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Clinical Experience with Cone Beam CT Navigation for Tumor Ablation

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Abstract

Purpose—To describe clinical use and potential benefits of Cone Beam Computed Tomography (CBCT) navigation to perform image guided percutaneous tumor ablations.

Materials and Methods—All ablations performed between February 2011 and February 2013 using CBCT navigation, were included. Sixteen patients underwent 20 ablations for 29 lesions. CBCT ablation planning capabilities include multimodality image fusion and tumor segmentation for visualization, depiction of the predicted ablation zones for intra-procedural planning and segmentation of the ablated area for immediate post-treatment verification. Number and purpose of CBCT were examined. The initial ablation plan defined as number of probes and duration of energy delivery was recorded for 20/29 lesions. Technical success and local recurrences were recorded. Primary and secondary effectiveness rates were calculated.

Results—Image fusion was utilized for 16 lesions and intra-procedural ultrasound for 4. Of the 20/29 lesions, where the ablation plans were recorded, there was no deviation from the plan in 14. In the remaining 6/20, iterative planning was needed for complete tumor coverage. An average of 8.7 ± 3.2 CBCT were performed per procedure, including 1.3 ± 0.5 for tumor segmentation and planning, 1.7 ± 0.7 for probe position confirmation, 3.9 ± 2 to ensure complete coverage. Mean follow-up was 18.6 ± 6.5 months.

28/29 ablations were technically successful (96.5%). Of ablations performed with curative intent, technical effectiveness at one-month was 25/26 (96.1%) and 22/26 (84.6%) at last follow-up. Local tumor progression was observed in 11.5% (3/26).

Conclusion—CBCT navigation may add information to assist and improve ablation guidance and monitoring.

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Keywords

Image guide ablations; Navigation; Cone Beam CT

Introduction

Optimal image guidance is critical to successful tumor ablation[1]. As described by Cho et al. improved tumor ablation outcomes rely upon 3 key factors: adequate visualization of the tumor for ablation planning, real-time localization of ablation probe in relation to tumor and real-time monitoring of the ablation zone[1]. Many tumors are not readily visible with ultrasound or become obscured during the ablation by the transient hyper-echogenic zone[2]. Computed tomography does not offer real-time guidance unless CT fluoroscopy is employed, resulting in increased radiation to the patient and operator. Many interventional radiology sections do not have access to a dedicated interventional CT. Cone-beam CT (CBCT), integrated in newer generation C-arms obviates this challenge[3]. Additional dedicated software enables CBCT navigation without additional hardware or disposables required for other tracking or image fusion technologies[4]. Our purpose was to evaluate the safety and technique effectiveness of CBCT guided ablations.

Methods and Materials

Institutional Board review approval was obtained for this retrospective study.

Patient characteristics and selection

Between February 2011 and February 2013 a total of sixteen patients (7 women-9 men, average age: 56.5 years) underwent 20 ablation procedures for 29 lesions. All percutaneous non-prostate ablations in our institution are performed under CT or CBCT guidance complemented by ultrasound, for sonographically visible lesions. Operator preference was the main factor in determining the selection of CT vs. CBCT navigation. All ablations were performed under general anesthesia. Radiofrequency ablation was used in 5 procedures for 6 lesions, cryoablation in 11 procedures for 15 lesions. Microwave ablation was employed in 4 procedures to treat 8 lesions. The average number of lesions per patients was 1.8 ± 1.3 and the average number of lesions treated per session was 1.4 ± 0.7. The primary malignancy was adrenocortical (ACC) carcinoma in 6 patients, renal cell carcinoma in 7, and one patient each with hepatocellular carcinoma, mesothelioma and medullary thyroid carcinoma. The lesions were located in the liver (n=6), in the kidney (n=9), in the lung (n=6) and in the psoas and/or intercostal muscles (n=8). Tumor size ranged from 0.5-4.8cm with an average 2.1cm ± 1.2cm. The average depth of the tumor from skin was 5.8cm ±1.9cm (range: 3.1-10cm).

CBCT Workflow

Patients were positioned to ensure that tumor and skin were included in the CBCT images and to enable optimal probe placement. The patients' arms were positioned out of the field of view. EKG leads, wires and radio-opaque objects were kept out of the field of view to minimize streak artifact.

