different sizes may be molded in the same material or objects such as olives, grapes or peas may act as targets of different sizes. These phantoms have a lifetime of up to 3–4 weeks, prolonged by the addition of antiseptics. A more durable material simulating realistic US qualities can be made using paraffin wax gel for a INVUS phantom [123]. Using the same equipment as in a clinical situation brings realism to the phantom training, which may be more important than the actual realism of the target. To practice and maintain skillfulness in complex and rarely performed procedures, the introduction of more sophisticated commercial phantoms (full procedure trainers) which mimic the anatomy may be a good investment [124].

Interventional phantoms used with real interventional needles have a limited life span, and computer simulations may be adequate in order to reach level 3. Another advantage of computer simulators is that training can be performed individually without occupying or having expensive clinical equipment at hand. The disadvantage is that the clinical equipment is not used in the simulation situation, and hands-on realism is not part of the training. Web-based teaching resources are also available, and have been shown to be as efficient as lectures in increasing competence in US-guided vascular access [125].

Who should perform interventional ultrasound?

Interventional ultrasound is performed both by radiologists and by clinical specialists. The organization of the INVUS service may vary from country to country and from hospital to hospital, and is based on local traditions. A common model is that the radiological department provides a broad range of image-guided procedures including US-guided interventional procedures for therapy or for diagnosis. In addition, the clinical specialists provide selected procedures frequently used in their patient populations, some which are not in the armamentarium of radiologists. Some practitioners have advocated that image-guided therapy should become a new specialty [126].

Independent of the organization, proper training is of utmost importance, performed under supervision with an adequate number of procedures performed over time to maintain and develop the skills in order to uphold patient safety and comfort.

National and European courses

Courses in interventional ultrasound are held by different medical ultrasound societies and by national providers of medical specialties as part of a curriculum. In some countries competence in medical ultrasound is formalized in three different levels achieved by attending courses and documented supervised US examinations. In other countries quality assurance is more informal, the learning is tutor-candidate based, and the tutor decides when the candidate has reached adequate competence to perform an INVUS procedure. The Euroson Schools comprise a series of ultrasound teaching courses and INVUS [courses www.efsumb.org/euroson-sch/euroson-school.asp].

Online US learning resources are important and provide knowledge to all who have access to the internet. The EFSUMB course-book is an example of an up-to-date extensive US course freely available online [www.efsumb.org/ecb/ecb-01.asp]. This book has a chapter dedicated to INVUS and the book is also available in a more comprehensive student edition on the same web page. The EFSUMB web page also contains a verified learning site where users can register and achieve verification of their educational activities online. EFSUMB encourages competent centers to arrange courses in INVUS and supports the course curriculum by endorsing such courses of high quality [www.efsumb.org/vllink/index.asp]. The site includes web atlases and other educational material from previous Euroson schools and a list of upcoming EFSUMB-endorsed courses including specific courses in INVUS.

EFSUMB levels of interventional ultrasound expertise

In 2007 EFSUMB issued a document defining the minimal training requirements for the practitioners of medical ultrasound [www.efsumb.org/guidelines/2009-04-14apx1.pdf]. The European societies of Ultrasound in medicine and biology are urged to pursue training for three different levels of competence in ultrasound. INVUS is only mentioned at levels 2 and 3, which implies that INVUS builds on competence and experience in noninvasive ultrasonography of the relevant organ system.

A tool for the assessment of ultrasound competence across multiple applications has been established by a Delphi consensus survey conducted in several countries and clinical applications resulting in the Objective Structured Assessment of Ultrasound Skills (OSAUS). This is a scoring tool for the assessment of current US competence during training [127].

Recommendation 31

Ultrasound interventional procedures on phantoms improve skill and are useful before commencing clinical INVUS training. (LoE 2b, GoR B). Strong consensus (100%).

