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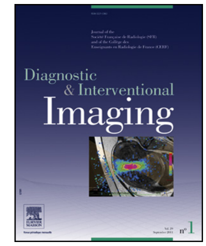

SOLICITED REVIEW / *Interventional imaging*

Planning and guidance: New tools to enhance the human skills in interventional oncology

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Abstract Navigation systems have the potential to achieve a high accuracy for percutaneous ablation of tumors even for those in difficult locations. In the last years, successful research has been conducted to make navigation devices applicable to percutaneous tumor ablation with special planning software that now allows high accuracy even for deep-located small lesions close to critical structures. Because of the high number of available navigation systems, this review focuses on those with preexisting clinical studies.

The accuracy of minimally invasive percutaneous tumor ablation procedures is continuously improving [1]. This is particularly applicable to tumors in difficult locations such as the caudate lobe of the liver because of its deep location between the hepatic hilum and the inferior vena cava. Computed tomography (CT) is the method of choice when visibility and adjustability in ultrasound are poor and the percutaneous access path to the tumor is difficult. Manual positioning of the probes, particularly out-of-plane, requires a high degree of experience and can lead to high radiation exposure for the patient as well as for the interventional radiologist. In addition, each probe repositioning increases the risk of complications and tumor cell seeding.

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Navigation systems have the potential to overcome the aforementioned problems, even if they were originally developed for rigid structures in neurosurgery. The first ones were established in the late 1980s [2—4]. Over the last few years, a lot of research has been conducted to make navigation devices applicable to internal organs with special attention to their softer consistency and the breathing-dependent location and configuration [5—10].

High accuracy of navigation systems enables the precise ablation of deep-located small tumor lesions as well as lesions close to critical structures such as large vessels, gallbladder or stomach. Patients with multiple tumor lesions and decreased liver function will benefit the most, because accurate positioning of the probe will preserve healthy liver tissue. It will also prevent the risk of local recurrence, which is still higher after conventional tumor ablation in comparison to surgical resection. Optimizing the safety margin is one of the big challenges particularly for tumor lesions $\geq$ 3 cm.

The ablation procedure of tumors $\geq$ 3 cm often requires repositioning of the needle-like probes with overlapping ablation areas. This increases the complexity of the procedure and makes it more susceptible for human errors. Integrated planning options for percutaneous tumor ablations are a helpful tool in some navigation systems. In addition to simulation of the ablation volume using predefined settings, some systems also allow a simultaneous or sequential placement of the ablation probes.

Because of the high number of available navigation systems, this review focuses on the ones with preexisting clinical studies.

Peri-interventional setting

Navigation-guided interventions presume no movement of the target region between planning computed tomography (CT) or magnetic resonance imaging (MRI) scans and probe placement. Initially, the target area of the patient must be immobilized to achieve accurate results. This can be realized using a vacuum-mattress or various other fixation systems [11,12]. Secondly, preinterventional imaging and probe placement must be performed in the same respiratory position if the target organ is subject to breathing movement.

When the intervention is performed under local anesthesia, several approaches have been developed to compensate for respiratory movement. Most frequently used are respiratory gating techniques, which rely on the fact that the organs occupy the same position and shape at identical points during the breathing cycle. The liver, for example, is considered motionless at the point of full expiration or inspiration. To reproduce breath-holds in spontaneously breathing patients, biofeedback may be used, e.g. with the help of a respiratory belt [13]. A further attempt is real-time automatic registration of fiducial markers glued on the patient's abdomen to find the point in the breathing cycle when the planning CT scan was performed [14].

As an alternative to respiratory gating, real-time deformation models can be applied, which estimate the position of the target structure continuously from the positions of tracked fiducials [10,15]. Because movements of the target organ cannot be traced by surface-based methods, effort has been made to combine them with X-ray or magnetic [16] organ tracking, which requires placement of markers inside the target organ.

For better accuracy navigation-guided percutaneous tumor ablations are often performed under general anesthesia. For intubated patients, respiratory motion control is indispensable to warrant high accuracy. Two techniques are currently available:

- high-frequency jet ventilation (HFJV);
- temporary disconnection of the endotracheal tube.

HFJV utilizes high respiratory rates combined with small low tidal volumes thus leading to minimal movement of the lung and abdominal organs and preserved sufficient ventilation even during long interventions. A prospective study involving 41 patients undergoing percutaneous tumor ablation has shown HFJV to be a safe method to reach motion control and nearly complete immobility of the liver with a measured internal target movement in X- and Y-axis of only 0.3 mm [17]. A similar study involving 26 patients using endotracheal tube disconnection for breathing control showed a mean movement of 2.0 mm for external targets and 1.4 mm for internal targets [18]. Therefore, HFJV seems to be the better method in relation to accuracy.

Optical or electromagnetic tracking systems

Tracking systems are using either optical and/or electromagnetic methods to locate the instruments during the intervention in real-time [19]. Optical tracking systems are more accurate than electromagnetic ones, but they require continuous visibility of the instruments. This can cause problems in case of multiprobe setups as for example during irreversible electroporation (IRE). For electromagnetic systems, on the other hand, continuous visibility of the instruments is not necessary.

Transformation of coordinates is performed to locate the position of the ablation probe towards anatomical structures. In this so-called registration, the instrument's position in three-dimensional space (tracking coordinate system) is transferred to the coordinate system of the preinterventionally acquired CT or MRI images (image coordinate system).

Fiducial markers are attached to the patient before the preinterventional CT or MRI scan, which can be registered by the tracking system and are visible in the acquired images. They are either glued on the patient's skin or fixated on needles, which are placed inside the liver. The fiducial markers then enable the registration between the tracking and image coordinate system [20].

Commercially available navigation systems use respiratory gating to compensate for breathing movement. Real-time deformation models are being developed, which estimate the position of the target structure continuously through the position of the tracked fiducial [15,21] markers.

At present, there is only one commercially available tracking system for percutaneous tumor ablation (CAS-One I®; CAScination AG, Bern, Switzerland) (Fig. 1). The working group of Bale et al. have used a self-developed system for their studies. The available clinical studies of percutaneous