9.1 CT-Guided Biopsy

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9.1.1 Introduction

Image-guided percutaneous biopsy using ultrasound (US) and computed tomography (CT) is widely established as a safe method for differentiation of benign and malignant masses while magnetic resonance (MR) imaging was only introduced as guidance method in the mid-1990s. Most of the procedures are performed in patients with a known primary tumor in order to rule out metastatic malignancy and to establish the final diagnosis or to differentiate between tumor necrosis and potential vital tumor tissue in residual lesions after therapy.

9.1.2 Patient Preparation and Aftercare

Most image-guided biopsies can be performed on an outpatient basis. Informed patient consent including possible conscious sedation after detailed explanation of potential complications should be obtained at least 24 h before the intervention. Coagulation disorders should be ruled out by taking platelet levels (more than 50,000/mm³), partial thromboplastin time (PTT: less than 50 s), prothrombin time (PT: more than 50 %), and International Normalized Ratio (1.5 or less)
in all patients, especially if the lesion is located in the depth of the chest and abdomen. In superficial lesions (e.g., in the neck), direct pressure is usually sufficient for hemostasis, and dedicated coagulation studies are not required. In case the patient has taken nonsteroidal anti-inflammatory drugs inhibiting platelet aggregation (e.g., acetylic salicylic acid), a core biopsy should be postponed by 7 days. In absence of any abnormalities regarding platelet levels, PTT, and PT, a fine-needle biopsy (20 G or smaller) may be performed because the risk of hemorrhage due to nonsteroidal anti-inflammatory drugs alone is low (Table 9.1) (Cardella et al. 2003).

The majority of CT-guided biopsies can be performed under local anesthesia. Children, incompliant adult patients, or biopsies of deep abdominal lesions (e.g., pancreatic masses) represent potential exceptions. In those selected cases, sufficient analgosedation can be reached by intravenous administration of benzodiazepines, for example, Midazolam (1 mg/dose; given in two to four doses) for anxiolysis and opioids, for example, Fentanyl (0.02 mg/dose; given in one to five doses) for analgesia (see Chap. 5). If analgosedation is used, the patient should be monitored during the whole procedure using pulse oximetry. The nurse or radiology technician is responsible for keeping the patient compliant while the radiologist can concentrate on the procedure. Before the intervention, the patient should be placed in a stable and comfortable position. Depending on the lesion location supine, prone, or lateral decubitus position are most commonly used.

For correlation, pre-, peri- and post-interventional CT images should be obtained in the same position during the same respiratory cycle, preferably during expiration. In case of an anterior approach, the CT or MR table is set as low as possible in order to leave enough room for the needle insertion. Preparation of the skin area overlying the entry point of the biopsy needle includes shaving (if necessary), sterile draping, and skin disinfection.

Following CT guided biopsy, patients are kept in the ward with vital signs observed every 15 min for 1 h. In high-risk patients, observation can be continued beyond this time, for example, with checking of vital signs every 30 min for 3 h.

After lung biopsy, the patient should lie with the puncture site down for 2 h. The two pleural layers are compressed by the weight of the lung itself, and further air leakage through the pleural defect is minimized. Chest radiographs (p.a.) are obtained 2 and 4 h after the intervention in order to rule out delayed pneumothorax. If the chest radiograph in erect position after 2 h shows a small pneumothorax, a further chest X-ray should be obtained after 4 h. In case of pneumothorax and patient symptoms, air aspiration or a chest tube should be inserted for treatment (see Sect. 11.2.2).

At discharge, patients should be advised to take care of the puncture site. They are instructed to call their physician in the event of bleeding or marked swelling at the puncture site. Patients are advised not to bath for 24 h if no dedicated water proof bandage is used for sealing the puncture site.

### Table 9.1 Contraindications for computed tomography (CT)-guided biopsy

<table>
<thead>
<tr>
<th>Contraindication</th>
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<tbody>
<tr>
<td>Uncorrectable coagulation disorder</td>
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<tr>
<td>Platelets &lt; 50,000/mm³&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>INR &gt; 1.5&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Prothrombin time (quick) &lt; 50 %&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Partial thromboplastin time &gt; 50 s&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>Intake of platelet inhibitors &lt; 24 h before the</td>
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<tr>
<td>intervention&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>Massive ascites</td>
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<td>Adipositas in combination with small cirrhotic liver</td>
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<td>(transjugular or surgical biopsy recommended)</td>
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<tr>
<td>Incompliant patients</td>
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<tr>
<td>Absence of a safe pathway from the skin to the target</td>
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<td>site</td>
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<sup>a</sup>A preprocedural platelet transfusion may be necessary  
<sup>b</sup>Usually due to coumarins or liver disease; coumarin withdrawal takes a few days to reverse INR. INR can also be reversed by vitamin K or fresh frozen plasma  
<sup>c</sup>Usually prolonged secondary to heparin or heparin-like drugs. These agents generally have short half-lives and can be quickly reversed  
<sup>d</sup>Clinical assessment should be made as to whether to proceed or reschedule the biopsy

#### 9.1.3 CT and CT-Fluoroscopic Guidance

CT as guiding method is especially suitable for lesions located deep under the skin surface which
are not or not easily depictable via ultrasound (e.g., deep retroperitoneal, pelvic and thoracic lesions). With some exceptions such as liver lesions isodense to normal parenchyma at non-enhanced CT scans, CT usually provides excellent visualization of the target lesion and differentiation from adjacent organs. It is generally preferable not to schedule a biopsy procedure at the same time as the first diagnostic scan. If available, recent images not older than 2 weeks or a separate preceding diagnostic study should be used for selection of target lesions for biopsy and planning of the access pathway. Two different techniques of CT guidance can be utilized.

**9.1.3.1 Sequential CT-Guidance**

For planning of the access route, a CT scan of the region of interest is performed first. The preliminary scan can be performed without contrast if a recent diagnostic study is available and the lesion is easily visible. In the chest, a non-enhanced CT scan (slice thickness 3 mm or less) is also sufficient for detection of intrapulmonary lesions suitable for aspiration or punch biopsy. For suspect masses in the mediastinum and abdomen (intra- and retroperitoneal), a contrast-enhanced CT scan is necessary for clear differentiation of parenchymal organs, intestines, and blood vessels. Focal lesions within parenchymal organs are usually visualized during venous phase (scan delay 50–70 s). An additional arterial phase (scan delay approximately 30 s) may be beneficial if arteries are present along the access path (e.g., parasternal access, internal mammary artery) and in hypervascularized lesions (e.g., hepatocellular carcinoma, metastases of renal cell carcinoma).

For defining the skin entry point of the biopsy needle, a radiopaque grid is placed on the skin of the patient (Fig. 9.1a). The patient is positioned either in prone, supine, or lateral decubitus position, depending on the shortest distance from the skin surface to the lesion. Then, the CT scan is performed covering the region of interest. Grid systems are either commercially available, while also a homemade grid from several 4–5 F catheters that are cut into a length of 15–30 cm, and taped together at intervals of 1 cm, can be used. The use of barium paste instead of a radiopaque grid has also been described. After the planning CT scan (with the grid system taped on the skin of the patient) has been performed, the slice position showing both, the lesion and the potential in-plane access route, or the intended needle entry point only (double-oblique access), is chosen. The distance from the skin level of the needle entry point to the lesion is measured. The CT table is moved to the position of choice for biopsy, and the needle entry point can be marked with a felt pen using the grid as well as the centering laser light beam.

After skin disinfection, local anesthesia using 10–20 cc of 1–2 % lidocaine hydrochloride is applied in the subcutaneous fat and down to the capsule of parenchymal organs (e.g., the liver),
down to the pleura, or down to the periosteum of bones using a 22-G needle that additionally marks the entry point and intended angle of the biopsy needle. After a small skin incision with a scalpel and CT rescanning with the local anesthesia needle in the skin entry point to confirm the correct position, the biopsy needle is inserted parallel to the local anesthesia needle. Thereafter, repeated CT scans covering a short range above and below the needle entry point (e.g., 3–5 cm along the z-axis) are performed, and the angulation of the needle is adapted to interfering anatomical structures if necessary (Fig. 9.1b). The use of multislice spiral CT with its inherent ability to simultaneously acquire several sections is beneficial for this purpose, as it omits the need for multiple scans above and below the needle entry point. The direction of the needle in relation to the lesion can be easily detected using the streak artifact at the needle tip. Finally, the needle is inserted into the edge of the lesion for tissue sampling.

9.1.3.2 CT-Fluoroscopic Guidance
Since the introduction of CT-fluoroscopy (CTF) with faster image reconstruction on multislice CT scanners, real-time visualization nearly comparable to US is available. Cross-sectional CT images are reconstructed at reduced spatial resolution and updated continually at a rate of up to 10 frames/s by using a high-speed array processor (Carlson et al. 2001). In contrast to the sequential technique using repeated non-enhanced CT scans covering the volume of interest, the needle is visualized on an in-room monitor. The operator can dynamically adjust the needle position under single-shot or continuous CTF until the lesion is reached. The main advantages are a substantial reduction of in-room time for both, the patient and the operator, and real-time visualization of critical anatomical structures along the trajectory such as vessels during needle insertion. This technique is particularly helpful in case of incompliant patients who are unable to cooperate, for example, to hold their breath or in regions with persistent motion as it may be found close to the heart and diaphragm. In contrast to conventional CT guidance, the main disadvantage is the radiation exposure of the operator (Silverman et al. 1999). The use of a grab handle for holding the needle helps to avoid the direct exposure of the operator’s hand to the radiation beam during CTF. As important advantages of this technique, patient-absorbed radiation dose and in-room time can be significantly reduced by 94 and 32 %, respectively (Carlson et al. 2001).