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References

- McGahan JP. The history of interventional ultrasound. *J Ultrasound Med* 2004; 23: 727–741
- Lutz H. Interventional Ultrasound: Introduction and Historical Background. In: Dietrich CF, Nuenberg D eds. *Interventional Ultrasound: Practical Guide and Atlas*. Thieme Publishers; 2014
- Dietrich CF, Lorentzen T, Sidhu PS et al. An introduction into the EFSUMB guidelines on interventional ultrasound. *Ultraschall in Med* 2015; 36: 460–463
- Nolsoe CP, Lorentzen T, Skjoldbye BO et al. The basics of interventional ultrasound. *Ultraschall in Med* 2007; 28: 248–263; quiz 264, 267
- Lencioni R, Caramella D, Bartolozzi C. Percutaneous biopsy of liver tumors with color Doppler US guidance. *Abdom Imaging* 1995; 20: 206–208
- Polakow J, Ladny JR, Dzieciol J et al. Ultrasound guided percutaneous fine-needle biopsy of the liver: efficacy of color doppler sonography. *Hepatogastroenterology* 1998; 45: 1829–1830
- Bang N, Bachmann Nielsen M, Vejborg I et al. Clinical report: contrast enhancement of tumor perfusion as a guidance for biopsy. *Eur J Ultrasound* 2000; 12: 159–161
- Wu W, Chen MH, Yin SS et al. The role of contrast-enhanced sonography of focal liver lesions before percutaneous biopsy. *Am J Roentgenol* Am J Roentgenol 2006; 187: 752–761
- Schlottmann K, Klebl F, Zorger N et al. Contrast-enhanced ultrasound allows for interventions of hepatic lesions which are invisible on conventional B-mode. *Z Gastroenterol* 2004; 42: 303–310
- Yoon SH, Lee KH, Kim SY et al. Real-time contrast-enhanced ultrasound-guided biopsy of focal hepatic lesions not localised on B-mode ultrasound. *Eur Radiol* 2010; 20: 2047–2056
- Sparchez Z, Radu P, Zaharia T et al. Usefulness of contrast enhanced ultrasound guidance in percutaneous biopsies of liver tumors. *J Gastrointest Liver Dis* 2011; 20: 191–196
- Lorentzen T, Skjoldbye BO, Nolsoe CP. Microwave ablation of liver metastases guided by contrast-enhanced ultrasound: experience with 125 metastases in 39 patients. *Ultraschall in Med* 2011; 32: 492–496
- Liu F, Yu X, Liang P et al. Contrast-enhanced ultrasound-guided microwave ablation for hepatocellular carcinoma inconspicuous on conventional ultrasound. *Int J Hyperthermia* 2011; 27: 555–562
- Lu MD, Yu XL, Li AH et al. Comparison of contrast enhanced ultrasound and contrast enhanced CT or MRI in monitoring percutaneous thermal ablation procedure in patients with hepatocellular carcinoma: a multicenter study in China. *Ultrasound Med Biol* 2007; 33: 1736–1749
- Frieser M, Kiesel J, Lindner A et al. Efficacy of contrast-enhanced US versus CT or MRI for the therapeutic control of percutaneous radiofrequency ablation in the case of hepatic malignancies. *Ultraschall in Med* 2011; 32: 148–153
- Nishigaki Y, Hayashi H, Tomita E et al. Usefulness of contrast-enhanced ultrasonography using Sonazoid for the assessment of therapeutic response to percutaneous radiofrequency ablation for hepatocellular carcinoma. *Hepatol Res* 2014
- Matalon TA, Silver B. US guidance of interventional procedures. *Radiology* 1990; 174: 43–47
- Phal PM, Brooks DM, Wolfe R. Sonographically guided biopsy of focal lesions: a comparison of freehand and probe-guided techniques using a phantom. *Am J Roentgenol* Am J Roentgenol 2005; 184: 1652–1656
- Shabana W, Kielar A, Vermani V et al. Accuracy of sonographically guided biopsy using a freehand versus needle-guided technique: computed tomographic correlation study. *J Ultrasound Med* 2013; 32: 535–540