Two CBCT acquisition protocols were used with the C-arm in propeller/head position. The first, low-dose protocol involved the acquisition of 242 projections (120 kV, 4*4 binning) during a 240° rotation for a total scan time of 4 seconds. This protocol was used for thoracic imaging and probe position monitoring. The second protocol was used for abdominal imaging and utilized the same rotational trajectory but involved the acquisition of 312 projections (120 kV, 4*4 binning) and a total scan time of 5.2 seconds. The number of projections determined the level of image quality and radiation exposure (1-3mSv). Vertical collimation was used to minimize radiation exposure whenever possible. The reconstructed 3D field of view was 25×25×19 cm with an isotropic resolution of 0.6 mm.

Contrast-enhanced CBCT was obtained in 13 of 20 ablation procedures through a peripheral IV at a rate of 1.5 to 2.5mL/sec for a total of 1-2mL/kg. In 7 cases, a single phase CBCT as described above was performed. In the remaining 6 cases, a dual-phase CBCT protocol consisting of two consecutive scans was obtained with the first and second rotations acquired with a 25 and 50 seconds delays respectively post contrast injection.

Image fusion was used in 4 patients with 11 lesions for whom contrast was contra-indicated, in 3 patients with 3 lesions because the tumors were only visible on contrast enhanced CT, MRI or ^{18F}FDG PET and in 2 patients with 2 lesions to improve lesion conspicuity. CBCT was fused to MRI, ^{18}F-FDG PET-CT and contrast-enhanced CT to treat 7 lesions, 3 lesions and 6 lesions respectively.

Image fusion was performed on a dedicated workstation (Xtravision workstation, Philips Healthcare, Best NL) with manual rigid registration. For maximal accuracy, emphasis was placed on registering the organ in question rather than more distant anatomy and/or bony structures.

Dedicated software (XperGuide Ablation, Philips Healthcare, Best NL) was used to plan the ablation procedure. The tumor was first segmented using an interactive 3D segmentation tool on the appropriate imaging. A safety margin around the tumor was automatically generated (normally 5-10 mm). The ablation planner also displayed the ablation profiles of various probes according to manufacturer's specifications, enabling the operator to select the number of probes and their position to achieve complete tumor and safety margin coverage. The ablation plan was defined as number and trajectory of the probes as well as duration of energy delivery. Once established, the planned path of each probe was verified in axial, sagittal and coronal views. Each planned path was selected sequentially and projected on the fluoroscopic image. This enabled the probe to be aligned and advanced along the pre-determined trajectory with both a bull eye view and an orthogonal progress view available for probe guidance during insertion. If a probe deviated significantly from the planned path during insertion, the probe and ablation zone were adjusted and the virtual position of subsequent probes was adjusted using the software, and if needed, additional probes were inserted, enabling iterative planning. Once the ablation was completed, the planning CBCT was fused to the monitoring CBCT enabling comparison of the segmented lesion and ablation zone to ensure coverage of the tumor and a prescribed safety margin.

All lung tumor ablation zones were visible and could be segmented on CBCT. Similarly, the iceball of soft tumors treated with cryoablation were visible on CBCT. However contrast enhanced CBCT was needed to depict and segment the ablation zone of soft tissue tumors treated with microwave or radiofrequency ablation.

Technical success was defined as completion of the procedure with complete tumor coverage. A deviation from the ablation plan was defined as placement of additional ablation probes or delivery of additional thermoablative energy. Local tumor progression, metastasis and complications as well as primary and secondary effectiveness were reported according to Standardization of Terminology and Reporting Criteria[5].

Patients were seen in clinic with laboratory exams and imaging at following time frames between 1-3 months, 6-9 months and 12-13 months post procedure.

Results

All procedures except one were technically successful. The average number of scans per ablation session was 8.7 ± 3.2 (range 3-14). An average of 1.3 ± 0.5 (range 1-2) scans were obtained for ablation planning, including lesion segmentation and determination of probe number. An average of 1.7 ± 0.7 (range 0-3) were obtained for probe position confirmation. The majority of the scans, on average 3.9 ± 2 (range 1-9) were performed to monitor ablation ensuring complete tumor coverage including 13 contrast-enhanced CBCTs. Reasons for contrast-enhanced CBCT included tumor visualization in 4 ablation sessions, verifying complete tumor coverage in 5 sessions and both in 4 sessions.

In 9 ablation sessions, an average of 2.2 ± 0.9 (range 1-4) scans were performed to ensure that the tumor was included in the CBCT field of view. If the area of interest was located peripherally on the localizing fluoroscopy image, it did not appear on the reconstructed CBCT images. Thus, during 9 ablation sessions, repositioning the patient or re-centering the C-arm was necessary to ensure inclusion of the tumor in the field of view.

