Clinical applications

MR-guided ablative therapy of malignant liver tumors employing the Panorama HFO open MR scanner

Primary and secondary malignant hepatic tumors are some of the most common tumors worldwide. Unfortunately, chemotherapy and radiation therapy are ineffective treatment methods. Surgical resection is considered the only potentially curative option, however only a few patients are surgical candidates [1, 2].

Besides locoregional treatments by chemoperfusion or chemoembolization, several percutaneous image guided treatment alternatives have been introduced. These ablation techniques offer the advantage of reduced morbidity and mortality, as well as lower procedural costs when compared with traditional surgical methods. They can also be performed on an outpatient basis, repeated over time, or combined with other anticancer treatments [3, 4].

Substantial tumor kill is achieved by directly applying chemicals such as ethanol or acetic acid, temperature changes using liquid nitrogen or NO₂ for cryosurgical ablation or radiofrequency ablation (RFA), and laser interstitial thermotherapy (LITT) for coagulative necrosis [3, 5]. In addition, local radiation was introduced recently [6-8].

To enable access to the liver tumors, ultrasonography (US) or computed tomography (CT) are most commonly used. However, both methods have their limitations.

US is limited by the need for an acoustic window. CT is limited to single plane imaging and by the fact that both the patient and the staff are exposed to ionizing radiation. Further on, CT is hampered by the limited soft tissue contrast in native fluoroscopic sequences and the inability to perform heavily angulated approaches. Hence magnetic resonance imaging is considered as an attractive alternative for guiding the intervention. It combines excellent soft tissue contrast, achieved without ionizing radiation, and arbitrary slice selection for biopsies in delicate locations.

General working groups have tested closed bore, high-field MRI for image-guided needle placement. However, in these systems, access to the patient is severely limited and needle repositioning has to be performed outside the magnet, with intermittent acquisition of images [9].

Finally, open low-field MRI has been tested for MR fluoroscopy in liver intervention [10-12], but image quality has never been acceptable, hence this kind of intervention was never translated into routine clinical use.

The interventional technique for implantation of the ablative device

In recent years, open MR systems have been introduced with high field strength, such as 1.5 T (employing a short magnet with a wide opening) or 1.0 T, as applied by our own working group. The latter magnet is configured in a doughnut design, using two superconductive coils as part of a yoke to generate a vertical magnetic field, with specific challenges and opportunities [13-15]. This magnet design gives high temporal stability and spatial homogeneity of the magnetic field. Due to the vertical orientation of the magnetic field, solenoid type coils can be used for imaging, allowing good signal-to-noise ratio and signal homogeneity. The patient table can be moved in the lateral direction, allowing positioning of the field of view into the isocenter of the magnet for all anatomies. In this way, off-center imaging in left-right direction can be avoided altogether. A large left-right aperture of 160 cm, and 45 cm in the AP direction, gives sufficient space for the patient and for the interventional radiologist in the direct vicinity of the volume of interest.
images, whereas malignant focal liver lesions do not exhibit T1 shortening. This increases image contrast and thus lesion visibility compared with plain investigations. Peak liver signal intensities are seen 15–20 min after injection followed by a plateau of constant signal intensities for approximately 2 hours. This extended imaging window provides ample time for minimally invasive liver interventions [16-18].

To perform the procedure, the patient is placed in supine position. Depending on the intended percutaneous access route and the position of the target inside the liver, the patient position is rotated up to 30° towards, occasionally, a lateral decubitus position. This maneuver helps optimizing the presumed angle between needle and the vertical B0 field for improved visibility of the needle, despite susceptibility effects [19].

To determine the position of the target lesion at the beginning of the intervention, breath hold static transversal images of the liver are obtained with a T1-weighted, fat signal-saturated 3D high resolution isotropic volume examination (THRIVE) with a flip angle of 12°, a repetition (TR) of 5.4 ms and an echo time (TE) of 2.6 ms. A voxel size of 1.5 x 2 mm and a slice thickness of 3 mm are chosen.