- 20 Bluvol N, Kornecki A, Shaikh A *et al*. Freehand versus guided breast biopsy: comparison of accuracy, needle motion, and biopsy time in a tissue model. *Am J Roentgenol* Am J Roentgenol 2009; 192: 1720–1725
- 21 Sekhar A, Sun MR, Siewert B. A tissue phantom model for training residents in ultrasound-guided liver biopsy. *Acad Radiol* 2014; 21: 902–908
- 22 Nielsen MB, Torp-Pedersen S. Sonographically guided transrectal or transvaginal one-step catheter placement in deep pelvic and perirectal abscesses. *Am J Roentgenol* Am J Roentgenol 2004; 183: 1035–1036
- 23 Hakime A, Deschamps F, De Carvalho EG *et al*. Clinical evaluation of spatial accuracy of a fusion imaging technique combining previously acquired computed tomography and real-time ultrasound for imaging of liver metastases. *Cardiovasc Intervent Radiol* 2011; 34: 338–344
- 24 Mauri G, Cova L, De Beni S *et al*. Real-time US-CT/MRI image fusion for guidance of thermal ablation of liver tumors undetectable with US: results in 295 cases. *Cardiovasc Intervent Radiol* 2014
- 25 Ewertsen C, Nielsen KR, Nielsen MB. Freehand biopsy guided by electromagnetic needle tracking: a phantom study. *Ultraschall in Med* 2011; 32: 614–618
- 26 Hakime A, Barah A, Deschamps F *et al*. Prospective comparison of free-hand and electromagnetic needle tracking for US-guided percutaneous liver biopsy. *J Vasc Interv Radiol* 2013; 24: 1682–1689
- 27 Sinan T, Leven H, Sheikh M. Is fasting a necessary preparation for abdominal ultrasound? *BMC Med Imaging* 2003; 3: 1
- 28 Pinto PN, Chojniak R, Cohen MP *et al*. Comparison of three types of preparations for abdominal sonography. *J Clin Ultrasound* 2011; 39: 203–208
- 29 Copel L, Sosna J, Kruskal JB *et al*. Ultrasound-guided percutaneous liver biopsy: indications, risks, and technique. *Surg Technol Int* 2003; 11: 154–160
- 30 Heavner JE. Local anesthetics. *Curr Opin Anaesthesiol* 2007; 20: 336–342
- 31 Achar S, Kundu S. Principles of office anesthesia: part I. Infiltrative anesthesia. *Am Fam Physician* 2002; 66: 91–94
- 32 Chan D, Downing D, Keough CE *et al*. Joint Practice Guideline for Sterile Technique during Vascular and Interventional Radiology Procedures: From the Society of Interventional Radiology, Association of periOperative Registered Nurses, and Association for Radiologic and Imaging Nursing, for the Society of Interventional Radiology [corrected] Standards of Practice Committee, and Endorsed by the Cardiovascular Interventional Radiological Society of Europe and the Canadian Interventional Radiology Association. *J Vasc Interv Radiol* 2012; 23: 1603–1612
- 33 Lipp A, Edwards P. Disposable surgical face masks for preventing surgical wound infection in clean surgery. *Cochrane Database Syst Rev* 2014, CD002929 2
- 34 Masood J, Voulgaris S, Awogu O *et al*. Condom perforation during transrectal ultrasound guided (TRUS) prostate biopsies: a potential infection risk. *Int Urol Nephrol* 2007; 39: 1121–1124