In 6 procedures, an average of 2.6 ± 1.3 (range 1-5) scans were obtained for additional interventions such as hydrodissection (n=4 cases) or pre-ablation biopsy (n=2 cases).

Among the 20 procedures performed, fluoroscopy time was not recorded in 2. In the remaining sessions, an average of 13.9± 4.2 minutes of fluoroscopy was used per patient. The initial ablation plan i.e. number of ablation probes, energy and time needed was noted in 20/29 lesions. In 14/20 lesions, there was no deviation from that ablation plan i.e. no change in number of probes or energy/time delivered. Iterative planning with additional probe insertions or added ablation time was deemed necessary by the operator to achieve complete tumor coverage in 6/20 lesions.

The average clinical and imaging follow-up was 18.3 ± 6.5 months (range 9-29 months). Ablation was performed with palliative intent in two patients who presented with large and/or multifocal disease. The remaining eighteen procedures in 14 patients with 26 lesions were performed with curative intent.

Overall technique effectiveness at one-month follow-up for procedures with curative intent was 25/26 (96.1%). Secondary technique effectiveness at last follow-up (median of 19.8 months) was 22/26 (84.6%). Local tumor progression rate was 11.5% (3/26). There was one major complication in a patient with prior bilioenteric anastomosis who developed an abscess despite prophylactic antibiotics. The patient responded to 4 weeks of IV piperacillin and tazobactam (Pfizer Philadelphia, PA).

Discussion

Tumor recurrence defines failure of ablative therapies with curative intent[6]. Improving image guidance, including enhanced tumor visualization, localization of the ablation probes and ablation monitoring, may lead to more complete coverage of the tumor and margin[3]. Functional and advanced imaging modalities such ^{18}F-PET-CT and MRI provide superior tumor depiction compared to conventional intra-procedural imaging guidance modalities such as unenhanced CT and ultrasound[7,8]. In our study, image fusion was used for 16 lesions in 9 patients to improve tumor visualization. In fact, three lesions were only visible on PET or MRI. Without image fusion and navigation, the operator would have relied on anatomical landmarks if available and a large amount of educated estimations. In the remaining lesions, either contrast was contra-indicated or lesions were better seen on advanced imaging modalities. Similar results have been seen with other image fusion and navigation technologies. Song et al. published their experience with image fusion software integrated with ultrasound enabling them to ablate an additional 64 HCC in 57 patients that were initially not amenable to RFA with conventional ultrasound because the lesions were not visible[9]. Kruecker et al. also experienced similar findings using electromagnetic (EM) tracking navigation and image fusion. Among the 40 patients undergoing ablation or biopsy, the operators deemed the technology enabling in 19, meaning that the procedures would have high probability for technical failure or could not have been performed without it[10]. Not only do advanced imaging modalities improve tumor visualization, they can improve tumor coverage. Ryan et al. published their results using PET guidance with split FDG dose to ablate 29 lesions in 23 patients, with 1/3 of the FDG dose given for tumor localization and 2/3 for ablation monitoring[8]. At the second intra-procedural FDG dose, none of the tumors showed uptake except one. A biopsy of an FDG -avid area demonstrated residual tumor. The patient was treated immediately and did not show local tumor progression on follow-up. Despite the potential for improved outcome, cost and availability have restricted use of PET or MRI for real-time intra-procedural ablation, with most being performed using conventional ultrasound or CT[9,11]. Image fusion and navigation technologies attempt to bridge the gap[12].

In our study, CBCT navigation also enabled iterative ablation planning. Unfortunately due to the retrospective nature of this study, the initial ablation plan was not noted for 9 of the treated lesions. However of the remaining 20 lesions, CBCT navigation and ablation planning resulted in a modification of the pre-determined ablation plan in 1/3 of the cases to achieve complete coverage either because the final probe position deviated from the plan or intra-procedural CBCT demonstrated incomplete tumor coverage. Similarly, Iwazawa's[13,14] illustrated the feasibility and value of CBCT for ablation monitoring in two case series. In one study, 5 patients underwent contrast-enhanced (CE) CBCT immediately post RFA and