Sixty-five slices in a breath-hold time of 17 s are sufficient to cover most livers. For interactive dynamic imaging in fluoroscopy mode, a T1 weighted gradient echo sequence (T1-FFE) with a flip angle of 35°; a TR/TE of 11 and 6 ms is used. The voxel size is 2.0 x 2.4 mm and the slice thickness 8 mm. Images are acquired with a rate of 1 image per second. First of all, the skin entry site is determined with the finger pointing method. In case of interfering ribs or interposed pulmonary recessus the entrance point is determined more caudal to the lesion.

For interventional purposes, a circular-shaped 210 mm diameter surface coil for signal reception is placed in the liver region, over the area of interest. The coil provides depth coverage, roughly equal to the diameter of the coil. In addition, an in-room RF-shielded liquid crystal monitor is used for image viewing at the side of the magnet, analogous to a fluoroscopy monitor (Figure 1).

Interactive software, originally designed for cardiac imaging, allows switching between viewpoints in different arbitrary slice orientations while imaging continuously (Figure 2). The slice orientation can be adjusted by the technician with a mouse or within the magnet room by the radiologist with a USB footswitch (Herga Electric Ltd., Suffolk, United Kingdom). Before intervention, patients receive 0.1 ml/kg body weight of a 0.25 mol/l (181.43 mg/ml) solution of gadoxetic acid disodium (Gd-EOB-DTPA, Primovist, Bayer-Schering, Germany). Primovist is a paramagnetic liver-specific contrast agent. As a result of hepatocyte uptake, normal liver parenchyma exhibits T1 shortening, leading to an increase in signal intensity on T1-weighted images.
Disappearance of the needle tip from the imaging plane caused by deviation from the intended path can, in interactive continuous imaging mode, be corrected by alternating between the two imaging planes. In addition, the technician can diligently modify the orientation of the imaging plane according to the needle path.

After final positioning of the needle in the lesion the correct placement can be documented with a repetitive THRIVE sequence perpendicular to the needle pathway using 15 slices, to increase the signal-to-noise ratio in a single breath hold of 4.8 s.

Finally, fat suppressed T2W-TSE sequences (TR/TE 1600 and 110 ms) in axial orientation with a slice thickness of 6 mm and an acquisition time of approximately three minutes can be added to rule out post-interventional hematoma or bilioma.

**Percutaneous tumor ablation using radiofrequency or brachytherapy**

In our institution, the most frequently used ablation methods are brachytherapy and radiofrequency ablation, hence these two methods are described in more detail.

Alternating electric current operating in the radiofrequency range can produce a focal thermal injury in living tissue. Shielded needle electrodes are used to concentrate the energy in the selected tissue. Each device consists of a needle, an electrical generator and a ground pad. The generator outputs an ablation signal with a fundamental frequency of 460 kHz +/-5%. It has to be placed outside the MR scanner room using an extension cable as the construction incorporates ferrous materials. Although the generator is working at a much lower frequency than the MR system, a broad spectrum of harmonics is produced up into the range of tens of MHz. To prevent interaction between the RF generator and the MR scanner, the RF current must be filtered. This can be done with a low-pass filter in a filter box where the Faraday cage shielding the MR scanner room is entered [20, 21].

Using the open MR Panorama system, the probe can be placed accurately in the center of the lesion. RFA is performed by continuous heating under temperature control and the ablation procedure is continued until the mean temperature of all thermal probes is 105 °C. After the RFA cycle we perform the T2-weighted TSE sequence to check whether the thermal ablation is complete, as the treated lesion shows a signal loss on the T2-weighted images [22, 23].

It would be desirable to have the additional use of MR-thermometry in order to determine the exact ablation zone and to monitor the heating more precisely. An online tool using the Proton Resonance Frequency (PRF) method with suppression of artifacts from respiratory movement is under development.

Tumors ideal for RFA are smaller than 3 cm in diameter, completely surrounded by hepatic parenchyma, 1 cm or deeper within the liver capsule, and at least 2 cm away from large hepatic or portal veins. Subcapsular liver tumors can be ablated, but their treatment is usually associated with greater procedural and postprocedural pain. Tumors adjacent to large blood vessels are more difficult to ablate completely because the blood flow in the vessels cools the adjacent tumor, thus limiting the extent of the ablation. A single ablation takes 8–20 minutes, hence the treatment is limited to patients with three lesions or less in order to minimize the time for the interventional procedure.