9.1.4 CT-Guided Aspiration Biopsy
Percutaneous fine-needle aspiration biopsy (FNAB) is a well established method to obtain an aspirate with a thin needle (20 G or greater) which usually provides enough material to confirm or rule out malignancy by cytologic analysis. In most cases, a histological diagnosis is not possible due to an insufficient amount of material.

9.1.4.1 Indication
FNAB is suitable for tissue sampling of pulmonary lesions as well as neck lesions (e.g., lymph nodes) and abdominal lesions given a known primary tumor in combination with suspected metastases of the liver, lymph nodes, etc. In abdominal lesions, FNAB is preferable where a direct access is precluded by surrounding organs. It is generally considered insufficient if the primary tumor is unknown.

9.1.4.2 Material
Fine-needle biopsies are performed with 20- to 25-G needles (small gauge) including various commercially available needle types and needle tip designs. The needle tip is either sharp-beveled (e.g., Chiba or spinal needle) or cutting (Turner needle, 45° bevel tip with cutting edge; Franseen needle, three-pronged needle tip; Westcott needle, slotted side-opening proximal to the needle tip; and E-Z-EM needle, trough cut in the needle tip) (Lee 2004) (Fig. 9.2). Coaxial biopsy sets consist of an outer guide needle in combination with a smaller aspiration needle. Typical needle combinations for coaxial FNAB are 23 G/20 G or 22 G/19 G sets (Table 9.2).
FNAB can be performed either by solely using the fine needle, applying a coaxial approach, or using a tandem technique. The first technique is characterized by the straightforward puncture of the target lesion. This technique has some disadvantages including limited controllability. The coaxial technique is characterized by a combination of two needles. A thicker, shorter needle is inserted down to the anterior edge of the lesion. Then, a thinner, longer needle is introduced through the first needle. Multiple samples can be taken using the thinner needle without several punctures. If necessary, the larger needle can be pulled back and its angle changed in order to reach different areas of the lesion. With the tandem technique, first a single reference needle is introduced into the lesion. Then, further needles are introduced “in tandem,” that is, parallel to the first needle without having to guide them separately.

After the appropriate needle length has been measured in the planning scan, preparation of the chosen entry site, and local anesthesia, the fine-needle is inserted to the lesion under image control, that is, repeated non-enhanced short CT scans or CTF sequences triggered by the operator. As soon as the needle has been introduced into the lesion, the trocar is removed, and a 10- or 20-ml Luer-Lok syringe is connected to the proximal end of the needle and suction is applied. The aspirated volume ranges between 3 and 5 ml for most biopsies and should be reduced (1–2 ml) in hypervascularized lesions in order to avoid

![Fig. 9.2](image_url)

**Fig. 9.2** The most common fine needle types: Turner (a), Franseen (b), Westcott (c), and E-Z-EM (d) needle. The Turner needle is characterized by a 45° bevel with a cutting edge. The Franseen needle has a three-pronged tip. The Westcott needle contains a side-cutting trough close to its tip. The E-Z-EM needle has a trough cut within the needle tip (schematic according to Lee (2004))

<table>
<thead>
<tr>
<th>Needle type (manufacturer)</th>
<th>Diameter (gauge)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiba (Boston Scientific, Natick, MA, USA)</td>
<td>22</td>
<td>6; 8</td>
</tr>
<tr>
<td>Franseen (Boston Scientific, Natick, MA, USA)</td>
<td>18; 20; 22</td>
<td>6; 8</td>
</tr>
<tr>
<td>Coaxial lung biopsy set Greene-type (Boston Scientific, Natick, MA, USA)</td>
<td>22</td>
<td>6</td>
</tr>
<tr>
<td>Chiba (Cook Medical, Bloomington, IN, USA)</td>
<td>18–23; 25</td>
<td>5; 10; 15; 20</td>
</tr>
<tr>
<td>Spinal needles (Cook Medical, Bloomington, IN, USA)</td>
<td>18; 20; 22</td>
<td>10; 15</td>
</tr>
<tr>
<td>Chiba-needle ultra (Somatex, Teltow, Germany)</td>
<td>19.5; 22</td>
<td>9; 12; 15; 22; 28</td>
</tr>
<tr>
<td>Chiba (E-Z-EM, Lake Success, NY, USA)</td>
<td>18; 20; 22</td>
<td>10; 15; 20</td>
</tr>
<tr>
<td>Percucut cut-biopsy needle with keyhole cutting edge (E-Z-EM, Lake Success, NY, USA)</td>
<td>18; 19.5; 21</td>
<td>5; 10; 15</td>
</tr>
</tbody>
</table>

*Not all diameter-length combinations may be available.

**Table 9.2** Commercially available needles for CT-guided aspiration biopsy (exemplary selection of different manufacturers and needles)
aspiration of larger amounts of blood. During application of suction, the needle is moved back and forth within the lesion for 10–15 s or until the hub of the syringe gets filled with blood. Before removing the needle from the lesion, the suction is stopped in order to avoid aspiration of further tissue potentially confusing cytologic evaluation of the sample.

In hypervascularized lesions like in the thyroid gland, non-aspiration fine-needle biopsy can be alternatively performed. The needle is introduced into the lesion without a syringe and moved back and forth several times.

If a cytopathologist is in the room during the biopsy procedure, he can give an initial statement if the tissue sample is sufficient for evaluation, or further samples have to be taken. Otherwise, the aspirated material is crossed out on a glass slide and immediately afterward fixated with alcohol. An additional blood clot should be obtained and fixated in formalin, as this will significantly increase sensitivity for malignancy (Wildberger et al. 2003).

Special Considerations

Lung
The advantage of CT-guided lung biopsy is that the lung parenchyma and not ventilated areas at the puncture site are visualized that can be used as access path to the lesion, substantially reducing the risk of pneumothorax. Local anesthesia is applied subcutaneously down to the pleura without touching the latter. Then, a coaxial needle can be inserted through the parietal pleura under suspended respiration. The operator can adjust the needle direction by withdrawing the coaxial needle to the periphery of the lung (without removing the needle outside the pleura). If the coaxial technique is used, the outer coaxial needle is inserted 2–3 mm into the edge of the lesion providing stability during coaxial biopsies. Then, the inner biopsy needle is introduced and at least two samples obtained (Fig. 9.3). The outer cannula should never be left inside the patient without the inner stylet in order to prevent air embolism. CT-guided biopsy of lung lesions can be done under stable pneumothorax if the lesion is close to the pleural surface. When pneumothorax occurs, the same position should be scanned 3 min later to see if the pneumothorax is progressing. If pneumothorax increases, a pigtail catheter should be inserted, and the procedure may be stopped (Tsai et al. 2009). In stable pneumothorax, the procedure should be completed and an end-expiratory chest radiograph should be obtained.

Mediastinum
Biopsies in the mediastinum have to be performed with special respect to vascular structures (Fig. 9.4). For planning of the biopsy procedure, a contrast-enhanced CT is performed in order to
rule out vascular abnormalities like aneurysms and to visualize the mediastinal vessels. For sampling lesions in the anterior mediastinum, an anterior parasternal approach is usually chosen. The internal mammary artery and vein that are located approximately 1 cm from the sternum have to be avoided (Fig. 9.4a). Additionally, the access path through the mediastinal fat can be widened by injection of sterile saline through a 22-G needle. After distension of the anterior mediastinum, the FNAB needle can be safely introduced without passing the paramediastinal lung parenchyma (Fig. 9.4b, c). In case the lesion is located in the posterior mediastinum, the paravertebral space can also be distended using sterile saline.

Liver
Depending on the experience of the operator and availability of an interventional CT unit, the majority of liver biopsies can also be performed under US guidance. If lesions in the dome of the liver cannot be visualized with US, a CT/CTF-guided (double) oblique approach may be preferable, while crossing the costophrenic sulcus should be avoided. Gantry angulation may help to access lesions in the liver dome. Before introducing the biopsy needle into the liver parenchyma, the capsule has to be infiltrated with local anesthetic. During penetration of the liver capsule, the patient should be asked not to breathe. Passing normal liver tissue before entering the lesion reduces the risk of relevant subcapsular or intraparenchymal bleeding occurring after the puncture due to self-tamponade. The biopsy may also be performed in a right decubitus position or under maximum expiration when the costophrenic sulcus is not inflated. The sample should normally be taken from the edge of the liver mass where the vital tumor tissue (in contrast to the central necrotic area) is located. In cases of liver lesions with large necrotic areas, a coaxial technique combining an outer cannula with the biopsy needle may be useful as the liver capsule is crossed only one time.

Pancreas
Typically, the pancreas is surrounded by various organs like the stomach, liver, transverse colon, kidney, or major vessels. Especially needle biopsy of small suspicious masses in the pancreatic head is therefore usually regarded as technically sophisticated, and CT-guidance preferred.

