3D Navigation: do we need it?

Reto Bale

Don't miss it !
New tools for guiding and monitoring liver ablation
Special Session
Saturday, September 16, 08:30-09:30
Auditorium 10

Reto Bale
Medical University Innsbruck
Innsbruck, Austria

Prof. Reto Bale is one of Europe's leading experts on stereotactic guidance. His technical expertise in a wide range of imaging modalities has formed the cornerstone of his pioneering work in real-time tracking and automation. This has been successfully applied within his department (the Department of Microinvasive Therapy at Innsbruck's University Clinic for Radiodiagnostics) to treat not only an impressive number of patients, but also a wide range of conditions. While liver tumours (both primary and secondary) form the bulk of their work, Prof. Bale's team also applied their unique skills in the treatment of pelvic fractures and other bone issues. Prof. Bale's work has been cited almost 4,000 times.

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]. However, in tumours >2 cm, 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 CRLM >3 cm local recurrence rates ranging from 45% to 70% have been reported. By contrast, the local R1/2 rates 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 related to 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 acquired. This is barely achievable by conventional freehand US, CT, or MRI 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 patient-specific imaging data (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 anaesthetised patient is immobilised on the CT table. Fiducials are attached to the skin of the patient. During temporary disconnection of the tracheal tube (TT), a contrast-enhanced CT is acquired. On the frameless stereotactic (neuro)navigation system (Medtronic Inc.), multiple trajectories are planned using the 3D CT dataset. A dynamic reference frame is attached to the patient immobilisation system. After unsterile 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 electrodes. To check the needle positions, a native control CT is superimposed to the planning CT. After biopsy, RFA electrodes are introduced via 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, 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 slightly different workflow. In contrast to the standard approach described above, the patient is sterilely 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 continuously 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 [19] and 2.3±1.3–2.8±1.6 mm [18]. In the patient, the median lateral error at the needle tip was 3.2 mm (range: 0.01–9.4 mm) [20]. Beyer et al. compared stereotactic IRE (SIRE) needle placement with non-navigated conventional 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 mean deviation, 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 CRLMs in 63 consecutive patients [17]. LR was identified in 16% of the tumours (31/189), with no significant differences (P=0.635) when comparing the tumour sizes <3 cm (17.7%), 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. Tumour size did not affect OS and DFS. SRFA challenges resection as the first-line local treatment of patients with CRLM.

Intrahepatic cholangiocellular carcinomas

Seventeen inoperable consecutive patients with 52 ICCs 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 unresectable ICCs 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 extrahepatic metastatic disease and 10/20 had liver recurrence at any location. The median OS from the date of SRFA was 19.3 months, with an OS of 64%, 41% and 17% at 1, 3 and 5 years, respectively, with no significant difference between patients with cutaneous and ocular melanoma. RFA 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 Ia and of a suspicious lesion in a 16-year-old girl with tyrosinemia type I and α-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 conventional US- and CT-guidance. The superior short- and long-term results after SRFA as compared to the standard approach definitely justify the additional costs and efforts that are associated with this technique. Stereotactic thermal ablation procedures (SRFA, SMWA, SIRE) are reliable and reproducible and challenge surgical resection as the first-line treatment in primary and secondary liver tumours. In addition, it may also be applied in other organs, such as 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 over the past sixteen years. In the first 6 months of this year, 130 liver SRFAs have already been performed by our group.

