RADIO-FREQUENCY ABLATION

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Image-guided interventions for diagnostic and therapeutic purposes are widely performed. Before discussing technical considerations in detail, it should be stressed that patient inclusion and exclusion is probably the most crucial part of the entire procedure, besides the individual learning curve of the operator and interventionalist. This decision should always reflect individual personal aspects of the patient as well.

The technical assessment can be made with a checklist on behalf of a diagnostic examination:

- Anticipated pathology (tumor type: benign / malignant / metastasis)
- Lesions (number / size / volume / depth)
- Risk consideration (safety issues: access path / tumor vascularisation / surrounding structures)

The clinical feasibility should be considered on an individual basis to answer fundamental questions in the forefront of the intervention:

- Is the patient able to cooperate?
- Are there contraindications for the intervention?
- Is the coagulatory status o.k.?

According to legal regulations, a written informed consent 24h prior to the procedure should be strived.

Oncologic expertise, not only of the interventional radiologist, but of the entire team (general practitioner, surgeon, oncologist, radiotherapist, pathologist, and many more) are indispensable for proper patient selection. The mandate for interventional treatment should be based on a consensus conference, ideally from a certified (quality assurance) cancer center. Treatment of RFA may be curative, but it is more likely to form part of a palliative treatment regime. The intention, however, should be always aim to completely ablate the tumor confined to a small area with a reasonable safety margin.

Another prerequisite should be the technical and logistical ability to control and manage potential complications related to the procedure, e.g. thoracocentesis / chest tube placement in case of pneumothorax, embolization in case of bleeding complications as well as surgical stand-by, if applicable.

An optimized approach during the procedure considers the anatomical pathway and will address the distance for control scans (e.g. pleura; potentially risky structures, such as vessels / bowel; the minimum / maximum distance for the lesion itself as well as the requested angulation [usually in the x- and y-direction]). For tumor interventions, a 3D-assessment (in the z-direction as well) is mandatory. Several supporting devices are available to guide the operator, ranging from simple measures (goniometer guidance for free-hand access) to high-tech systems (such as augmented reality). For complex anatomical trajectories, also CT-fluoroscopy (ideally with angular beam modulation) might be an option as well. However, the radiation exposure of the operator has to be taken into account. Therefore, this technique should be used as an exception to the rule, only.

After the intervention, ultrasound or conventional x-ray can be used to rule out complications such as bleeding or pneumothorax. Close oncological follow-up of the patient is mandatory, as “postablation is preablation” in palliative tumor therapy (liver metastasis, primary liver tumors and lung lesions). Ideally, imaging uses the modality that visualizes the lesion on the target organ best. The imaging intervals should reflect multidisciplinary standards of practice, e.g. follow-up scans every three months during the first 24 months after the intervention. Without tumor recurrence, these intervals can be extended to six months, if applicable.

Tumor interventions

In general, local tumor ablation is becoming an alternative therapy for patients with small volume disease who are not surgical candidates. The aim of all local ablative techniques is to induce cell death in a defined area of tissue.

According to the tumor location, the tumor type and the individual preference, different cross-sectional imaging modalities will be used to guide and monitor the intervention as well as for control and follow-up of the patient (ultrasound, MRI, CT). Usually, these procedures will be done under conscious sedation or general anesthesia (according to logistical considerations and the individual preference). Different thermal ablation methods can be applied (radiofrequency ablation [RFA], cryotherapy, laser-induced thermotherapy, microwave ablation, high intensity focused ultrasound, as well as injection of ablative chemicals such as alcohol or acetic acid).

Radiofrequency Ablation

Using RFA, a focal coagulation necrosis is induced using high-frequency alternating current (375 – 480 kHz). The latter is delivered through an electrode placed into the tumor: Frictional heating results by local ionic agitation within the tissue adjacent to the tip of the electrode(s). As these ions try to follow the alternating current, a rise in temperature results. If this rise exceeds 60°C, protein denaturation starts. Higher local tissue temperatures lead to dehydration and, ultimately, to cell death. As a result of thrombosis, the microvasculature of the tumor is destroyed as well. If the temperature increases to more than 100 – 110°C, tissue vaporization and carbonization lead to an reduced effectiveness of the RF energy applied (due to increasing resistance). The protein denaturation, therefore, has to be achieved slowly (within the range of 60 – 100°C), so that no tumor cells within the lesion will stay vital.

All RFA systems work in combination with an external power generator. The power output (in watts) is manually adjusted. The effective time needed for the intervention is directly influenced by the power output, the amount of electrode array deployment from the trocar, and local factors (volume of ablation, safety margin, tumor surrounding). The end point is a rapid increase of tissue impedance (i.e., electric resistance, measured in ohms) above the relatively constant baseline value observed during energy deposition while the electrode(s) is / are active. Theoretically, the radius of surrounding tissue that is destroyed is dependant on the impedance of the tissue and is inversely proportional the square of the distance from the electrode. Local factors will also influence the necrosis areal: Proximity to large blood vessels plays a significant role in heat transmission. Blood flow protects the vessel wall from damage, but also acts as a heat sink and cools tissue nearby, limiting coagulative potential. On the other hand, e.g. surrounding air has an insulating effect for the heat disposal in lung RFA.