Fig. 9.4 Patient (supine position) with a paraaortal mass in the upper mediastinum. The preinterventional CT (arterial phase) showed the right internal mammary artery and vein (arrow) next to the sternum (a). First, sterile saline was injected with a 22 G needle for widening of the parasternal space. Then, an 18-G (13 cm) Tru-Cut biopsy needle was introduced under CTF-guidance. Note the typical black streak artifact (arrow) along the needle pathway (b, c). Histopathologic analysis revealed a mesenchymal tumor.
over of ultrasound. For differentiation of the tumor from surrounding normal parenchyma or inflammation, an arterial phase contrast-enhanced CT scan should be performed prior to the intervention. The most common access route is from an anterior approach and often traverses gastrointestinal structures and the mesenteric vessels, increasing the general risk of the procedure. On the other hand, with CT-fluoroscopy, transgression of vital structures can be avoided in most cases. In difficult-to-access lesions, the stomach or the small intestines may be punctured with a 20–22-G needle. Given an immunocompetent patient, FNAB traversing the GI tract or the liver has been shown to be technically feasible and safe in many studies (Brandt et al. 1993; Elvin et al. 1990; Luning et al. 1985; Mueller 1993). Transhepatic, transsplenic, and paracaval/transcaval approaches have also been described (Brandt et al. 1993).

If the pancreatic tumor is too scirrhous to obtain a sufficient specimen in spite of several attempts, usually a switch to a large-gauge core biopsy system is necessary. The colon should generally not be penetrated even with a small gauge needle in order to avoid superinfection, especially if cystic pancreatic lesions containing fluid are sampled (Mueller 1993). In case of unintended penetration, metronidazole should be administered prophylactically.

Kidney
Biopsies of the kidney are rarely performed because they are often interpreted as hemorrhagic or inconclusive, and most solid renal masses are surgically removed. Exceptional indications for biopsy are suggested lymphoma and metastasis to the kidney from another primary tumor, since these conditions are usually not treated surgically. The usual access route under CT guidance is posterior or lateral while the renal hilum should be avoided (Fig. 9.5).

Adrenal Glands
Owing to the anatomic localization in the upper retroperitoneum, the access path for biopsy is relatively sophisticated while several approaches are possible:

- The right lateral transhepatic approach (right adrenal gland: through right liver lobe, supine position)
- The left anterior transhepatic approach (left adrenal gland: through left liver lobe, supine position)
- The angled prone approach (both adrenals: subcostal approach in a 45° angle, prone position; Fig. 9.6)
- The lateral decubitus approach (the patient side with the adrenal lesion is placed next to the table, preventing full expansion of the ipsilateral pulmonary recessus while the overlying lung is fully expanded)

Retroperitoneum
Biopsies of retroperitoneal lesions are usually performed under CT-guidance. With the most common posterior approach, the needle passes...
Biopsy through or parallel to the psoas muscle (Figs. 9.7 and 9.8). This approach permits the safe use of large needles, while small-gauge needles are recommendable in an anterior approach.

**Pelvic Lesions**
While transrectal and transvaginal biopsies are routinely guided using ultrasound, the access routes for CT-guided biopsy in the pelvis include:
- The transgluteal approach through the greater sciatic foramen
- The presacral approach through the gluteal cleft
- The anterior approach (Fig. 9.9)

For the transgluteal approach, the patient is placed in prone position. The needle is introduced from the buttock through the greater sciatic foramen into the deep pelvis as close to the coccygeal bone as possible in order to avoid puncture of the sciatic nerve.

**9.1.4.4 Results**

**Lung**
In pulmonary lesions, FNAB has been reported to have diagnostic accuracy and sensitivity rates of more than 93 % (Swischuk et al. 1998) and 95 % (Klein et al. 1996; Laurent et al. 2000), respectively. Kothary et al. recently performed a study to compare the diagnostic accuracy and complication rate of CT-guided biopsy of lung nodules of 1.5 cm or smaller versus nodules of more than 1.5 cm in diameter. Though not statistically significant, diagnostic accuracy for malignancy was higher in larger nodules than in lesions of 1.5 cm or smaller (81.3 % vs. 69.6 %), whereas there was no correlation between nodule size and the incidence of complications (Kothary et al. 2009). While other authors have also reported accuracy rates of less than 75 % for lesions 1 cm or smaller (Li et al. 1996; Tsukada et al. 2000;
van Sonnenberg et al. 1988), respiratory gating (Tomiyama et al. 2000) and CTF (Irie et al. 2001) have contributed to improve success rates. In patients with peripheral intrapulmonary nodules larger than 1 cm, an interactive breath-hold control system (IBC) including a strain detector belt indicating the respiratory position of the patient on a LED array could significantly reduce the number of imaging steps, as well as the intervention time (Schoth et al. 2010). The work by Kim et al. showed a significantly lower complication rate (pneumothorax, hemoptysis) when comparing percutaneous CT-guided pulmonary aspiration biopsy with (Group I: 13.4 %) and without (Group II: 31.4 %) CTF. Mean estimated effective dose to the interventionalist was 0.054 mSv in Group I and 0.029 mSv in Group II (Kim et al. 2011). Subpleural pulmonary nodules are often more challenging than deep lesions. Especially the ribs or scapula may potentially hinder the direct access to a nodule. In the comparison of an oblique-versus a right-angle access path (n=61 subpleural lesions) by Tanaka et al. (1996), success rates were significantly better for the oblique path (81.2 %) compared to the right-angle access (43.3 %). With a direct access, the parenchymal distance to the subpleural nodule may be less than 1 cm, not allowing to correct the needle direction without another pleural passage. Once a pneumothorax has occurred, usually a retraction of the lung is observed making further sampling difficult if not impossible. A longer, tangential

**Fig. 9.8** Patient (prone position) with suspect mass of the right psoas muscle (a). A posterior paravertebral (fifth lumbar vertebra) access was chosen for Tru-Cut biopsy with an 18-G (13-cm) needle under CT-fluoroscopic guidance (b). Histopathology revealed metastasis of ovarian carcinoma.

**Fig. 9.9** Patient (supine position) with a history of diffuse large B-cell lymphoma (DLCL). Preinterventional CT showed a moderately enhancing nodule (large arrow) next to the iliac vessels (small arrows) (a). The 18-G (13-cm) Tru-Cut biopsy needle was introduced under CT-fluoroscopic guidance next to the left iliac crest through the peritoneal fat (b). Histopathology revealed recurrence of DLCL.
transparenchymal access route implies an improved needle stability (Wallace et al. 2002).

**Mediastinum**

In 89 patients undergoing CT-guided mediastinal FNAB for lung cancer staging (50 with and 39 without core biopsy of lymph nodes with short axis diameter greater than 1.5 cm) before mediastinoscopy, Zwischenberger et al. reported diagnostic success (cancer cell type, sarcoidosis, or caseating granulomas) in 78% of the cases, while only in 9 patients, lymph nodes (paraesophageal, pulmonary ligament, parasternal and paraaortic) could not be accessed (Zwischenberger et al. 2002). In the study by Assaad et al. (157 mediastinal FNAB), adequate diagnostic cytological material could be obtained in 82% of the cases, with concordance of subsequent histological and FNAB diagnosis in 78% (53 of 68) of the corresponding cases (Assaad et al. 2007).

**Liver**

FNAB in the abdomen with both ultrasound and CT-guidance has been described as safe and technically successful procedure by several authors (Ferrucci et al. 1980; Memel et al. 1996; Smith 1991; Welch et al. 1989). CT-guided FNAB of liver lesions has been reported to have sensitivity rates of 92% and specificity rates of 96% (Luning et al. 1984). Tatli et al. described a technique of CT-guided fine needle biopsy of abdominal lesions using the nonenhanced intraprocedural CT scan registered to PET/CT images acquired earlier. The authors recommended the technique especially for biopsy of masses with heterogeneous metabolic activity (Tatli et al. 2010).

**Kidney**

Most renal masses can be characterized with high accuracy by noninvasive imaging alone, and a solid nonfat-containing or complex renal mass should be considered a renal cell carcinoma until proven otherwise. Metastases to the kidney are usually small and multifocal or perinephric. Lymphomatous involvement of the kidneys usually occurs in the setting of disseminated disease and is characterized by typical CT patterns with multiple small masses, spread from retroperitoneal disease, diffuse infiltration, and perinephric encasement.

In a study by Brierly et al. with 49 patients undergoing FNAB for various renal masses, the sensitivity of CT-guided biopsy for the diagnosis of malignancy ranged from 89% in large solid masses to only 50% in complex cysts. Inadequate specimens were obtained in 16% of the patients (Brierly et al. 2000). In another study by Lechevallier et al., CT-guided renal biopsy of 63 patients had an overall accuracy of 89%. Biopsy material was not sufficient for analysis in 15 patients (21%). Unsuccessful biopsy was related to lesion size: Biopsy was unsuccessful in 11 of 30 tumors (37%) of 3 cm or less versus 4 of 43 (9%) of tumors greater than 3 cm (Lechevallier et al. 2000).

**Adrenal Glands**

Incidentally, discovered adrenal masses (incidentalomas) are relatively frequent. Adrenal incidentalomas (AI) exceeding 1 cm in size are found in 1–5% of the patients undergoing chest or abdominal CT for unrelated reasons. The risk of malignancy in patients with nonfunctioning adrenal masses is between 3.5 and 34% (Lumachi et al. 2001). Since the development of dedicated MR-imaging techniques for differentiation of adrenal masses, adrenal biopsy is performed only in exceptional cases, and benign adrenocortical nodules are the most common lesion to be found with FNAB (more than 40%).