- 35 Amis S, Ruddy M, Kibbler CC *et al*. Assessment of condoms as probe covers for transvaginal sonography. *J Clin Ultrasound* 2000; 28: 295–298
- 36 Kac G, Podglajen I, Si-Mohamed A *et al*. Evaluation of ultraviolet C for disinfection of endocavitary ultrasound transducers persistently contaminated despite probe covers. *Infect Control Hosp Epidemiol* 2010; 31: 165–170
- 37 German Institute for medicine and medical products (BfArM). Washing of ultrasound probes with mucosa contact. *Ultraschall in Med* 2005; 05
- 38 Gaillot O, Maruejols C, Abachin E *et al*. Nosocomial outbreak of *Klebsiella pneumoniae* producing SHV-5 extended-spectrum beta-lactamase, originating from a contaminated ultrasonography coupling gel. *J Clin Microbiol* 1998; 36: 1357–1360
- 39 Hutchinson J, Runge W, Mulvey M *et al*. *Burkholderia cepacia* infections associated with intrinsically contaminated ultrasound gel: the role of microbial degradation of parabens. *Infect Control Hosp Epidemiol* 2004; 25: 291–296
- 40 Jacobson M, Wray R, Kovach D *et al*. Sustained endemicity of *Burkholderia cepacia* complex in a pediatric institution, associated with contaminated ultrasound gel. *Infect Control Hosp Epidemiol* 2006; 27: 362–366
- 41 Marigliano A, D'Errico MM, Pellegrini I *et al*. Ultrasound echocardiographic gel contamination by *Burkholderia cepacia* in an Italian hospital. *J Hosp Infect* 2010; 76: 360–361
- 42 Muradali D, Gold WL, Phillips A *et al*. Can ultrasound probes and coupling gel be a source of nosocomial infection in patients undergoing sonography? An in vivo and in vitro study. *Am J Roentgenol* Am J Roentgenol 1995; 164: 1521–1524
- 43 Olshstein-Pops K, Block C, Temper V *et al*. An outbreak of *achromobacter xylosoxidans* associated with ultrasound gel used during transrectal ultrasound guided prostate biopsy. *J Urol* 2011; 185: 144–147
- 44 Provenzano DA, Liebert MA, Steen B *et al*. Investigation of current infection-control practices for ultrasound coupling gel: a survey, microbiological analysis, and examination of practice patterns. *Reg Anesth Pain Med* 2013; 38: 415–424
- 45 Schabrun S, Chipchase L, Rickard H. Are therapeutic ultrasound units a potential vector for nosocomial infection? *Physiother Res Int* 2006; 11: 61–71
- 46 Weist K, Wendt C, Petersen LR *et al*. An outbreak of pyoderma among neonates caused by ultrasound gel contaminated with methicillin-susceptible *Staphylococcus aureus*. *Infect Control Hosp Epidemiol* 2000; 21: 761–764
- 47 Boyce JM, Pittet D. Healthcare Infection Control Practices Advisory Committee. Society for Healthcare Epidemiology of America. Association for Professionals in Infection Control. Infectious Diseases Society of America. Hand Hygiene Task F. Guideline for Hand Hygiene in Health-Care Settings: recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. *Infect Control Hosp Epidemiol* 2002; 23: S3–S40
- 48 Marra AR, Edmond MB. Hand Hygiene: State-of-the-Art Review With Emphasis on New Technologies and Mechanisms of Surveillance. *Curr Infect Dis Rep* 2012; 14: 585–591