Recently a local radioablative high-dose-rate (HDR) brachytherapy technique in which an iridium-192 source is temporarily inserted through catheters has been presented [8]. The therapeutic effect of this technique is not influenced by the cooling of surrounding large vessels and is not limited by tumor size.

For puncture of the lesion an 18-gauge MR-compatible needle with a length of 150 or 200 mm is used. Positioning of the needle is carried out under real-time image guidance as described above. Exchange of the needle with an angiography sheath is performed using the Seldinger technique, for safety reasons without simultaneous imaging and outside the magnet. Brachytherapy catheters are then positioned in the sheath. Final THRIVE images are transferred to a treatment planning system to determine the

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![Figure 2. Biopsy of the liver using the interactive scan mode. Image planes could be interactively adjusted to image the entrance point and the lesion in one plane while scanning continuously. A second plane, perpendicular to the first, is adjusted so one can follow the pathway of the needle in two perspectives orthogonal to each other. Left: finger pointing to determine the entrance point in coronal (upper) and axial (lower) orientation. Middle and right: puncture of the lesion in corresponding slice orientations.](image-url)
Another study, focusing on MR guided biopsies, demonstrated, with high accuracy, pinpoint punctures even for small lesions [25]. Hence we shifted our indications for MR guided ablation to earlier stages with smaller tumors, below 1 cm. What contributes to the good results is the fact that the technique requires just a basic interventional package and skills common among radiologists who regularly perform percutaneous procedures with ultrasound or CT guidance. No external devices, dedicated monitoring or extra software for calculating coordinates are necessary.

Of course, data are based solely on reports from a single institution. Also, there is ample room for improvement: there are still difficulties in communication and further developments of MR compatible interventional devices are necessary. But we predict that this new technique will be implemented effectively in clinical routine and have great value in oncology therapy.

Relative coordinates \((x, y, z)\) of the catheters as well as the tumor boundaries, manually (Figures 3, 4). The duration of the irradiation is typically 20–40 min. Generally, one catheter per 1–2 cm of tumor diameter is implanted.

### Assessment of the role of MR guided tumor ablation using the Panorama HFO

The MR guidance technique for treatment of non-resectable malignant liver lesions has drawn increasing interest since its introduction in our clinic two years ago. In 2009 almost half of the interventions were shifted to the MR unit and more than 160 patients were treated under MR guidance using the open system.

The recently published study by Ricke et al. [24] demonstrated a technical success rate of 97% and a local control rate at three months of 96%. Superiority of lesion detection compared to plain CT imaging was unmistakeable.

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### Parameters for diagnostic and fluoroscopic dynamic imaging of the liver

<table>
<thead>
<tr>
<th>sequence</th>
<th>TR (ms)</th>
<th>TE (mm)</th>
<th>Flip</th>
<th>Voxel (cm)</th>
<th>SD (ms)</th>
<th>FOV (mm)</th>
<th>time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>THRIVE</td>
<td>5.4</td>
<td>2.6</td>
<td>12°</td>
<td>1.5 x 2</td>
<td>3</td>
<td>30 x 30</td>
<td>16 1)</td>
</tr>
<tr>
<td>T1 FFE</td>
<td>11</td>
<td>6</td>
<td>35°</td>
<td>2.0 x 2.4</td>
<td>8</td>
<td>30 x 30</td>
<td>1.0 2)</td>
</tr>
<tr>
<td>T2 TSE fs</td>
<td>1600</td>
<td>110     90°</td>
<td>1.2 x 1.3</td>
<td>6</td>
<td>30 x 30</td>
<td>180</td>
<td></td>
</tr>
</tbody>
</table>

**Abbreviations:**

- **TR** = repetition time
- **TE** = echo time
- **SD** = slice thickness
- **FOV** = field of view
- **THRIVE** = fat saturated 3D high resolution isotropic volume examination
- **FFE** = fast field echo imaging
- **TSE** = turbo spin-echo
- **fs** = fat saturation

**Notes:**
- 1) acquisition time for 3D whole liver scan in breath hold
- 2) acquisition time for 1 image/slice (frame rate)
Reference