Lumachi et al. performed a study in order to compare the usefulness of FNAB cytology, CT and MR imaging in patients with nonfunctioning adrenal masses. Including 34 patients with adrenal masses incidentally discovered in a CT scan, the authors found a sensitivity and specificity of 100% for the combination of both, MR imaging and FNAB. The authors recommended performing image-guided FNAB in all patients with nonfunctioning adrenal masses of 2 cm or more in size. Morbidity rate of the study was 2.9% (Lumachi et al. 2003).

**Retroperitoneum and Pelvis**

Nahar Saikia et al. performed 242 aspiration biopsies of deep-seated thoracic, abdominal, and
retroperitoneal lymph nodes under ultrasound \((n=216)\) and CT \((n=26)\) guidance, respectively. The diagnostic accuracy rate was 86 % (Nahar Saikia et al. 2002). In 23 patients with 26 suspect abdominal, pelvic \((n=6)\), or retroperitoneal \((n=12)\) lymph nodes, Memel et al. reported technical success, that is, sampling of adequate tissue for cytologic or histologic evaluation, in 21 of 23 ultrasound-guided biopsies (91 %). Three of 26 lymph nodes (11.5 %) could not be sampled due to poor visualization under ultrasound (Memel et al. 1996).

9.1.4.5 Complications
In the lung, apart from pneumothorax (16–44.6 %) and consecutive thoracostomy tube insertion, complication rates for image-guided FNAB are low (Laurent et al. 2000; Swischuk et al. 1998; van Sonnenberg et al. 1988). Factors increasing the risk of pneumothorax are small lesion size (Cox et al. 1999; Fish et al. 1988; Kazerooni et al. 1996), increasing depth of the lesion, several passes through the pleura, and underlying pulmonary disease (Poe et al. 1984; Quon et al. 1988). Zaetta et al. evaluated an expanding hydrogel biopsy tract plug deployed through the coaxial needle to reduce rates of pneumothoraces. Compared with control subjects (31 %), treatment subjects developed fewer pneumothoraces (18 %). Rates of chest tube placement and postprocedure hospital admission were also reduced (Zaetta et al. 2010). Pulmonary hemorrhage and hemoptysis are observed in up to 1.4 and 1.7 % of the procedures, respectively (Arslan et al. 2002). In case of hemoptysis, the patient should lie in a lateral decubitus position on the punctured side, preventing aspiration of blood into the contralateral lung. Air embolism is also a rare complication of thoracic FNAB resulting from a direct communication between a pulmonary vein and atmospheric air. Reasons for the entry of air are the operator leaving the proximal end of the biopsy needle open after insertion into the chest and the patient breathing deeply during the intervention. The patient should receive 100 % oxygen and lie in the left lateral decubitus position with the head down in order to prevent cerebral embolism.

Complication rates of FNAB in the abdomen are very low. In the meta-analysis including literature data and results of questionnaires distributed in North American and European hospitals in the 1980s, Smith found mortality rates between 0.006 % (63,108 biopsies) and 0.031 % (16,381 biopsies) in the USA and between 0.008 and 0.018 % in European hospitals (Smith 1991). Leading causes of death reported in Europe \((n=33)\) were hemorrhage after liver biopsy (17 of 21) and pancreatitis after pancreas biopsy (five of six). Frequency of needle tract seeding was in a range between 0.003 and 0.009 % in the four questionnaires.

In hepatocellular carcinoma, given a high positive predictive value of suspicious imaging findings alone (Torzilli et al. 1999), percutaneous biopsy has a limited role. Common risks include intraperitoneal bleeding and needle tract tumor implantation. In the study of Bret et al., 2.5 % of 159 patients \((n=4)\) with HCC who underwent fine-needle aspiration biopsy developed serious bleeding after the procedure, and one died (Bret et al. 1988). Factors that may contribute to hemorrhage include tumor hypervascularization, failure of cirrhotic liver tissue to seal the needle track, free bleeding into perihepatic ascites, and coagulopathy secondary to liver dysfunction (Grant and Neuberger 1999). Needle tract implantation has a reported incidence of up to 5 % (Takamori et al. 2000).

Acute pancreatitis has been described as rare but potentially fatal complication of needle biopsy of the pancreas (Mueller et al. 1988; Smith 1991). In their series of 184 pancreatic biopsies in 178 patients, Mueller et al. reported severe postprocedure pancreatitis in 5 patients (3 %) (Mueller et al. 1988).

As far as vascular structures are concerned, many studies have shown that the transgression of vessels, especially low-pressure veins, does not significantly elevate the complication rate (Ferrucci et al. 1980; Smith 1991; Welch et al. 1989).
9.1.5 CT-Guided Punch Biopsy

In comparison to aspiration biopsy, the punch biopsy (synonym: core biopsy) technique is either performed with (semi-)automatic spring-activated cutting needles (Tru-Cut) in combination with a biopsy gun or with manually activated cutting needles. This technique allows for obtaining cores of tissue with an intact histological structure that facilitates a precise histological diagnosis or immunohistochemical analysis.

9.1.5.1 Indication
Large-gauge automated needle biopsies (12–19 G) are traditionally performed in patients without a known primary tumor, in cases of potential lymphoma, and after inconclusive fine-needle aspiration biopsy. Owing to the varying availability of a cytopathologist and results that are comparable to FNAB (or even better), punch biopsy has meanwhile been established as the primary technique of choice in most radiological departments. Moreover 18–19 G needles are almost as thin as fine needles but provide specimen for histology instead of mere cytological specimen.

9.1.5.2 Material
In comparison to the aspiration technique, core biopsy needles are defined by diameters of 12–19 G (large gauge) and usually by the combination with a spring-activated Tru-Cut system. The Tru-Cut biopsy needle is characterized by a trough at the distal end. First, the biopsy gun fires the inner needle into the lesion where a core of tissue falls into the trough. Then, the outer needle cuts the sample lying in the trough out of the surrounding tissue and captures the sample which can be safely removed through the outer needle or with the whole system (Fig. 9.10). When an automated

![Fig. 9.10](image-url)

The automated Tru-Cut biopsy technique: (a) The inner needle (characterized by a trough at its end) is fired into the target lesion by the biopsy gun (1). A core of tissue falls into the trough (2). The outer needle slides across the trough and thereby cuts out the specimen (3). (b) Finally, the specimen can be safely removed with the inner needle or with the whole system (4)
Tru-Cut system is used for biopsy, the localization of the needle tip next to the lesion should be documented before taking the sample. Usually, at least two samples are taken for histological evaluation and instantly put into 10 % formalin. Different manufacturers offer either disposable all-in-one systems or the combination of disposable biopsy needles of various diameters and lengths (up to 30 cm) with a standard multi-use gun (Table 9.3). The main advantage is cost reduction. With respect to histopathological evaluation, the advantages of the core biopsy system are that the amount of obtained tissue is more or less constant while the sample keeps its histological structure. In contrast to manually handled large-gauge biopsy systems, the automated mechanism ensures a quick procedure with the biopsy needle in the patient only for a short period of time.

9.1.5.3 Technique

Before introduction of the biopsy needle, local anesthesia is applied with a 22 G needle. In children, elderly, and anxious patients, IV anxiolysis and sedation may be used. During the intervention, cardiorespiratory monitoring is needed in case of conscious sedation. After local anesthesia, a small skin incision is made at the intended needle entry point. The rest of the puncture procedure is performed in an identical manner as described in chap. 2 and Sect. 9.1.4.3.

9.1.5.4 Results

Lung

Anderson et al. performed a study to determine diagnostic accuracy comparing fine-needle aspiration with core biopsies of 195 pulmonary lesions in 182 patients and found a significantly higher diagnostic yield of the core biopsy technique (93 %) compared to FNAB (78 %) (Anderson et al. 2003). The authors concluded that core biopsy should be the method of choice especially if a dedicated cytopathologist is not available (Fig. 9.11). Charig et al. reported their results of 185 core lung biopsies in 183 patients with predominantly 18 and 20 G needles. Diagnostic accuracy (93.5 %) and complication rates were comparable to the published figures for FNAB (Charig and Phillips 2000).