- 49 Darouiche RO, Wall MJ Jr, Itani KM *et al*. Chlorhexidine-Alcohol versus Povidone-Iodine for Surgical-Site Antisepsis. *N Engl J Med* 2010; 362: 18–26
- 50 Goncalves Kde J, Graziano KU, Kawagoe JY. A systematic review of surgical hand antisepsis utilizing an alcohol preparation compared to traditional products. *Rev Esc Enferm USP* 2012; 46: 1484–1493
- 51 Noorani A, Rabey N, Walsh SR *et al*. Systematic review and meta-analysis of preoperative antisepsis with chlorhexidine versus povidone-iodine in clean-contaminated surgery. *Br J Surg* 2010; 97: 1614–1620
- 52 Robert Koch-Institut, Deutsche Gesellschaft zur Bekämpfung der Viruskrankheiten, Desinfektionsmittelkommission der Deutschen Gesellschaft für Hygiene und Mikrobiologie. Evaluation and declaration of effectiveness of disinfectants against viruses. Position of the Virucide Study Group of the Robert Koch Institute (RKI) and the "Virus Disinfection" Professional Committee of the German Society for Control of "Virus Infections" and the Disinfectant Committee of the German Society of Public Health and Microbiology. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* 2004; 47: 62–66
- 53 Sabler IM, Lazarovitch T, Haifler M *et al*. Sterility of reusable transrectal ultrasound transducer assemblies for prostate biopsy reprocessed according to food and drug administration guidelines—bacteriologic outcomes in a clinical setup. *Urology* 2011; 77: 17–19
- 54 O'Grady NP, Alexander M, Burns LA *et al*. Guidelines for the prevention of intravascular catheter-related infections. *Clin Infect Dis* 2011; 52: e162–e193
- 55 Singh AK, Shankar S, Gervais DA *et al*. Image-guided percutaneous splenic interventions. *Radiographics* 2012; 32: 523–534
- 56 Gupta S, Wallace MJ, Cardella JF *et al*. Quality improvement guidelines for percutaneous needle biopsy. *J Vasc Interv Radiol* 2010; 21: 969–975
- 57 Weiss H, Duntsch U, Weiss A. Risks of fine needle puncture—results of a survey in West Germany (German Society of Ultrasound in Medicine survey). *Ultraschall in Med* 1988; 9: 121–127
- 58 Weiss H, Duntsch U. Complications of fine needle puncture. DEGUM survey II. *Ultraschall in Med* 1996; 17: 118–130
- 59 Fornari F, Civardi G, Cavanna L *et al*. Complications of ultrasonically guided fine-needle abdominal biopsy. Results of a multicenter Italian study and review of the literature. The Cooperative Italian Study Group. *Scand J Gastroenterol* 1989; 24: 949–955
- 60 Atwell TD, Smith RL, Hesley GK *et al*. Incidence of bleeding after 15181 percutaneous biopsies and the role of aspirin. *Am J Roentgenol* Am J Roentgenol 2010; 194: 784–789
- 61 Piccinino F, Sagnelli E, Pasquale G *et al*. Complications following percutaneous liver biopsy. A multicentre retrospective study on 68276 biopsies. *J Hepatol* 1986; 2: 165–173
- 62 Frieser M, Lindner A, Meyer S *et al*. Spectrum and bleeding complications of sonographically guided interventions of the liver and pancreas. *Ultraschall in Med* 2009; 30: 168–174

