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TUMOUR ABLATION

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Tumour ablation: technical aspects

Gerlig Widmann, Gerd Bodner and Reto Bale

Department for Microinvasive Therapy, Department of Radiology, Innsbruck Medical University, Innsbruck, Austria

Corresponding address: Reto Bale, SIP - Department for Microinvasive Therapy, Department of Radiology, Innsbruck Medical University, Anichstrasse 35, A-6020 Innsbruck, Austria.
Email: reto.bale@i-med.ac.at

Abstract

Image-guided percutaneous radiofrequency ablation (RFA) is a minimally invasive, relatively low-risk procedure for tumour treatment. Local recurrence and survival rates depend on the rate of complete ablation of the entire tumour including a sufficient margin of surrounding healthy tissue. Currently a variety of different RFA devices are available. The interventionalist must be able to predict the configuration and extent of the resulting ablation necrosis. Accurate planning and execution of RFA according to the size and geometry of the tumour is essential. In order to minimize complications, individualized treatment strategies may be necessary for tumours close to vital structures. This review examines the state-of-the art of different device technologies, approaches, and treatment strategies for percutaneous RFA of liver tumours.

Keywords: Radiofrequency ablation; planning; technique.

Introduction

Radiofrequency ablation (RFA) is a minimally invasive, relatively low-risk local ablative therapy achieved by converting electrical radiofrequency current (200–1200 kHz) into heat creating a zone of thermal necrosis[1,2]. A volume of tissue is devitalized without removing it from the body, resulting in a similar effect to surgery[3–5]. The success of RFA in terms of complete tumour ablation, local recurrence and survival rates are excellent for treatment of small tumours (<3 cm), but the results are less encouraging in larger tumours. Tumour size and insufficient safety margin were identified as the most important prognostic factors of recurrence and overall survival[6–9]. The goal of RFA treatment of large tumours is therefore to generate an overlapping ablation necrosis which covers the entire tumour and a sufficient margin of surrounding healthy tissue[9–11]. In order to generate a reliable and successful treatment plan and to minimize complications, the interventionalist must be able to predict the extent of the resulting necrosis by applying the different available techniques.

Principle of RFA

In RFA, the high-frequency alternating current from the electrode generates marked agitation of the ions in the tissue that surrounds the uninsulated tip of the probe. The frictional heat results in thermal coagulation necrosis of the surrounding tissue. Hence, the heat is generated in the tissue surrounding the RFA probe. Roughly the size of ablation correlates with the intensity and duration of energy deposition. The diameter of local coagulation necrosis is a function of the local mean temperature[12]. To achieve an effective heating throughout the tumour 60–100°C have to be achieved and maintained throughout the entire target volume for at least 4–6 min. Due to slow thermal conduction from the electrode surface through the tissue the duration of application may increase to 10–30 min[2]. Flow of current and heat absorption depend on tissue characteristics such as electrical and thermal conductivity and tissue perfusion[13,14].

Due to the 'oven effect', the size of ablation necrosis is larger in hepatocellular carcinomas (HCCs) than in the surrounding cirrhotic liver tissue[15] because the

surrounding fibrous tissue acts as a shell insulating the heat and leading to a temperature increase inside the nodule. However, the 'oven effect' may limit heat diffusion from the tumour into satellite lesions of HCC[7]. Due to perfusion-mediated tissue cooling (vascular flow) the threshold for coagulation necrosis is 8.5°C higher in living tissue than *ex vivo*. In addition, the size and shape of coagulation necrosis are smaller and less uniform *in vivo* compared with *ex vivo*. This phenomenon is called the 'heat sink effect'[13].

Thus, the coagulation size may be increased by reduction of the hepatic perfusion during RFA by temporary occlusion of the portal vein or the hepatic artery. Portal inflow occlusion (Pringle maneuver) during open or laparoscopic RFA leads to a 10°C increase of temperature around the probe and results in larger diameters of coagulation necrosis[13]. However, it is associated with an increased risk of portal vein thrombosis[13,16]. For percutaneous RFA the celiac or hepatic artery may be occluded with a balloon catheter, or the feeding arteries may be embolized with gelatine sponge particles[17–19].