Table 9.3 Commercially available needles for CT-guided punch biopsy (exemplary selection of different manufacturers and needles)

<table>
<thead>
<tr>
<th>Needle type (manufacturer)</th>
<th>Diameter (gauge)</th>
<th>Length (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tru-Cut manual biopsy needle (Allegiance, McGaw Park, IL, USA)</td>
<td>14; 18</td>
<td>7; 11; 15</td>
<td></td>
</tr>
<tr>
<td>Temno semiautomated biopsy system, adjustable cutting length (Allegiance, McGaw Park, IL, USA)</td>
<td>14–22</td>
<td>6; 9; 11; 15; 20; 48</td>
<td></td>
</tr>
<tr>
<td>Percucut self-aspirating type cut needle (E-Z-EM, Lake Success, NY, USA)</td>
<td>18; 19.5; 21</td>
<td>5; 10; 15</td>
<td></td>
</tr>
<tr>
<td>Easy Core automated biopsy system (Boston Scientific, Natick, MA, USA)</td>
<td>15; 18; 20</td>
<td>10; 15; 21; 25</td>
<td></td>
</tr>
<tr>
<td>Magnum reusable core biopsy gun with disposable biopsy needles (Bard Biopsy, Tempe, AZ, USA)</td>
<td>12–20</td>
<td>10; 13; 16; 20; 25; 30</td>
<td></td>
</tr>
<tr>
<td>Max Core disposable automated biopsy needle (Bard Biopsy, Tempe, AZ, USA)</td>
<td>14; 16; 18; 20</td>
<td>10; 16; 20; 25</td>
<td></td>
</tr>
<tr>
<td>Monopty disposable core biopsy system (Bard Biopsy, Tempe, AZ, USA)</td>
<td>12; 14; 16; 18; 20</td>
<td>10; 16; 20</td>
<td></td>
</tr>
<tr>
<td>Quick Core automated biopsy needle with spring (Cook, Medical, Bloomington, IN, USA)</td>
<td>14; 16; 18; 19; 20</td>
<td>6; 9; 15; 20</td>
<td></td>
</tr>
<tr>
<td>Biopsy-Handy (Somatex, Teltow, Germany)</td>
<td>14–20</td>
<td>10; 15; 20</td>
<td></td>
</tr>
<tr>
<td>Semiautomated biopsy device SABD (Pflugbeil, Zorneding, Germany)</td>
<td>14–21</td>
<td>11.5; 15; 20</td>
<td></td>
</tr>
</tbody>
</table>

*a Not all diameter-length combinations may be available

*b Coaxial needles available
Abdomen

In contrast to FNAB, histological classification of liver masses is only possible with larger core biopsy systems in most cases, as true-positive findings increase from 84 to 98 % (Pagani 1983) (Fig. 9.12). Regarding the ability to differentiate samples obtained with either 14 or 18 G needles, no significant difference was found between both large-gauge needle types (Haage et al. 1999). Automated cutting needles have additionally contributed to increase the accuracy of the histological sample (Hopper et al. 1993). Stattaus et al. conducted a study to determine the visibility of small liver lesions in 50 patients during CT-guided biopsy with 16 and 18 G semiautomated biopsy needles and the influence on biopsy results. 38 patients underwent biopsy guided by non-enhanced CT (89.5 % accuracy), and 12 patients received contrast media at different time points during the biopsy for better visualization leading to a reduced accuracy (75 %). Overall accuracy was 86 %. The authors concluded that in case of poor visualization of liver lesions in non-enhanced CT scans, correlation between the liver lesion and anatomical landmarks can be used for verifying the correct position of the biopsy needle. In addition, interventional MR imaging has the potential to reveal lesions that are poorly visible in CT and US, providing results comparable to CT-guidance: 87–94 % sensitivity, 90–100 % specificity, and 85–93 % accuracy (Salomonowitz 2001; Zangos et al. 2003).

Fig. 9.11 Patient (right lateral decubitus position) with a history of asbestos exposure. Preinterventional CT showed pleural wall thickening of the left lung. An 18-G (10-cm) Tru-Cut biopsy needle was introduced under CT-fluoroscopic guidance parallel to the posterior thoracic wall through an intercostal access. Histopathology revealed pleural mesothelioma.

Fig. 9.12 Patient (supine position) with multiple hepatic rim-enhancing lesions in both liver lobes (preinterventional CT; venous phase) (a). An easy-to-access lesion in segment 3 was chosen for Tru-Cut biopsy with a 16-G (10-cm) needle under CT-fluoroscopic guidance (b). Histopathology revealed hepatic metastases of gall bladder carcinoma.
Numerous studies evaluated fine-needle aspiration of pancreatic masses (Gupta et al. 2002; Luning et al. 1985; Sofocleous et al. 2004), while only few authors focused on core biopsy in the pancreas (Elvin et al. 1990; Tseng et al. 2009; Wutke et al. 2001). Tseng et al. published 34 CT-guided biopsies of the pancreas including 9 successful transgastric procedures with a 17-gauge coaxial introducer needle and an 18-gauge biopsy needle, without any complications of peritonitis or bleeding (Tseng et al. 2009). For CT-guided core biopsies conducted in intraabdominal organs (liver, pancreas) the study by Wutke et al. showed sensitivity, specificity, and accuracy values of 88.4, 100, and 90.4 %, respectively. CTF can furthermore help avoid penetration of vital structures with the core biopsy needle along its pathway (Fig. 9.13).

**Retroperitoneum and Pelvis**

In their analysis of 180 CT-guided coaxial core biopsies, Wutke et al. reported markedly higher diagnostic utility rates for non-organ-related retroperitoneal (88 %) than liver and pancreatic lesions (66 %). Overall sensitivity, specificity, and accuracy rates were 91.1, 100, and 93.3 %, respectively (Wutke et al. 2001). The study of Hau et al. focused on the diagnostic accuracy of both, CT-guided fine-needle and core biopsy of musculoskeletal lesions. The authors found an accuracy rate of 74 % for the subset of core biopsies (258 procedures) in comparison to 63 % for CT-guided fine-needle aspiration (101 procedures). Diagnostic accuracy rates for pelvic and non-pelvic musculoskeletal lesions were 81 and 68 %, respectively (Hau et al. 2002). Stattaus et al. examined 49 cases of coaxial core biopsies performed in the retroperitoneal space. Diagnostic accuracy was 95.9 %, while a specific histological diagnosis could be established in 92.9 % of malignant lesions (Stattaus et al. 2008).

**Complications**

The study by Anderson et al. (see Sect. 9.1.5.4) showed an initial pneumothorax rate after the biopsy of 30 % which was reduced to 18 % after 4-h follow-up. Only 2 % of the patients developed clinical symptoms requiring further therapy with a chest tube. Separated pneumothorax rates according to the biopsy technique were 35 % (FNAB) and 16 % (core biopsy), respectively (Anderson et al. 2003). Charig and Phillips reported pneumothoraces in 25.9 % (4 of 48 patients (8.3 %) requiring an intercostal drain) and small hemoptyses without pneumothorax in 7 % of their patients (Charig and Phillips 2000).

In a large retrospective multicenter study by Piccinino et al. including 68,276 liver biopsies with a Tru-Cut system, a complication rate of only 0.4 % was found (Piccinino et al. 1986). Deaths after liver biopsy were rarely observed, usually due to hemoperitoneum in patients with
malignant disease or cirrhosis. The authors reported a higher rate of deaths, serious hemorrhagic complications, pneumothorax, and biliary peritonitis in biopsies performed with the Tru-Cut needle (0.003 %) than with the Menghini needle (0.001 %). In contrast to the analysis by Smith, revealing values between 0.003 and 0.009 % (Smith 1991), the rate of tumor cell seeding after percutaneous tumor puncture of HCC has been reported to be in the range between 1 % (Llovet et al. 2001) and 5 % (Takamori et al. 2000). In biopsy of subcapsular lesions, the rate may even increase up to 12 % (Llovet et al. 2001).

### 9.1.6 CT-Guided Drill Biopsy

During the past few decades, surgical (open) biopsy of musculoskeletal tumors could be gradually replaced by image-guided (closed) biopsy techniques (Bickels et al. 1999). Main advantages of image-guided percutaneous biopsy in the musculoskeletal system are reduced morbidity and costs. Fine-needle aspiration biopsy is often limited in bone tumors given an inadequate ability to sample the tissue matrix while core biopsy reaches accuracy rates of 68–100 % (Pramesh et al. 2001). On the other hand, in young patients with deep subcortical lesions or suspect lesions with a sclerotic rim, the core biopsy needle alone may not be sufficient to penetrate the cortical bone.

#### 9.1.6.1 Indications

Indications for image-guided percutaneous bone biopsy are bone metastases and primary bone tumors and sometimes infectious disease. The biopsy is performed to verify that a suspicious bone lesion is indeed a metastasis in order to detect the primary tumor or to further investigate the diagnosis of osteomyelitis. In patients with breast cancer, hormone sensitivity of a metastatic bone lesion can be important for adequate therapy. In suspected primary bone tumors, biopsy is only exceptionally performed for histological evaluation with respect to the intended therapy. Special attention should be given to potential tumor seeding and the access path for biopsy carefully planned together with the surgeon responsible for resection (Schweitzer et al. 1996). Another indication for percutaneous bone biopsy is suspected osseous infection with microorganisms that have to be identified before antibiotic therapy. In infectious disease, it is sometimes difficult to distinguish osteomyelitis from other diseases such as Charcot osteoarthropathy. Common contraindications are an uncorrectable coagulopathy and potential soft tissue infection with the danger of superinfection of the bone.

#### 9.1.6.2 Material

A variety of bone biopsy needles are available, ranging from sharp-threaded, drilling-type 17-G needles to large-bore 8-G needles (Table 9.4).
For sclerotic or osteoplastic bone lesions of the spine, it is advantageous to collect as much material as possible, because these lesions are often difficult to adequately decalcify for diagnostic workup. Therefore, for sclerotic bone lesions, bone biopsy needles of 11 G or larger are usually best.

When a spinal lesion is in a location that is difficult to access (e.g., a tight passage between the carotid sheath and vertebral artery in the upper cervical spine), lightweight short drilling needles may be advantageous in setting and keeping trajectories in shallow soft tissues, in contrast to larger 11-G needles with heavy handles, which often throw the trajectory of the needle off course when used under CT-guidance. Because the small 17-G E-Z-EM needles are short and very lightweight, they can be set in shallow soft tissues during targeting and still hold their trajectory without hand support. Because they are also very sharp and threaded, they can thus be drilled deeply into the bone to obtain core samples very effectively in most cases.