- 63 Padia SA, Baker ME, Schaeffer CJ *et al.* Safety and efficacy of sonographic-guided random real-time core needle biopsy of the liver. *J Clin Ultrasound* 2009; 37: 138–143
- 64 Riemann B, Menzel J, Schiemann U *et al.* Ultrasound-guided biopsies of abdominal organs with an automatic biopsy system. A retrospective analysis of the quality of biopsies and of hemorrhagic complications. *Scand J Gastroenterol* 2000; 35: 102–107
- 65 Strobel D. Incidence of bleeding in 8172 percutaneous ultrasound guided intraabdominal diagnostic and therapeutic interventions – results of the prospective multicentre DEGUM interventional ultrasound trial. Submitted 2015
- 66 Di Stasi M, Lencioni R, Solmi L *et al.* Ultrasound-guided fine needle biopsy of pancreatic masses: results of a multicenter study. *Am J Gastroenterol* 1998; 93: 1329–1333
- 67 Eiro M, Katoh T, Watanabe T. Risk factors for bleeding complications in percutaneous renal biopsy. *Clin Exp Nephrol* 2005; 9: 40–45
- 68 Mueller M, Kratzer W, Oeztuerk S *et al.* Percutaneous ultrasonographically guided liver punctures: an analysis of 1961 patients over a period of ten years. *BMC Gastroenterol* 2012; 12: 173
- 69 Chevallier P, Ruitort F, Denys A *et al.* Influence of operator experience on performance of ultrasound-guided percutaneous liver biopsy. *Eur Radiol* 2004; 14: 2086–2091
- 70 Djavan B, Waldert M, Zlotta A *et al.* Safety and morbidity of first and repeat transrectal ultrasound guided prostate needle biopsies: results of a prospective European prostate cancer detection study. *J Urol* 2001; 166: 856–860
- 71 Howlett DC, Drinkwater KJ, Lawrence D *et al.* Findings of the UK national audit evaluating image-guided or image-assisted liver biopsy. Part II. Minor and major complications and procedure-related mortality. *Radiology* 2013; 266: 226–235
- 72 Cadranell JF, Rufat P, Degos F. Practices of liver biopsy in France: results of a prospective nationwide survey. For the Group of Epidemiology of the French Association for the Study of the Liver (AFEF). *Hepatology* 2000; 32: 477–481
- 73 Sagnelli E, Sagnelli C, Pisaturo MA *et al.* Liver biopsy in chronic hepatitis C: the experience of 15 Italian wards of infectious diseases. *Infez Med* 2012; 20: 31–36
- 74 Weiss H. Metastases caused by fine needle puncture? *Ultraschall in Med* 1989; 10: 147–151
- 75 Smith EH. Complications of percutaneous abdominal fine-needle biopsy. Review. *Radiology* 1991; 178: 253–258
- 76 Chang S, Kim SH, Lim HK *et al.* Needle tract implantation after sonographically guided percutaneous biopsy of hepatocellular carcinoma: evaluation of doubling time, frequency, and features on CT. *Am J Roentgenol* 2005; 185: 400–405
- 77 Kosugi C, Furruse J, Ishii H *et al.* Needle tract implantation of hepatocellular carcinoma and pancreatic carcinoma after ultrasound-guided percutaneous puncture: clinical and pathologic characteristics and the treatment of needle tract implantation. *World J Surg* 2004; 28: 29–32
- 78 Robertson EG, Baxter G. Tumour seeding following percutaneous needle biopsy: the real story! *Clin Radiol* 2011; 66: 1007–1014
- 79 Merskey H. Classification of Chronic Pain: Descriptions of chronic pain syndromes and definition of pain terms. *Pain* 1986; 3: 226
- 80 Patrick DL, Ferketich SL, Frame PS *et al.* National Institutes of Health State-of-the-Science Conference Statement: Symptom management in cancer: pain, depression, and fatigue, July 15–17, 2002. *J Natl Cancer Inst Monogr* 2004; 9–16
- 81 Lindner A, Frieser M, Heide R *et al.* Postinterventional pain and complications of sonographically guided interventions in the liver and pancreas. *Ultraschall in Med* 2014; 35: 159–165
- 82 Lindor KD, Bru C, Jorgensen RA *et al.* The role of ultrasonography and automatic-needle biopsy in outpatient percutaneous liver biopsy. *Hepatology* 1996; 23: 1079–1083
- 83 Froehlich F, Lamy O, Fried M *et al.* Practice and complications of liver biopsy. Results of a nationwide survey in Switzerland. *Dig Dis Sci* 1993; 38: 1480–1484
- 84 Chuah SY, Moody GA, Wicks AC *et al.* A nationwide survey of liver biopsy—is there a need to increase resources, manpower and training? *Hepatogastroenterology* 1994; 41: 4–8
- 85 Hatfield MK, Beres RA, Sane SS *et al.* Percutaneous imaging-guided solid organ core needle biopsy: coaxial versus noncoaxial method. *Am J Roentgenol* 2008; 190: 413–417