Electrode design

Plain electrodes

Plain electrodes are needles with an insulated shaft and an active tip[9]. Due to charring around the active probe tip, plain electrodes may only be used for the treatment of tiny lesions <5 mm (e.g. nidus of osteoidosteomas).

Expandable electrodes

Expandable electrodes contain curved needles or umbrella-shaped retractable electrodes (prongs) which can be extended from the central cannula to a diameter of up to 7 cm[5,20–22]. Depending on the size of the electrode surface, the expandable electrodes create rather large, spherical or conical shaped lesions[3,10,23]. *In vivo* coagulation volumes of multitine electrodes were less reproducible than those induced with plain cluster electrodes[24]. There is the potential danger of damage to adjacent vessels, bile ducts, liver capsule, surgical staples, pleura, etc., during expansion of the electrodes[3,25,26].

Cooled electrodes

Cooled probes contain an internal chamber that is perfused with cold saline solution (0–8°C) to permit greater energy deposition into the tissue, resulting in a greater coagulation diameter compared with plain electrodes. With a single probe, a lesion diameter of 2.4 cm can be achieved within 12 min[12]. Using three cooled-tip RFA probes with an interprobe distance of up to 3 cm simultaneously, a uniform RF necrosis with a diameter of 4.8 ± 0.8 cm can be achieved[27].

Wet electrodes

Injection of saline solution into the tumour increases electrical conductivity leading to a larger thermal necrosis[1,7,20,28]. Wet electrodes have openings at the tip or along the electrode for perfusion of 0.9–36% saline solution at a rate of 0.5–2 ml/min. With various electrode designs, wet RFA provided significant larger mean ablation volumes compared with dry ablation or a single pretreatment saline injection[21,29,30]. A drawback of the saline perfusion technique is the concern for an irregular shape of coagulation necrosis due to uneven distribution of injected saline[31]. In addition, diffusion of hot saline along vessels, the needle track and the liver capsule is associated with an increased risk of portal vein thrombosis or thermal injury to adjacent organs[32].

Monopolar versus multipolar

Monopolar RFA

Single electrode

In monopolar systems the radiofrequency current flows from the generator through the non-insulated tip of the probe into the tissue and follows the natural paths in the soft tissue towards a large dispersive electrode (grounding pad) to form a closed-loop electric circuit[30,32–34]. To disperse equal amounts of energy and heat and to prevent skin burns at the grounding pad sites, multiple large dispersive electrodes are applied. During the ablation cycle, the generator's impedance feedback system senses maximum energy deposition into the lesion and uses pulsing to keep the energy output at its optimal level. Single cooled monopolar electrodes produced maximal coagulation diameters of 2.9 cm in *ex vivo* and 1.8 cm in *in vivo* liver[35].

Cluster electrodes

Simultaneous RF application to clusters of three electrodes spaced 0.5 cm apart produced RFA necrosis of 4.7 ± 0.1 cm in *ex vivo* liver and 3.1 ± 0.2 cm in *in vivo* liver[35].

Rapid-switching multiple-electrode RF system

Multiple electrode ablation based on 3 cooled monopolar electrodes and a rapid-switching multi-electrode control allows physicians to simultaneously treat multiple tumours[35,36]. *In vivo*, 3 cooled monopolar electrodes at 2 cm interprobe distance produced areas of well-defined coagulation with a volume and short-axis coagulation diameter of $35.5 \pm 5.7(3)$ cm and 4.6 ± 0.5 cm, respectively. The circularity (isometric ratio) decreases with increasing interprobe diameter, an interprobe distance of larger than 3 cm cannot create confluent coagulation necrosis[27].

Bipolar RFA

In bipolar RFA the radiofrequency current flows exclusively between the two poles of the electrode, not necessitating a grounding pad[31,37–39]. In a multipolar setting, up to six probes may be used simultaneously, the current flowing between the corresponding probes. *Ex vivo* bipolar mode showed a more rapid increase and higher temperature between two electrodes compared with monopolar modes[32,40,41]. *In vivo* multiple-electrode multipolar RFA provided similar results when compared with monopolar rapid-switching multi-electrode mode. To avoid bizarrely shaped necroses, bipolar electrodes have to be placed parallel and equidistant. This may be difficult due to critical anatomical structures or obstacles on the entrance path.