### 9.1.6.3 Technique

In comparison to MR imaging, CT is inexpensive and readily available in most institutions. Therefore, most bone biopsies are performed under CT-guidance. First, a CT scan is performed in order to visualize the bone lesion, and the needle entry point and access path are chosen. In case of superficial bone biopsies without potential interference with vascular and nerve structures along the access path, a non-enhanced CT scan is usually sufficient for planning of the access route. Vessels, nerves, visceral, and articular structures should be avoided. Depending on the localization of the bone lesion, different approaches are available:

- **Vertebral body:** Depending on the vertebral level, the access path is anterior (cervical spine), transpedicular (Fig. 9.14) or intercostovertebral (thoracic spine) (Fig. 9.15), and transpedicular or posterolateral (lumbar spine).
- **Pelvis:** An anterior, lateral, or posterior approach (avoiding the femoral and sacral nerve plexus and the sacral canal) are used (Fig. 9.16).

### Table 9.4 Commercially available needles for CT-guided drill biopsy (exemplary selection of different manufacturers and needles)

<table>
<thead>
<tr>
<th>Needle type (manufacturer)</th>
<th>Diameter (gauge)</th>
<th>Length (cm)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ackermann biopsy needle set (Cook, Medical, Bloomington, IN, USA)</td>
<td>14</td>
<td>9.6; 10.8</td>
</tr>
<tr>
<td>Elson biopsy needle set (Cook, Medical, Bloomington, IN, USA)</td>
<td>14 (with 22 G introducer and 12 G coaxial needle)</td>
<td>17.1; 18.3</td>
</tr>
<tr>
<td>Geremia vertebral biopsy set (Cook, Medical, Bloomington, IN, USA)</td>
<td>16 (with 22 G introducer needle)</td>
<td>15</td>
</tr>
<tr>
<td>Myers biopsy needle set (Cook, Medical, Bloomington, IN, USA)</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Spi-Cut biopsy needle (Somatex, Teltow, Germany)(^b)</td>
<td>12.5; 14</td>
<td>5; 10; 15; 20</td>
</tr>
<tr>
<td>Ostycut Bone biopsy needle (Bard Biopsy, Tempe, AZ, USA)(^b)</td>
<td>13–17</td>
<td>5; 7.5; 10; 12.5; 15</td>
</tr>
<tr>
<td>Bonopty coaxial biopsy system eccentric drill penetration set (Radi Medical Systems, Uppsala, Sweden)</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Percucut bone biopsy needle (E-Z-EM, Lake Success, NY, USA)</td>
<td>17</td>
<td>5; 7.5; 10; 12.5; 15</td>
</tr>
<tr>
<td>Percucut coaxial sheath cut-biopsy needle with keyhole cutting edge (E-Z-EM, Lake Success, NY, USA)</td>
<td>19.5</td>
<td>15</td>
</tr>
<tr>
<td>Laredo trephine needle</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Not all diameter-length combinations may be available

\(^b\)Removal of sample under aspiration
Peripheral long tubular bones: an approach orthogonal to the cortical bone is used. This reduces the risk of the biopsy needle gliding off the cortex. The shortest possible access path should be chosen in order to avoid critical structures like vessels and nerves (Fig. 9.17).

Flat bones (ribs, sternum, scapula): An oblique approach angle of 30–60° is chosen that provides more material for biopsy and helps to protect the underlying structures behind the flat bone (Fig. 9.18).

The whole procedure has to be carried out under strictly sterile conditions to avoid osseous infection with subsequent osteomyelitis. Percutaneous drill biopsy is usually performed under local anesthesia or analgesedation (in incompliant patients), while pediatric bone biopsy represents an exception requiring general

Fig. 9.14 Patient (prone position) with major osteolysis (anterior 2/3) of lower thoracic vertebra showing osteosclerosis of the posterior 1/3 and both pedicles. First, transpedicular access was obtained with a surgical manual drill (a). Then, the soft tissue sample was taken with an 18-G (13-cm) Tru-Cut biopsy needle under CT-fluoroscopic guidance (b). Histopathology revealed a spinal metastasis of prostate carcinoma

Fig. 9.15 Patient (prone position) with suspicion of spondylodiscitis in the Th°7/8 spinal segment. Preinterventional CT showed small osteolytic defects close to the upper end plate of thoracic vertebra 8. After local anesthesia with a 22-G needle (a), a 12.5-G bone biopsy needle was introduced through the left costovertebral joint (b). Microbiological analysis revealed spondylodiscitis due to a Staphylococcus aureus infection
anesthesia. Local anesthesia is applied from the skin level down to the periosteum of the intended entry point of the biopsy needle with a 22-G needle. Leaving the anesthetic needle in the skin by detaching the syringe from the needle with the needle along the intended trajectory course saves time in subsequent needle placements. The initial anesthetic needle serves as a relative directional marker on both the images and the skin, and longer needles can subsequently be placed with positional readjustments as necessary, so that the final needle can be placed in tandem (or coaxial) fashion relative to the target zone. The biopsy needle is introduced through the cortical bone under intermittent CT/CTF control verifying the correct needle direction. The needle containing the sample is completely removed, and the sample fixed in 10% formalin. In case of suspected infection, the specimen is not fixed but directly put into a sterile container for microbiological analysis. Osteolyses characterized by a soft tissue core are directly sampled using a 16- or 18-G Tru-Cut biopsy needle (Fig. 9.14b). Depending on the thickness of the cortical bone and the degree of sclerosis surrounding the bone lesion, either a surgical hammer in combination with the bone biopsy needle (e.g., 14 G Somatex Spi-Cut, Teltow, Germany), an 8-G trephine needle (e.g., Laredo type), a dedicated bone penetration set (e.g., Bonopty; AprioMed, Uppsala, Sweden), or a manual drill can be used in order to penetrate the cortex (Fig. 9.14a).

9.1.6.4 Results
In their study including 359 CT-guided bone biopsies of musculoskeletal lesions with the FNAB and core biopsy technique, Hau et al.

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**Fig. 9.16** Patient (supine position) with osteolysis of the anterior column of the right acetabulum (a). A 14-G bone biopsy needle was introduced with a sterile surgical hammer avoiding the right common femoral artery and vein (b). Histopathology revealed multiple myeloma.

**Fig. 9.17** Patient with history of breast cancer and hip pain. Fat-suppressed MR imaging (Short Tau Inversion Recovery (STIR) sequence) of the pelvis showed a hyperintense lesion of the right proximal femoral neck (a). A 14-G bone biopsy needle was introduced in a left lateral decubitus position providing stability during insertion with a surgical hammer (b). Histopathology revealed bone metastasis of breast cancer.
Biopsy reported accuracy rates of 63 % (n = 101) and 74 % (n = 258), respectively (Hau et al. 2002). Especially sarcomas have been shown to be undergraded with FNAB sampling only. Therefore core biopsy is the technique of choice. Jelinek et al. reported their results in 110 primary bone tumors that were sampled under CT and fluoroscopic guidance, respectively. Correct final diagnosis could be obtained by biopsy in 88 % of the patients, while the only minor complication was a small hematoma (0.9 % complication rate) (Jelinek et al. 2002). Dupuy et al. performed 176 CT-guided core needle biopsies and 45 fine-needle biopsies with accuracy rates of 93 and 80 %, respectively, and a complication rate below 1 % (Dupuy et al. 1998). In a recently published large retrospective analysis including 2027 cases of CT-guided core needle biopsies of musculoskeletal lesions, the correct diagnosis was possible in 77.3 %, while the remaining patients underwent a second biopsy within 30 days, finally allowing a diagnostic accuracy of 94 %. Most false negative results were found in cervical lesions and in benign, pseudotumoral, inflammatory, and systemic pathologies. The complication rate was low (22 minor adverse events; 1 %), predominantly including transient pareses and hematomas (Rimondi et al. 2011).

In comparison with conventional CT guidance, the advantage of CT-fluoroscopy is the online visualization, the excellent resolution of bone, and the surrounding soft tissue and the possibility to even target small lesions (Daly and Templeton 1999). The very good resolution of bone and soft tissue helps to reduce the amount of complications due to misplacement of the needle. Another major advantage is the possibility to perform biopsies in an off-plane direction enabling the physician to easily target spinal lesions of lumbar vertebra 5 or the sacrum. In the upper lumbar and thoracic regions, CTF provides a means of real-time, visualizing the adjacent lung and other posteriorly located visceral organs, such as the kidneys, in the case of a high lumbar target. In the cervical region, CTF may also be the preferred method of image guidance for biopsies because it can be used to define the positions of the jugular vein, carotid artery, vertebral artery, and pharyngeal and esophageal structures.

9.1.6.5 Complications
In bone lesions that are assumed to be extremely hypervascularized such as suspected metastases of renal cell carcinoma, a digital subtraction angiography may have to be obtained prior to biopsy. Transarterial embolization or direct puncture of the lesion with injection of absorbable gelatin sponge or polyvinyl alcohol particles helps to prevent serious hemorrhage when samples of the lesion are taken.

When biopsies are performed in thoracic lesions, the operator should always be cautious of...
a possible pneumothorax; at the end of the procedure, either a follow-up CT scan or an expiratory chest radiograph should be obtained to rule out a pneumothorax. A chest tube kit should be available before biopsy of the thoracic spine.