There are a number of commercially available systems with various electrode designs. Monopolar devices consist of stainless-steel extendible flexible tines that deploy from a trocar tip in an umbrella or Christmas tree configuration. The advantage of these systems is e.g. that multi-tined electrodes permit a wider radius with a single access. In this set-up, the patient becomes part of the radiofrequency circuit. Therefore, large surface, low-ohmic neutral electrode(s) contacting the patient's skin are needed.

Also, bi- and multipolar devices are commercially available: The ratio is to apply RF energy exclusively within the target tissue: The electric circuit is closed between the electrodes inside the tumor. Therefore, no neutral electrode(s) will be needed. The electrodes can be located on the same applicator shaft (or on different applicator shafts), in multipolar RFA the electric field is switched between the various electrodes. Especially this assembly will enable larger ablation volumes, at the expense of several needle placements.

Several suppliers work with an internal cooling with saline or water adjacent to the tips of the RF electrode. This will prevent vaporization and carbonization of the tissue in the immediate surrounding of the tines, and allows for higher generator output – and shorter procedure times.

Complications resulting from RFA are related to imaging-guided electrode placement (bleeding, infection, tumor seeding, pneumothorax) and related to thermal therapy (general: thermal damage to adjacent organs; monopolar RFA specific: ground pad burns on the patient's thigh).

RFA has received increasing attention and has proven to be technically effective for liver lesions (predominantly colo-rectal and breast cancer metastases), for primary hepatocellular carcinoma (also in combination with transarterial chemoembolization), for primary renal cell cancer as well as for lung metastases and primary non-small cell lung cancer (NSCLC), respectively.

Prospective studies are warranted to finally define the clinical role of percutaneous tumor treatment in an individualized multidisciplinary treatment concept.

SUGGESTED READING

1. *Fahy BN, Jarnagin WR*
   Evolving techniques in the treatment of liver colorectal metastases: Role of laparoscopy, radiofrequency ablation, microwave coagulation, hepatic artery chemotherapy, indications and contraindications for resection, role of transplantation, and timing of chemotherapy
   Surg Clin N Am 2006; 86: 1005 – 1022

2. *Garrean S, Hering J, Saied A, Helton WS, Espat NJ.*
   Radiofrequency ablation of primary and metastatic liver tumors: A critical review of the literature
   Am J Surg 2008; 195: 508 – 520

3. *Gervais DA, Arellano RS, McGovern FJ, McDougal WS, Mueller PR*
   Radiofrequency ablation of renal cell carcinoma: part 2, Lessons learned with ablation of 100 tumors
   Am J Roentgenol 2005; 185: 72 – 80

4. *Gervais DA, Goldberg SN, Brown DB, Soulen MC, Millward SF, Rajan DK;* Interventional Oncology Task Force and Standards Division, Society of Interventional Radiology
   Society of Interventional Radiology position statement on percutaneous radiofrequency ablation for the treatment of liver tumors
   J Vasc Interv Radiol 2009; 20: 3 – 8

5. *Gervais DA, McGovern FJ, Arellano RS, McDougal WS, Mueller PR*
   Radiofrequency ablation of renal cell carcinoma: part 1, Indications, results, and role in patient management over a 6-year period and ablation of 100 tumors
   Am J Roentgenol 2005; 185: 64 – 71

6. *Gillams AR*
   Image guided tumor ablation
   Cancer Imaging 2005; 5: 103 – 109

7. *Gillams AR*
Complications of percutaneous therapy
Cancer Imaging 2005; 5: 110 – 113

8. *Higgins H, Berger DL*
RFA for liver tumors: Does it really work?
Oncologist 2006; 11: 801 – 808

9. *Leen E, Horgan PG*
Radiofrequency ablation of colorectal liver metastases
Surg Oncol 2007; 16: 47 – 51

10. *Lencioni R, Crocetti L, Cioni R, Suh R, Glenn D, Regge D, Helmberger T, Gillams AR, Frilling A, Ambrogi M, Bartolozzi C, Mussi A*
Response to radiofrequency ablation of pulmonary tumors: a prospective, intention-to-treat, multicenter clinical trial (the RAPTURE study)
Lancet Oncol 2008; 9: 621 – 628

11. *McGrane S, McSweeney SE, Maher MM*
Which patients will benefit from percutaneous radiofrequency ablation of colorectal liver metastases? Critically appraised topic
Abdom Imag 2008; 33: 48 – 53

12. *Zhu JC, Yan TD, Glenn D, Morris DL*
Radiofrequency ablation of lung tumors: Feasibility and safety
Ann Thorac Surg 2009; 87: 1023 – 1029

13. *Zhu JC, Yan TD, Morris DL*
A systematic review of radiofrequency ablation for lung tumors
Ann Surg Oncol 2008; 15: 1765 – 1774