Patient selection and preparation

The decision of RFA treatment should be discussed by an interdisciplinary tumour board. Conventional liver biochemical tests, prothrombin time, and complete blood cell counts are measured before treatment. Liver cirrhosis classified lower than Child–Pugh class A/B, prothrombin time <23 s, prothrombin activity >40% and platelet count >40,000/ml are required for RFA therapy[7,42]. If large liver tumours are treated in patients with advanced liver disease there is an increased risk of liver failure. Ascites and pneumobilia increase the risk of infection. The presence of a bilioenteric anastomosis is generally seen as a contraindication for RFA[43]. Percutaneous image-guided RFA can be performed repeatedly under conscious sedation or general anesthesia. Perioperative intravenous broadband antibiotics may be administered.

Approach

The selection of safe trajectories is essential as many different obstacles including the ribs, pleura, lung, stomach, intestine and large vessels have to be passed. Movement of the target and the obstacles due to respiration have to be taken into concern. Every probe repositioning and the final removal of the probe after RFA must be performed with 'hot withdrawal' (70–90°C), in order to prevent local haemorrhage and neoplastic seeding[43].

Tumour location

Central tumours

Tumours adjacent to or within 1 cm of the central structures of the liver include the risk of thermal damage to the bile duct with bile duct stenosis or formation of bilioma[43,44]. For prevention, intraductal cooling by cold perfusion via a choledochal incision has been reported to allow ablation without bile duct damage[45]. However, the procedure still carries the risk of biliary infection by ascending gastrointestinal bacteria.

Tumours close to adjacent organs

RFA of lesions adjacent to organs carries the risk of thermal damage and perforation. Tumours abutting the diaphragm may increase the risk of pneumothorax, pleural effusion, pleuritis, perforation of the diaphragm, bilio-pleural fistulas or abscess formation. RFA of tumours adjacent to the gallbladder has proved to be safe and feasible, taking into account self limited mild iatrogenic cholecystitis[46]. The colon is at greater risk than the stomach or small bowel for thermally mediated perforation[44]. In order to prevent thermal injury, adjacent organs can be separated from the liver by injection of various amounts (150–1000 ml) of 5% dextrose solution into the peritoneum[47], percutaneous interposition of a balloon[48] or 'laparoscopic liver packing' in which prior to RFA, swabs soaked with 5% dextrose are placed between the liver and adjacent organs under laparoscopy and removed afterwards in the same session[25,49]. The key area may be treated by multiple small ablations, percutaneous ethanol injection (PEI) or transcatheter arterial chemoembolization (TACE). However, hypovascular metastases do not respond to these therapies[25].

Tumours close to vessels

In the vicinity of large vessels, cooling effects have to be considered[3]. The electrodes should be placed as close as achievable to the vessel without damaging it[50]. To reduce tissue cooling, the area of the tumour, where the feeding vessel is entering, should be ablated first[25].

Subcapsular tumours

In order to avoid bleeding and seeding through the perforated capsula, subcapsular lesions should be targeted through non-tumourous tissue.

Tumour size and shape

The size of the ablation necrosis should cover the entire tumour including a safety margin of surrounding tissue. Ablation margins of 0.5 cm are recommended for well-circumscribed HCCs and 1 cm margins for tumours with ill-defined borders[25]. Large lesions require more than one probe or several probe positions in order to treat the tumour with overlapping ablation zones[3]. Chen et al.[25,51] proposed a mathematical protocol for RFA of spherical tumours with a 5.0 cm ablation device. Using this mathematical model in a total of 332 patients with 503 liver lesions, the early necrosis rate of tumours larger than 3.5 cm was 91.3%[25]. The implementation of stereotaxy will supposedly improve the 3D planning and

execution of multiple overlapping ablation spheres and further decrease the local recurrence rate after RFA[52].

Conclusion

In addition to proper patient selection, knowledge about the principles of RFA and strategies to prevent complications are essential for a successful outcome. To achieve R0 ablation (in analogy to surgery) large tumours require several overlapping ablation zones that are optimally distributed in and around the tumour.

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