When pushing or drilling a needle through very dense bone, and when vital structures such as the aorta, the carotid artery, or the vertebral artery are located just beyond the target zone along the trajectory path, the operator may want to use a détente technique with one hand pushing the needle toward the target and the other hand grasping the needle shaft to provide a counteraction force in order to prevent piercing beyond the target area into vital structures if resistance to the needle should suddenly give way.

When delivering a bone core that is impacted within the bone biopsy needle, it is prudent to avoid pushing the core out of the needle with such force that it suddenly flies off and becomes lost. To remove a bone core from the biopsy needle, the operator should use the appropriate trocar design that is intended for such removal.

### Appraisal

The growing availability and inexpensiveness, as well as the ability to safely access musculoskeletal structures have substantially increased the role of computed tomography for guidance of percutaneous biopsies in comparison to other imaging modalities like ultrasound and conventional fluoroscopy. Adjacent major vessels, nerves, and visceral structures can be avoided, and the biopsy needle precisely positioned within the target lesion for histopathologic sampling. CT provides an excellent visualization of bone with the exception of some bone marrow lesions only detectable on MR imaging. Though CTF is necessary only in selected cases, given an experienced operator using repeated single-shot CT-fluoroscopy for needle positioning – CTF can markedly reduce both, the in-room time and radiation dose for the patient.

### Key Points
- Needle diameter 8–19 G
- Needle lengths 5–20 cm
- Strictly sterile conditions mandatory during the whole biopsy procedure
- For primary bone tumors, the needle pathway should lie within the surgical resection area
- The access angle should be chosen according to type of bone (tangential access in flat bones, orthogonal access in tubular bones)
- Access to the spine should be anterior/anterolateral in the cervical, intercostovertebral/transpedicular in the thoracic, and transpedicular/posterolateral in the lumbar spine
- Needle insertion should be with a hand-grip or a surgical hammer
- A hand drill preferable for access to lesions with a sclerotic rim/thickened cortical bone

### 9.2 MR-Guided Biopsies

Christoph Thomas

#### 9.2.1 Indications

In comparison to computed tomography (CT) or ultrasound guided procedures, magnetic resonance (MR)-guided biopsies require a higher degree of training and experience and the use of MR-compatible materials. In addition, they tend to be more time consuming and expensive (Alanen et al. 2004). Furthermore, in most institutions magnet-time is limited. Thus, this technique is currently reserved to cases where MR imaging can unfold its advantages over other modalities:
- Multiplanar MR-fluoroscopy
- Excellent soft tissue contrast
- The lack of radiation exposure
Multiplanar fluoroscopy enables image guidance of extremely angulated trajectories which might be necessary to reach liver lesions in the liver dome and can also be advantageous in the biopsy of other intraabdominal lesions with otherwise limited access. The inherently high soft tissue contrast of MR imaging facilitates the biopsy of lesions which are isodense to their surrounding tissue and therefore invisible in CT imaging. This might be the case in certain liver lesions but also in bone marrow lesions and in inflammatory disease such as acute myositis, where the muscular edema can be targeted. MR imaging can also be used to target breast lesions which cannot be visualized clearly in ultrasound or mammography (Chap. 10). In children and young patients, the lack of radiation exposure using MR imaging is a major advantage.

9.2.2 Materials

9.2.2.1 MRI System

Basically, MR-guided interventions are possible using standard closed bore magnets (Fischbach et al. 2011). In an analogous matter to CT-guided interventions, the patient has to be moved in and out of the magnet for needle manipulation and imaging. Due to the spatial restrictions in a closed magnet, the maximal length of the biopsy devices is limited. Concepts like robotic assistance devices or augmented reality systems to support MR-guided biopsies in closed bore magnets are currently under development (Moche et al. 2008; Wacker et al. 2006). In contrast, an open magnet system allows patient access during imaging and facilitates real-time imaging during needle insertion. Furthermore, it offers more space for the use of longer biopsy devices within the magnet. Currently, two different open magnet designs are available: (1) Sandwich-like magnet designs with field strengths of up to 1.0 T (e.g., Panorama, Philips, Netherlands) with a vertical main magnetic field have been introduced; (2) short and wide bore magnets with a horizontal main magnetic field with field strengths of up to 3.0 T (e.g., MAGNETOM Espree, Siemens, Germany) also offer sufficient patient access. The newer high-field systems provide an improved image quality and imaging speed compared to open low-field systems (Stattaus et al. 2008; Streitparth et al. 2009).

Different surface coils can be used for interventional imaging. Typically, flexible loop coils and multipurpose body array coils are sufficient.

In addition to standard diagnostic setups, further materials are necessary to perform interventions in an MR-imaging suite: An RF-shielded in-room monitor or a beamer to project the acquired images against the wall is needed for image guidance. For communication of the interventionalist and the technician who normally works outside the magnet room, either the standard patient intercom system or a dedicated MR-compatible wireless communication system can be used (Guttler et al. 2011). If an MR-compatible wireless computer mouse or trackball are available in addition to the in-room monitor, the interventionalist can control the scanner and does not depend on the technician and communication, especially in the noisy environment of the MR-imaging suite. Especially in open bore scanners, an MR-compatible stool can facilitate patient access for the interventionalist, and an MR-compatible table is necessary to serve as a tray for the biopsy materials.

9.2.2.2 Instruments

For MR-guided biopsies, dedicated MR-compatible instruments have to be used in order to avoid an interaction of the needle with the magnetic field. Typical materials for MR-compatible biopsy systems are alloys of titanium, nickel, chromium, and molybdenum. MR-compatible materials tend to be softer than surgical steel, leading to a slightly decreased sharpness and stiffness in comparison to non-MR-compatible instruments. However, in recent years, technical advances
have been made regarding the alloys, continuously improving instrument sharpness. As nowadays, mainly core biopsies are requested and performed; this chapter omits fine-needle aspiration. MR-compatible biopsy instruments are available from different manufacturers (Table 9.5). MR-compatible bone biopsy sets and a piezoelectric drill can be purchased from Daum-InVivo (Schwerin, Germany). Basically, off-label use of non-MR-compatible biopsy instruments is possible, if an MR-compatible introducer sheath has been positioned under image guidance and if the device is strictly kept outside the 0.5 T line. However, due to the security hazards connected to the presence of ferromagnetic materials in an MR-imaging suite and the resignation to verify the correct needle position using non-MR-compatible instruments, an off-label use of non-MR-compatible instruments is not recommended.

### 9.2.2.3 Pulse Sequences

In interventional MR imaging, instruments are visualized by the signal void which is a result of the susceptibility differences of the instruments in comparison to the surrounding tissue. The sizes of the artifacts depend on the material itself (alloy and size), the magnetic field strength, the angle of the needle versus the main magnetic field, the sequence type, and certain sequence parameters (Chap. 3). Large artifacts are generated by a perpendicular needle orientation in relation to the main magnetic field ($B_0$), use of gradient echo sequences, phase-encoding direction parallel to the needle shaft, low bandwidth settings, and a high echo time, whereas needle orientations parallel to the magnetic field, spin echo or turbo spin echo sequences, phase-encoding direction perpendicular to the needle shaft, a high bandwidth, and low echo time cause smaller artifacts (Lewin et al. 1996). The true needle tip is not necessarily located at the end of the artifact; there can be a deviation of several millimeters. Two classes of sequences are used for MR-guided biopsies: MR-fluoroscopy sequences which repeatedly image one section with an acquisition time of less than 1 s/slice are applied to monitor the insertion of a device, and fast static 2D-sequences are employed for planning and for the verification of the correct needle position. Typically, gradient echo sequences are applied for MR fluoroscopy (e.g., T1w fast low-angle shot (FLASH) and T2w true fast imaging with steady state precession (TrueFISP)). For verification of the needle position, gradient echo, spin echo or turbo spin echo sequences are used. Modern biplanar MR-fluoroscopy sequences can image the needle in perpendicular slices which allows for the verification of the correct angulation in three dimensions. Due to the complex nature of the artifact generation, interventionalists planning to begin MR-guided interventions should perform in vitro experiments with their biopsy devices prior to clinical use in order to familiarize with sequences and artifacts.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Size (gauge)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daum InVivo (Schwerin, Germany)</td>
<td>Fully automatic BiopsyGun</td>
<td>14–18</td>
<td>100–175</td>
</tr>
<tr>
<td>Daum InVivo (Schwerin, Germany)</td>
<td>Semi automatic BiopsyGun</td>
<td>14–18</td>
<td>100–150</td>
</tr>
<tr>
<td>EZ-E-M (Lake Success, NY, USA)</td>
<td>Bio-Gun</td>
<td>14; 18</td>
<td>150</td>
</tr>
<tr>
<td>EZ-E-M (Lake Success, NY, USA)</td>
<td>Biopsy needles</td>
<td>18; 20</td>
<td>100–200</td>
</tr>
<tr>
<td>Somatex (Teltow, Germany)</td>
<td>MR Biopsy Handy</td>
<td>14–18</td>
<td>100–200</td>
</tr>
</tbody>
</table>
9.2.3 Technique

9.2.3.1 Pre-interventional Diagnostics + Informed Consent
Sufficient recent cross-sectional imaging studies (CT or MR imaging) should be available prior to the intervention to enable the planning of the trajectory and to preselect biopsy materials of the correct size and length. Pre-interventional CT imaging can depict osseous structures and calcifications which are only visualized indirectly in MR images and should be requested when in doubt.