References
1. Livraghi T, Goldberg SN, Lazzaroni S, et al. Hepatocellular carcinoma: radio-frequency ablation of medium and large lesions. Radiology 2000; 214:761-8
2. Solbiati L, Livraghi T, Goldberg SN, et al. Percutaneous radio-frequency ablation of hepatic metastases from colorectal cancer: long-term results in 117 patients. Radiology 2001; 221:159-66
3. Mulier S, Ni Y, Jamart J, Ruers T, Marchal G, Michel L. Local recurrence after hepatic radiofrequency coagulation. Annals of Surgery 2005; 242:158-71
4. Livraghi T, Meloni F, Morabito A, Vettori C. Multimodal image-guided tailored therapy of early and intermediate hepatocellular carcinoma: long-term survival in the experience of a single radiologic referral center. Liver transplantation: official publication of the American Association for the Study of Liver Diseases and the International Liver Transplantation Society 2004; 10:S98-106
5. EASL-EORTC. EASL-EORTC clinical practice guidelines: management of hepatocellular carcinoma. Journal of hepatology 2012; 56:908-43
6. Kudo M, Izumi N, Ichida T, et al. Report of the 19th follow-up survey of primary liver cancer in Japan. Hepatology research: the official journal of the Japan Society of Hepatology 2016; 46:372-90
7. Hamady ZZ, Lodge JP, Welsh FK, et al. One-millimeter cancer-free margin is curative for colorectal liver metastases: a propensity score case-match approach. Ann Surg 2014; 259:543-8
8. Bale R, Widmann G, Stoffner DI. Stereotaxy: breaking the limits of current radiofrequency ablation techniques. European journal of radiology 2010; 75:32-6
9. Wood BJ, Kruecker J, Abi-Jaoudeh N, et al. Navigation systems for ablation. Journal of vascular and interventional radiology: JVIR 2010; 21:S257-63
10. Bale RJ, Laimer I, Martin A, et al. Frameless stereotactic cannulation of the foramen ovale for ablative treatment of trigeminal neuralgia. Neurosurgery 2006; 59:ONS394-401; discussion ONS2
11. Bale RJ, Freysinger W, Gunkel AR, et al. Head and neck tumors: fractionated frameless stereotactic interstitial brachytherapy-initial experience. Radiology 2000; 214:591-5
12. Bale RJ, Kovacs P, Dolati B, Hinterleithner C, Rosenberger RE. Stereotactic CT-guided percutaneous stabilization of posterior pelvic ring fractures: a preclinical cadaver study. Journal of vascular and interventional radiology: JVIR 2008; 19:1093-8
13. Bale RJ, Hoser C, Rosenberger R, Rieger M, Benedetto KP, Fink C. Osteochondral lesions of the talus: computer-assisted retrograde drilling--feasibility and accuracy in initial experiences. Radiology 2001; 218:278-82
14. Bale RJ, Vogele M, Rieger M, Buchberger W, Lukas P, Jaschke W. A new vacuum device for extremity immobilization. AJR American journal of roentgenology 1999; 172:1093-4
15. Bale R, Freund M, Bodner G, Kovacs P, Jaschke W. Precise Computer- assisted Liver Tumor Puncture for Biopsy and Thermal Ablation. Radiology 2002; 225:242
16. Bale R, Widmann G, Haidu M. Stereotactic radiofrequency ablation. Cardiovascular and interventional radiology 2011; 34:852-6
17. Bale R, Widmann G, Schullian P, et al. Percutaneous stereotactic radiofrequency ablation of colorectal liver metastases. European radiology 2012; 22:930-7
18. Wallach D, Toporek G, Weber S, Bale R, Widmann G. Comparison of freehand-navigated and aiming device-navigated targeting of liver lesions. The international journal of medical robotics + computer assisted surgery: MRCAS 2014; 10:35-43
19. Stoffner R, Augscholl C, Widmann G, Bohler D, Bale R. Accuracy and feasibility of frameless stereotactic and robot-assisted CT-based puncture in interventional radiology: a comparative phantom study. RoFo : Fortschritte auf dem Gebiete der Rontgenstrahlen und der Nuklearmedizin 2009; 181:851-8
20. Schullian P, Widmann G, Lang TB, Knoflach M, Bale R. Accuracy and diagnostic yield of CT-guided stereotactic liver biopsy of primary and secondary liver tumors. Computer aided surgery: official journal of the International Society for Computer Aided Surgery 2011; 16:181-7
21. Beyer LP, Pregler B, Niessen C, et al. Stereotactically-navigated percutaneous Irreversible Electroporation (IRE) compared to conventional IRE: a prospective trial. PeerJ 2016; 4:e2277
22. Haidu M, Dobrozemsky G, Schullian P, et al. Stereotactic radiofrequency ablation of unresectable intrahepatic cholangiocarcinomas: a retrospective study. Cardiovascular and interventional radiology 2012; 35:1074-82
23. Bale R, Schullian P, Schmuth M, Widmann G, Jaschke W, Weinlich G. Stereotactic Radiofrequency Ablation for Metastatic Melanoma to the Liver. Cardiovascular and interventional radiology 2016; 39:1128-35
24. Karall D, Scholl-Burgi S, Widmann G, et al. Stereotactic radiofrequency ablation for liver tumors in inherited metabolic disorders. Cardiovascular and interventional radiology 2014; 37:1027-33