Thermal ablation is a minimally invasive method for local tumour treatment and is considered the first choice for treatment of unresectable liver malignancies. Long-term outcomes depend on the rate of complete ablation of the entire tumour [1–4]. Due to excellent short- and long-term results, thermal ablation is accepted as an alternative to surgical resection in very early HCC (single HCC ≤2 cm) [5]. Although surgical resection is still considered the method of choice, this is due to unacceptably high local recurrence rates after thermal ablation of larger lesions. For instance, in CRCLM >3 cm local recurrence rates ranging from 45% to 70% have been reported. By contrast, the local R0 rate after resection of primary and secondary liver tumours are in the range of 8–24% [6,7]. If similar rates can be achieved by minimally invasive thermal ablation, it will challenge resection as the first-line therapy.

Rationale for the application of 3D navigation systems in thermal ablation

Tumour size is the most important prognostic parameter for local control after thermal ablation. The unacceptable results after ablation of large lesions are explained by the insufficient coverage of the tumour by the ablation zone. If the volume of the ablation zone at one electrode/antenna position does not cover the tumour including a safety margin, multiple overlapping ablation zones must be used. This is barely achievable by conventional freehand US, CT, or MR guidance, and requires a major change in tumour ablation strategies. This challenging task is the transfer of a virtual three-dimensional ablation plan (with multiple probe/antenna placements) into the real patient [8].

3D navigation systems

3D navigation systems enable real-time tracking of different surgical instruments with respect to the patient’s anatomy (CT, MRI, PET, SPECT and real-time ultrasound) by using mechanical, optical or electromagnetic 3-D coordinate measuring systems [9]. Aiming devices allow for precise percutaneous targeting of any anatomical structure in the patient. The world’s first (non-commercial) aiming device for frameless stereotactic punctures was developed in Innsbruck in 1995 and it was first applied for radiofrequency ablation of the Gasserian ganglion in a patient with trigeminal neuralgia in the following year [10]. Later, the same guidance technique was used for fractionated frameless stereotactic interstitial brachytherapy in patients with head and neck cancer [11], percutaneous pelvic fracture fixation [12], retrograde drilling of osteochondral lesions [13] and thermal ablation of tumours in different organs [12-15]. The first multi-probe stereotactic RFA of a large liver tumour was performed in Innsbruck in 2001 [15].

Workflow of stereotactic thermal ablation

The technique of stereotactic radiofrequency ablation using multiple RFA probes has been described previously (16,17). In brief, the ablation procedure starts with the CT table. Fiducials are attached to the skin of the patient immobilisation system. After careful patient registration using the skin fiducials and checking the registration accuracy, sterile draping of the patient is performed. An aiming device (Atlas) is adjusted using special guidance software. Coaxial needles are advanced along the trajectory to the pre-planned target during temporary disconnection of the TT. The coaxial needles serve as guides for the RFA system. After that, check the needle positions, a native control CT is superimposed to the planning CT. After biological cooling, the thermal ablation amount is performed by the coaxial needles for serial tumour ablation. After ablation, a contrast-enhanced CT is obtained and superimposed to the planning CT by means of image-fusion software, thereby verifying the ablation zone covering the tumour including a safety margin.

Alternatively, the CAScination navigation system may be used (18). It was originally developed for intraoperative navigation for liver surgery and, in cooperation with our group, was adapted to the requirements of SRFA. It is also based on optical tracking technology. In contrast to the (neuro)navigation system, sterile reflective skin markers act as a dynamic reference frame. This requires a different workflow. In contrast to the standard approach described above, the patient is steriley draped and the sterile markers are attached to the skin prior to the planning CT. The markers are automatically detected on the image data set as well as on the real patient, allowing for fast automatic registration. The fiducials have to be placed in a way that they do not interfere with the needles. Registration continuum changes during the respiratory cycle, requiring adjustment of the aiming device during breath-hold.

Accuracy of stereotactic targeting

Using the Medtronic and the CAScination navigation system in combination with the Atlas aiming device, the reported accuracies in phantom studies were 1.64±0.919–1.84±1.189 mm [19] and 2.31±1.3–2.8±1.6 mm [18]. In the patient, the median lateral error at the start point was 3.2 mm (range: 0.01–9.4 mm) [20]. Beyer et al. compared stereotactic IRE (SIRE) needle placement with non-navigated and CAScination IRE (CIRE) for percutaneous ablation of liver malignancies in a total of 20 patients [21]. Accuracy of needle placement for SIRE was higher than that for CIRE (2.2 mm vs. 3.3 mm, P=0.001). SIRE demonstrated a significantly higher accuracy compared with CIRE.

Clinical mid- and long-term results after stereotactic thermal ablation

Colorectal liver metastases

Our group reported 98 SRFA treatment sessions of 189 CLM in 63 consecutive patients [17]. LR was identified in 16% of the tumours (31/188), with no significant differences (P=0.635) when comparing the tumour sizes <3 cm (77.7%), 3–5 cm (11.1%) and >5 cm (17.4%). Using SRFA, the overall survival (OS) is not affected by tumour size. The median OS was significantly different when comparing unresectable and resectable patients (27 vs. 58 months, P=0.002) with OS rates of 92%, 66% and 48% at 1, 3 and 5 years, respectively, in resectable patients. The tumour size did not affect OS and DFS. SRFA challenges resection as the first-line local treatment of patients with CRCLM.

Intrahepatic cholangiocellular carcinomas

Seventeen inoperable consecutive patients with 52 IJCs were treated with SRFA [22]. A median OS of 60 months was achieved. The two largest tumours with diameters >10 cm were completely ablated. These SRFA data of unselectable IJCs are superior to the published data on resection. SRFA is a minimally invasive alternative to resection.

Metastatic melanoma to the liver

In a recent paper, the results after SRFA of 75 melanoma liver metastases in 20 patients was presented (23). The primary and secondary success rates were 89.3% and 93.3%, respectively, with an overall local recurrence rate of 13.3%. Four of ten local recurrences were re-treated successfully by SRFA.

During follow-up, 9/20 patients developed extratemporal metastatic disease and 10/20 had liver recurrence at any location. The median OS from the start of SRFA was 19.3 months, with an OS of 65%, 41% and 17% at 1, 3 and 5 years, respectively, with no significant difference between patients with cutaneous and occult melanoma. SRFA is an attractive alternative to resection in patients with melanoma liver metastases.

Focal liver lesions in paediatric patients

SRFA may even be an alternative to surgical resection of focal liver lesions in patients with inherited metabolic disorders (24). SRFA was successfully applied for the removal of single large liver adenoma in a 22-year-old woman and a 20-year-old man with glycogen storage disease type I and of a suspicious lesion in a 16-year-old girl with tyrosinemia type I and o-fetoprotein elevation.

Conclusion

For thermal ablation, the lesion including a safety margin has to be covered by the ablation zone in order to achieve complete necrosis. In lesions >2.3 cm, multiple overlapping ablation zones are required. This is barely achievable by US- and CT-guidance. The superior short- and long-term results after SRFA as compared to the standard approach definitively justify the additional costs and efforts that are associated with the technique. Stereotactic thermal ablation procedures (SRFA, SWM, SIRE) are reliable and reproducible and challenge resection as the first-line treatment in primary and secondary liver tumours. In addition, it may also be applied in other organs, e.g. bone, lung, kidney, soft tissue and lymph nodes.

Multi-probe SRFA of liver tumours has become the main indication for 3D navigated interventions at our centre, with increasing numbers of patients in the past five years. During the first 6 months of this year, 130 liver SRFAs have already been performed by our group.