CE-CT 7 days post ablation. Each exam was fused to a pre-ablation CE-MRI or CT to assess the ablation margins[13]. In the second study, 12 patients were subjected to CE-CBCT and CE-CT immediately and 7 days post ablation[14]. In both studies CBCT was nearly equivalent to CT in determining ablation margins. Other navigation technologies such as optical and robotic systems have also been used for ablation guidance. Widmann et al. had a one-month technique effectiveness rate of 92.2% per patient and 95.5% per lesion using a stereotactic optical navigation system to ablate 177 lesions in 90 patients[15]. Our results were comparable with a one-month technique effectiveness of 96.1% and secondary technique effectiveness (median of 19.8 months) of 84.6%. CBCT navigation for biopsies has been established as safe and feasible with several large case series[16,17]. However few publications detailing feasibility and effectiveness of CBCT guided ablations are available and most consist of cases within review papers[4,7] . Morimoto discussed CBCT navigation to ablate 5 tumors in 5 patients. Patients underwent hepatic artery catheterization for contrast enhanced CBCT to visualize tumor and verify ablation completeness[18]. Technique effectiveness rate was 100% at one-month follow-up[18]. This study employed IV contrast and no arterial injections. Although the average contrast dose was not provided in Morimoto's paper, 5-10mL was administered per injection and the total dose was likely lower than in our study (129mL ± 50mL). However catheterization of the hepatic artery is not without risk or cost.

CBCT navigation delivers radiation to the patient and the operator during fluoroscopic needle placement. However, CT fluoroscopy results in operator radiation as well. In addition, CBCT radiation dose to the patient is lower than conventional CT[19,20]. The radiation dose to the patient can also be reduced once operators become more familiar with the technology. Indeed in our study, an additional 2.2 ± 0.9 scans were obtained in 9 ablation sessions just to include the tumor in the CBCT image. The tumor might appear in the field of view on X-rays however the marginal portion of the fluoroscopic image is not included in the CBCT reconstruction. Strategies of patient positioning and centering were acquired over time, likely reducing unnecessary rotational acquisitions.

Limitations of this study include its small number of patients and retrospective nature. Some data was not available i.e. initial ablation plan; however we did have the information for a majority of our cases. The population was complex and heterogeneous including some patients affected by Von Hippel Lindau and Li-Fraumeni syndrome. These diseases are associated with multiple neoplasia and recurring lesions that might have affected local tumor progression and distant metastasis rates.

In conclusion, CBCT navigation was useful in ablation guidance and monitoring especially for cases where the lesion is inconspicuous or contrast contra-indicated. CBCT navigation enabled iterative planning altering the ablation plan in one third of the cases. Our one-month technique effectiveness of 96.1% was comparable to the literature. Larger prospective randomized studies are needed to evaluate whether the added benefits of CBCT navigation such as iterative planning and improved tumor visualization result in improved efficacy and outcome.

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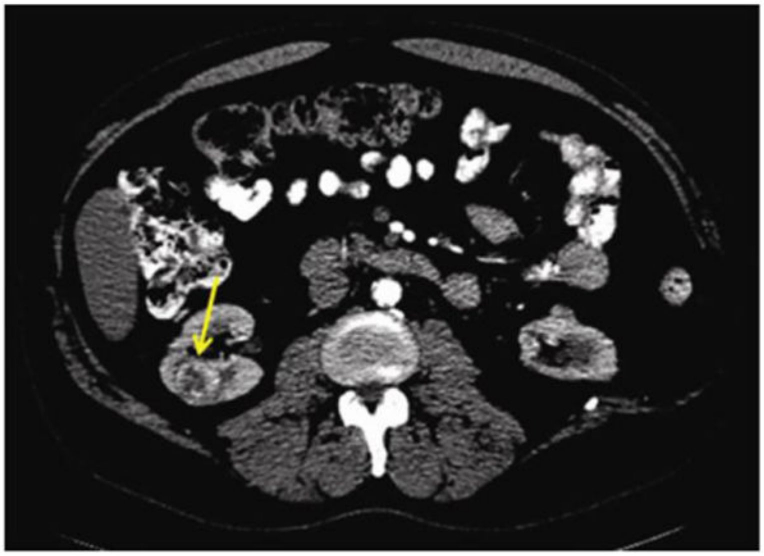

Figure 1.

Pre-procedural axial contrast-enhanced CT showing an enhancing lesion in the posterior aspect of mid right kidney (yellow arrow).