- 86 Seeff LB, Everson GT, Morgan TR *et al.* Complication rate of percutaneous liver biopsies among persons with advanced chronic liver disease in the HALT-C trial. *Clin Gastroenterol Hepatol* 2010; 8: 877–883
- 87 de Man RA, van Buuren HR, Hop WC. A randomised study on the efficacy and safety of an automated Tru-Cut needle for percutaneous liver biopsy. *Neth J Med* 2004; 62: 441–445
- 88 Westheim BH, Aagaes I, Ostensen AB *et al.* Effect of operator experience and frequency of procedure performance on complication rate after ultrasound-guided percutaneous liver biopsies. *J Pediatr Gastroenterol Nutr* 2013; 57: 638–643
- 89 Buscarini L, Fornari F, Bolondi L *et al.* Ultrasound-guided fine-needle biopsy of focal liver lesions: techniques, diagnostic accuracy and complications. A retrospective study on 2091 biopsies. *J Hepatol* 1990; 11: 344–348
- 90 Liang P, Gao Y, Wang Y *et al.* US-guided percutaneous needle biopsy of the spleen using 18-gauge versus 21-gauge needles. *J Clin Ultrasound* 2007; 35: 477–482
- 91 Nolsoe C, Nielsen L, Torp-Pedersen S *et al.* Major complications and deaths due to interventional ultrasonography: a review of 8000 cases. *J Clin Ultrasound* 1990; 18: 179–184
- 92 Nyman RS, Cappelen-Smith J, Brismar J *et al.* Yield and complications in ultrasound-guided biopsy of abdominal lesions. Comparison of fine-needle aspiration biopsy and 1.2-mm needle core biopsy using an automated biopsy gun. *Acta Radiol* 1995; 36: 485–490
- 93 Pagani JJ. Biopsy of focal hepatic lesions. Comparison of 18 and 22 gauge needles. *Radiology* 1983; 147: 673–675
- 94 van der Poorten D, Kwok A, Lam T *et al.* Twenty-year audit of percutaneous liver biopsy in a major Australian teaching hospital. *Intern Med J* 2006; 36: 692–699
- 95 Swobodnik W, Janowitz P, Kratzer W *et al.* Comparison of ultrasound-controlled fine needle and coarse needle puncture of defined lesions in the abdomen. *Ultraschall in Med* 1990; 11: 287–289
- 96 Gazelle GS, Haaga JR, Rowland DY. Effect of needle gauge, level of anticoagulation, and target organ on bleeding associated with aspiration biopsy. Work in progress. *Radiology* 1992; 183: 509–513
- 97 Khajehdehi P, Junaid SM, Salinas-Madrigal L *et al.* Percutaneous renal biopsy in the 1990s: safety, value, and implications for early hospital discharge. *Am J Kidney Dis* 1999; 34: 92–97
- 98 Corapi KM, Chen JL, Balk EM *et al.* Bleeding complications of native kidney biopsy: a systematic review and meta-analysis. *Am J Kidney Dis* 2012; 60: 62–73
- 99 Schwarz KB, Zellos A, Stamato L *et al.* Percutaneous liver biopsy in hemophilic children with chronic hepatitis C virus infection. *J Pediatr Gastroenterol Nutr* 2008; 46: 423–428
- 100 Sterling RK, Lyons CD, Stravitz RT *et al.* Percutaneous liver biopsy in adult haemophiliacs with hepatitis C virus: safety of outpatient procedure and impact of human immunodeficiency virus coinfection on the spectrum of liver disease. *Haemophilia* 2007; 13: 164–171
- 101 Patel JJ, Davidson JC, Nikolic B *et al.* Consensus guidelines for periprocedural management of coagulation status and hemostasis risk in percutaneous image-guided interventions. *J Vasc Interv Radiol* 2012; 23: 727–736
- 102 Patel JJ, Davidson JC, Nikolic B *et al.* Addendum of newer anticoagulants to the SIR consensus guideline. *J Vasc Interv Radiol* 2013; 24: 641–645
- 103 Chee YL, Crawford JC, Watson HG *et al.* Guidelines on the assessment of bleeding risk prior to surgery or invasive procedures. British Committee for Standards in Haematology. *Br J Haematol* 2008; 140: 496–504
- 104 Jalal DI, Chonchol M, Targher G. Disorders of hemostasis associated with chronic kidney disease. *Semin Thromb Hemost* 2010; 36: 34–40
- 105 Tripodi A, Primignani M, Mannucci PM. Abnormalities of hemostasis and bleeding in chronic liver disease: the paradigm is challenged. *Intern Emerg Med* 2010; 5: 7–12
- 106 Sparchez Z. Complications after percutaneous liver biopsy in diffuse hepatopathies. *Rom J Gastroenterol* 2005; 14: 379–384
- 107 Whittier WL, Korbet SM. Timing of complications in percutaneous renal biopsy. *J Am Soc Nephrol* 2004; 15: 142–147
- 108 Marwah DS, Korbet SM. Timing of complications in percutaneous renal biopsy: what is the optimal period of observation? *Am J Kidney Dis* 1996; 28: 47–52
- 109 Chen QW, Cheng CS, Chen H *et al.* Effectiveness and complications of ultrasound guided fine needle aspiration for primary liver cancer in

