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Review

Imaging appearances at follow-up after image-guided solid-organ abdominal tumour ablation

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The role of minimally invasive, locoregional therapies in cancer is increasingly driven by the detection of small asymptomatic disease either incidentally or under surveillance for a known primary malignancy. Percutaneous image-guided ablation has become established as a parenchyma-sparing tool in the management of small volume primary and metastatic disease in the liver as well as solitary renal masses. As ablation is non-extirpative, post-ablation imaging is critical for the assessment of treatment completion, recurrence, and complications. Within established regional cancer networks, understanding of normal post-ablation imaging appearances is essential for the early identification of primary treatment failure or local recurrence, which may be amenable to repeat treatment. We provide an imaging primer of two common ablation sites — kidney and liver — focusing on normal appearances and appreciation of local disease progression.

Introduction

Image-guided ablation (IGA) in the solid (abdominal) organs is seeking to obtain the same oncological outcomes as traditional surgical resection; fundamentally, however, it is an *in situ* treatment. Surgical cancer resection seeks to obtain negative histological margins as proof of oncological treatment efficacy. In the case of IGA, the ablation zone (AZ) must equally obtain oncologically adequate treatment margins effectively negating the risk of local tumour recurrence. Thermal ablation techniques, however, engender their own characteristic tissue changes and marginal or penumbral features. This article seeks to illustrate the typical post-treatment changes and marginal features following treatment so that oncological treatment efficacy can be confirmed.

Ablation modalities

The ablation modalities are predominantly thermal energy-based techniques, which include radiofrequency ablation (RFA), microwave ablation (MWA), and cryoablation (CRA). RFA works based on generating high-frequency alternating current within the tumour immediately adjacent to the RFA electrode. The soft tissue is resistive to the electrical current causing ionic agitation and frictional heating, which radiates outwards through conduction to cause coagulative necrosis.[1] This energy deposition must be carefully controlled as char tissue formation can occur with excessive heat, which increases impedance and can rate-limit the volume of effective ablation.

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MWA works by agitating polar water molecules in an oscillating electromagnetic field adjacent to the probe tip. Inefficiency in this process within the electromagnetic field leads to deposition of heat energy. Microwaves are not impeded by char tissue and are less reliant of conductive heating, so a more predictable and larger, active thermal AZ can usually be achieved.[2]

CRA is a cold-based thermal ablation technique that induces cell death through freeze and thaw cycles. Freezing leads to disruption of the cell membrane as well as a cell-lethal fluid shifts along with local microvascular injury.[3] CRA benefits significantly from peri-procedural visualisation of the "iceball", which directly correlates to a large degree with the tissue AZ. Newer-generation cryoprobes are thinner but this provides a limited cell-lethal zone so treatment of larger tumours requires planning and placement of several cryoprobes to form a larger compound and synergistic AZ.[4]

Thermal energy-based ablation modalities are susceptible to perfusion-mediated tissue cooling adjacent to flowing vessels (or heating in CRA), which is otherwise known as the "heat-sink" effect. Tumour ablation close to vessels is vulnerable to sublethal temperature zones and particular attention should be made on follow-up imaging for residual disease or recurrences adjacent to large vessels.[5]

Other ablation modalities include irreversible electroporation (IRE) and high-intensity focused ultrasound (HIFU). Clinical use of these modalities is not widespread and the role of these techniques will not be discussed further in this article.

Kidney

The progressive increase in use of cross-sectional imaging has led to the increased detection of incidental small renal masses (SRMs). This is reflected in the increase of incidental renal cell carcinoma (RCC) since 1975. Early detection has led to a stage migration with the increasing detection of stage 1 RCC and decrease in all other stages.[6–8] Age has been identified as an independent risk factor for development of RCC and plays a role in the decision to treat.[9] Older patients often bear co-morbidities and this increases surgical risk leaving active surveillance or IGA as treatment options for T1a (<4 cm) masses as reflected by the European Association of Urology guidance.[10] In practice, however, many patients enrolled into active surveillance default to delayed intervention with patient preference being the prevalent factor.[11] IGA of SRM demonstrates equivalent intermediate term and increasingly long-term oncological outcomes to partial nephrectomy with minimal patient morbidity.[12]

Renal IGA

The most widely used ablation modalities available for treatment of SRM are RFA and CRA. RFA has the largest and longest follow-up in published case series due to early uptake and is more suited towards smaller exophytic masses due to limitations of conduction-mediated RFA in the setting of more endophytic tumours. At the authors' institution, CRA is the preferred modality due to intra-procedural visualisation of the "iceball", which allows closer peri-procedural analysis of adequate ablation margins.[13] The placement of multiple probes increases procedural time but allows incorporation of large masses into a confluent and more predictable AZ. Additionally, due to its collagen-sparing effects, CRA is less injurious to the pelvicalyceal system compared to RFA as demonstrated in porcine models.[14]

Normal post-ablation appearances

Adherence to follow-up imaging is important to ensure treatment adequacy in this non-extirpative technique. The normal involution of a cryoablated lesion can be seen in Fig 1. In the authors' experience, follow-up is best performed using contrast-enhanced computed tomography (CT) or magnetic resonance imaging (MRI) with subtraction imaging of dynamic post-contrast sequences, the late arterial phase in particular. This allows direct comparison to the pre-ablation and peri-procedural studies, which are often performed under CT guidance. CT also allows concurrent assessment of possible nodal or metastatic disease and is more readily available.

The key marker of residual viable tumour is persistent tumour enhancement particularly in the late arterial phase.[15] Contrast-enhanced CT is performed with pre-contrast, late arterial, and portal venous phase assessment of the upper abdomen with arterial chest imaging ensuring complete assessment. Unenhanced imaging is necessary in the early post-treatment assessment as it helps identify areas of haemorrhage or degraded blood products within the AZ (Fig 1c–d) and helps distinguish this from residual tumour enhancement.[16] Associated perinephric or retroperitoneal haematoma may be seen due to probe placement.

A thin "penumbra" of apparent enhancement may be seen at the margin of the AZ, which represents retained iodinated contrast medium within injured and healing tissue at the interface between necrotic and viable tissue.[15] The AZ should extend beyond the margins of the index tumour and so will appear larger on the initial post-treatment CT. This will then involute over time with radial retraction towards the kidney leaving a better defined AZ and a remnant renal cortical defect. Occasionally, coarse calcification can develop within the AZ (Fig 1g–h) or the necrotic AZ can "auto-amputate" from the renal cortex.

A perilesional halo of thin curvilinear enhancement may be seen in the perinephric fat with RFA or occasionally CRA ablation of exophytic and occasionally central lesions. This often extends beyond and parallels the AZ margin with associated perinephric stranding. This enhancement represents a fibrotic scar at the margin of the thermal injury. It is important to note that this is a benign imaging finding and is sometimes referred to as the "renal halo" sign.[17] A similar appearance can be seen on MRI including patients treated with CRA (Fig 2b–d). The degree of AZ involution is slower with RFA due to the process of coagulative necrosis, compared to CRA, which incites disruptive cellular

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