Informed consent and pre-interventional screening of the coagulation status have to be obtained in the same way as for CT-guided biopsies. Contraindications for MR-guided biopsies include contraindications for CT-guided biopsies and contraindications for MR examinations, which include the presence of non-MR-compatible ferromagnetic implants and foreign bodies. Most electronic implants such as pacemakers, cochlea implants, and implanted pumps are not MR-compatible. Pregnancy is regarded as a relative contraindication.

9.2.3.2 Pre-interventional Preparation
The patient position on the examination table is determined by the intended access trajectory. For planning of the trajectory, physical factors have to be considered, since the size and contrast of the artifact which depicts the device depend on the angle of the device to $B_0$. The artifact is most pronounced if the needle is placed in a 90° angle versus $B_0$. In open sandwich-style magnets, $B_0$ is oriented vertically, which leads to optimal artifact characteristics in a horizontal direction, while in open bore scanners, $B_0$ is oriented horizontally, enabling a radial approach. The patient should be placed in a comfortable position to improve his compliance. Then, the surface coils are placed appropriately. A flexible loop coil with a diameter of approximately 10 cm can be placed around the intended skin incision site, allowing later skin disinfection and sterile draping. An additional multipurpose body array coil can be placed adjacently to the flexible loop coil to improve image quality especially in deeper body regions. The coils can be draped to avoid staining with disinfectant.

9.2.3.3 Intervention
Figure 9.19 illustrates the strategy for MR-guided biopsies in a step-by-step-approach. At first, planning images are acquired. In order to shorten the intervention time, only sequences which are necessary for planning should be selected, and it should be refrained from performing a complete diagnostic examination. For liver lesions, coronal and axial fast single shot-sequences can be recommended to gain to a good overview. Furthermore, the available fast needle verification and fluoroscopy sequences should be tested to determine which sequence leads to the best depiction of the anatomy and pathology and offers the highest background signal for an optimal depiction of the needle. After selection of the optimal sequences and determination of the trajectory, the designated needle path should be imaged in two orthogonal planes.

For the determination of the skin access site, the “finger pointing technique” can be used: Two orthogonal MR fluoroscopy planes are placed on the planned trajectory, and the interventionalist uses his index finger or a water-filled plastic syringe to find the correct position on the skin. Alternatively, the skin access site can be determined by placing a capsule (e.g., Nifedipine, Adalat®, Bayer Healthcare, Berlin) onto the estimated skin entry site, followed by repeated imaging and replacing of the capsule, until the correct position is found (Figs. 9.20, 9.21, 9.22, and 9.23). Furthermore, MR-compatible localization grids are available. The struts of these grids typically contain water or diluted gadolinium, leading to high-signal intensity in T1w and T2w sequences. After marking of the entry site, skin disinfection, sterile draping, and local anesthesia are performed in an analogous manner to CT-guided biopsies. Local anesthesia and skin incision can be performed using standard ferromagnetic equipment; however, special attention
Fig. 9.19 Step-by-step illustration of the strategy for MR-guided biopsies. A 37-year-old man with partly fat-equivalent, partly contrast-enhancing mass in the right obturator foramen (arrows). (a–c) Planning images (a: coronal fat-saturated T2w, b: axial T1w, c: Axial fat-saturated T1w after intravenous contrast administration). (d) Verification sequence after placement of an Adalat® capsule (arrow), revealing insufficient placement of the capsule (T1w FLASH-2D). (e) Identification of the skin entry site using the finger-pointing technique with a plastic syringe (arrow, T1w FLASH-2D) after removal of the capsule. (f) Biplanar real-time MR fluoroscopy for monitoring the introduction of the biopsy needle (T1w FLASH-2D). (g, h) Biplanar verification of needle position (T1w FLASH-2D). (i, j) Biplanar verification of the correct position of the biopsy chamber. Histology: Chondroid lipoma
Fig. 9.19 (continued)
Fig. 9.20 A 14-year-old girl with tumor-prosthesis of the tibia due to osteosarcoma and a new lesion adjacent to the tibia, which was invisible in CT due to metal artefacts. (a) Definition of the skin access site using an Adalat® capsule. (b) MR fluoroscopy-guided introduction of the biopsy sheath. (c) Introduction of the biopsy chamber (arrow) under MR fluoroscopy. Histology: Osteosarcoma

Fig. 9.21 A 35-year-old women with intramuscular lesion of the right rectus abdominis muscle. An oblique trajectory was chosen in order to spare the peritoneum. (a) Finger-pointing technique to determine the skin access site. (b) MR fluoroscopy-guided introduction of the biopsy sheath. (c) Introduction of the biopsy chamber (arrow) under MR fluoroscopic control. (d) Documentation of the correct position of the biopsy chamber (arrow; Turbo spin echo sequence). Histology: Endometriosis
Biopsy

A 32-year-old woman with painful lesion in proximity of the tibial nerve and vessels. The biopsy was performed under regional nerve block anesthesia. (a) Planning images with Adalat® capsule. (b) Documentation of the correct position of the introducer sheath. (c) Introduction of the biopsy chamber under MR fluoroscopy. Histology: Neurinoma

has to be paid to the magnetic forces which act onto ferromagnetic material inside the 0.5 T line. Then, the biopsy sheath is introduced until it penetrates the subcutaneous fat and the superficial fascia. At this point, two fast orthogonal control sequences should be performed to ensure the correct position and orientation of the needle in relation to the planned trajectory. If the position and angulation are correct, the needle can be advanced toward the target. For monitoring, either continuous MR-fluoroscopy or a sequential scanning approach with alternating imaging and advancement of the needle as in sequential CT-guided biopsies can be used. In open bore MR-imaging systems with patient access, the use of MR fluoroscopy is encouraged. If conventional closed bore scanners are used, the sequential strategy has to be applied. Unlike in CT imaging, it is difficult to detect a diversion of the needle from the imaging plane early enough if only one plane is used, thus, it is important to always acquire perpendicular image planes to verify the correct needle position. After the target is reached, biopsy can be performed. Especially in small lesions or in close proximity to relevant anatomic structures, the introduction of the biopsy chamber can be monitored using MR fluoroscopy, and the correct position within the lesion should be documented. The specimen are obtained and fixed in formalin as described for CT-guided biopsy. In case of bleeding out of the sheath which does not resolve spontaneously, gelatin sponge material (e.g., Gelfoam, Pfizer, New York) may be introduced for a more efficient hemostasis.

To rule out postinterventional hematoma, fatsaturated T2w images should be acquired after withdrawal of the cannula. After the intervention, patients are managed according to the rules described for CT-guided biopsies.

Unless the interventionalist controls the scanner himself, sufficient communication between interventionalist and technician is crucial, as the technician...
normally works outside the scanner room. Verbal communication through the standard patient intercom system can be difficult due to the distance of the interventionalist from the microphone and is impossible during MR fluoroscopy. To improve communication, previously practiced gestures can be used. Alternatively, the use of a MR-compatible communication systems with suppression of background noise is recommended (Guttler et al. 2011).

9.2.4 Results

Regarding sensitivity, specificity, and complications, reported results for MR-guided biopsies are widely comparable to CT-guided biopsies. Zangos et al. reported the largest retrospective study with 322 patients who received MR-guided biopsies of the liver, the prostate, other abdominal, retroperitoneal, musculoskeletal, and thoracic lesions and

Fig. 9.23 A 55-year-old woman with liver lesions. (a) Perpendicular planning sequences. (b) Biplanar MR fluoroscopy. (c) Biplanar documentation of correct position of the biopsy chamber in the lesion. Histology: Metastasis of breast cancer
lesions in the neck using an open 0.23-T device (Zangos et al. 2009). Combined sensitivity and specificity were 86 and 87%, respectively. Only two major complications (retroperitoneal and rectal bleeding) occurred, leading to a prolonged hospital stay. Other smaller studies reported comparable results using open low-field devices for abdominal lesions (Kariniemi et al. 2005; Zangos et al. 2006). Regarding the biopsy of musculoskeletal lesions, initial results have been published by Koenig et al. (2001). Carrino et al. have reported good overall results for bone- and soft-tissue biopsies (diagnostic accuracy of 91%) (Carrino et al. 2007). For the use of open high-field MR-imaging systems (1.0–1.5 T and even 3.0 T), recent publications show excellent results for 1.0-T sandwich magnets (Fischbach et al. 2011), open bore 1.5-T systems (Stattaus et al. 2008), and open bore 3.0-T systems (Kuhn et al. 2010), although for field strengths above 1.5 T, it might be necessary to specifically redesign instruments due to the dependence of the artifact size on the magnetic field.

### 9.2.5 Complications

As in CT-guided biopsies, possible complications include hemorrhage, infection, organ injury, and implantation of metastases. In the literature, only two major complications leading to a prolonged hospital stay are reported (Zangos et al. 2009). No fatal complications have been reported so far.

### Key Points for the Successful Intervention

- Sufficient pre-interventional imaging is necessary for planning the intervention thoroughly beforehand and to shorten intervention time.
- Communication between interventionalist and technician should be simple and clear and be ideally practiced beforehand; alternatively, the interventionalist should control the scanner by himself from the magnet room.
- The use of MR fluoroscopy can facilitate and accelerate the procedure.
- For needle verification and for MR fluoroscopy, two perpendicular images should be acquired.

### References

CT-Guided Biopsy


Salomonowitz E (2001) MR imaging-guided biopsy and therapeutic intervention in a closed-configuration

MR-Guided Biopsies