- a Chinese population with serum alpha-fetoprotein levels ≤ 200 ng/ml—a study based on 4312 patients. *PLoS One* 2014; 9: e101536
- 110 *Terjung B, Lemnitzer I, Dumoulin FL et al.* Bleeding complications after percutaneous liver biopsy. An analysis of risk factors. *Digestion* 2003; 67: 138–145
 - 111 *Kim KW, Kim MJ, Kim HC et al.* Value of "patent track" sign on Doppler sonography after percutaneous liver biopsy in detection of postbiopsy bleeding: a prospective study in 352 patients. *Am J Roentgenol* 2007; 189: 109–116
 - 112 *Ishikawa E, Nomura S, Hamaguchi T et al.* Ultrasonography as a predictor of overt bleeding after renal biopsy. *Clin Exp Nephrol* 2009; 13: 325–331
 - 113 *Waldo B, Korbet SM, Freimanis MG et al.* The value of post-biopsy ultrasound in predicting complications after percutaneous renal biopsy of native kidneys. *Nephrol Dial Transplant* 2009; 24: 2433–2439
 - 114 *Catalano O, Cusati B, Nunziata A et al.* Active abdominal bleeding: contrast-enhanced sonography. *Abdom Imaging* 2006; 31: 9–16
 - 115 *Ignée A, Baum U, Schuessler G et al.* Contrast-enhanced ultrasound-guided percutaneous cholangiography and cholangiodrainage (CEUS-PTCD). *Endoscopy* 2009; 41: 725–726
 - 116 *Eng M, Vaughan TE, Woo D et al.* Treatment of an extracapsular post-renal biopsy pseudoaneurysm with ultrasound-guided thrombin injection. *J Clin Ultrasound* 2010; 38: 215–217
 - 117 *Tang Y, Qian NS, Luo W et al.* Percutaneous injection of hemostatic agents for active liver hemorrhage. *Hepatobiliary Pancreat Dis Int* 2010; 9: 402–408
 - 118 *Mendiratta-Lala M, Williams T, de Quadros N et al.* The use of a simulation center to improve resident proficiency in performing ultrasound-guided procedures. *Acad Radiol* 2010; 17: 535–540
 - 119 *Moore DL, Ding L, Sadhasivam S.* Novel real-time feedback and integrated simulation model for teaching and evaluating ultrasound-guided regional anesthesia skills in pediatric anesthesia trainees. *Paediatr Anaesth* 2012; 22: 847–853
 - 120 *Konge L, Annema J, Clementsen P et al.* Using virtual-reality simulation to assess performance in endobronchial ultrasound. *Respiration* 2013; 86: 59–65
 - 121 *Stather DR, Maceachern P, Rimmer K et al.* Validation of an endobronchial ultrasound simulator: differentiating operator skill level. *Respiration* 2011; 81: 325–332
 - 122 *Barthet M.* Endoscopic ultrasound teaching and learning. *Minerva Med* 2007; 98: 247–251
 - 123 *Vieira SL, Pavan TZ, Junior JE et al.* Paraffin-gel tissue-mimicking material for ultrasound-guided needle biopsy phantom. *Ultrasound Med Biol* 2013; 39: 2477–2484
 - 124 *Kunkler K.* The role of medical simulation: an overview. *Int J Med Robot* 2006; 2: 203–210
 - 125 *Chenkin J, Lee S, Huynh T et al.* Procedures can be learned on the Web: a randomized study of ultrasound-guided vascular access training. *Acad Emerg Med* 2008; 15: 949–954
 - 126 *Laerum F.* Demand for a new main speciality in image-guided therapy. *Comput Methods Programs Biomed* 2001; 66: 81–85
 - 127 *Tolsgaard MG, Todsén T, Sørensen JL et al.* International multispecialty consensus on how to evaluate ultrasound competence: a Delphi consensus survey. *PLoS One* 2013; 8: e57687