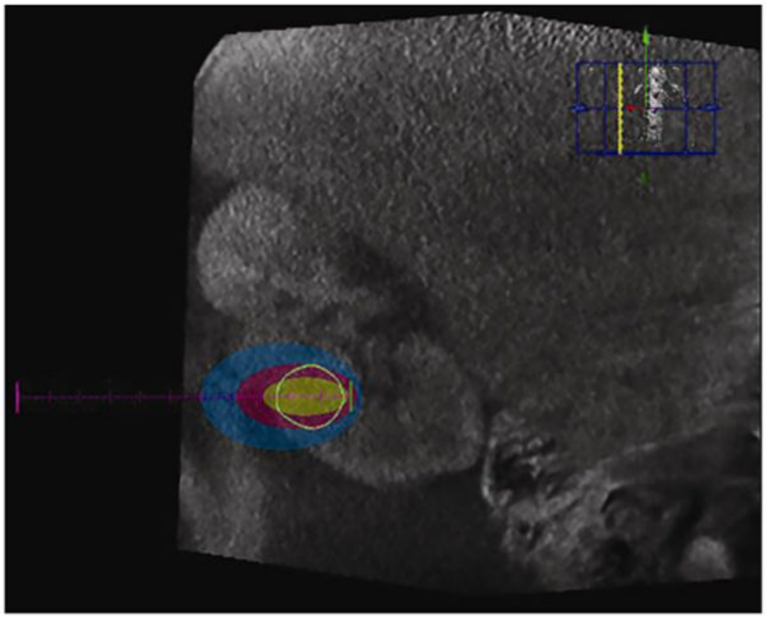

Figure 2.

Contrast-enhanced CBCT image showing the segmented tumor (green circle). The cryoablation isotherm according to the manufacturer's specifications is also displayed. The planned needle path is displayed

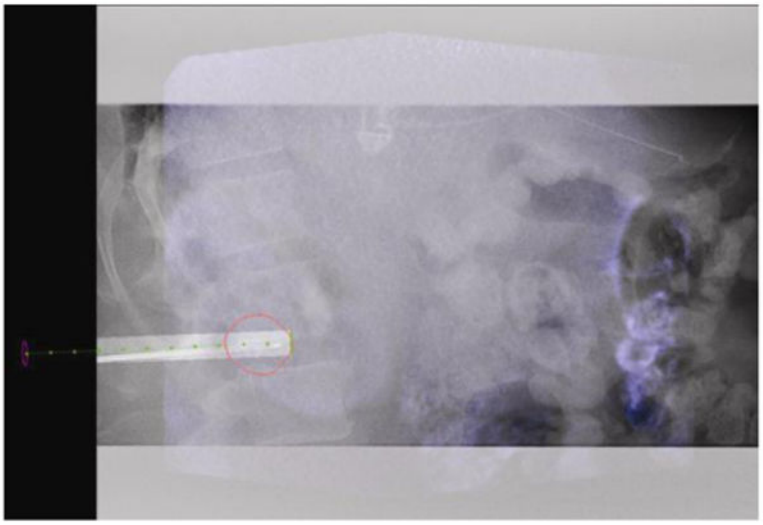

Figure 3.

Fluoroscopy image in progress view or along the planned probe path (green line with dots). The segmented tumor is also overlaid on the fluoroscopic image (pink circle). The needle is advanced along the planned needle path under fluoroscopic guidance.

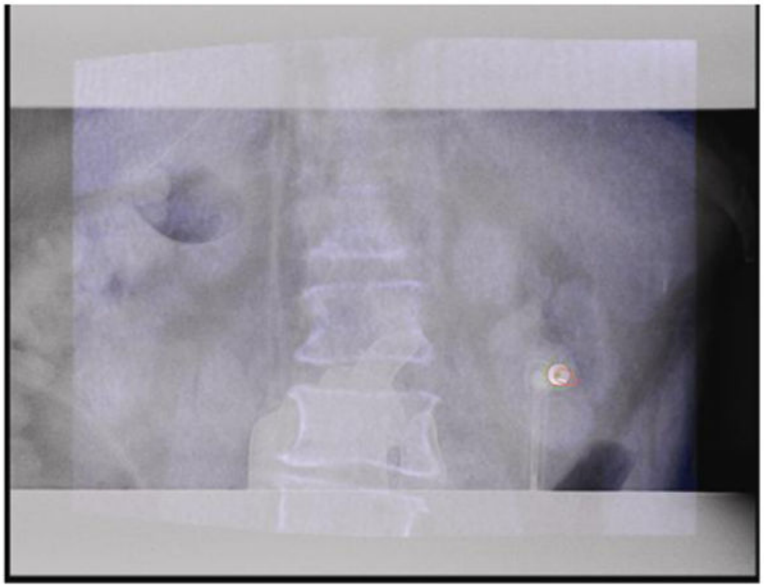

Figure 4.

Fluoroscopy image in bull eye's view, the planned needle path is seen as a small green dot within a green circle.

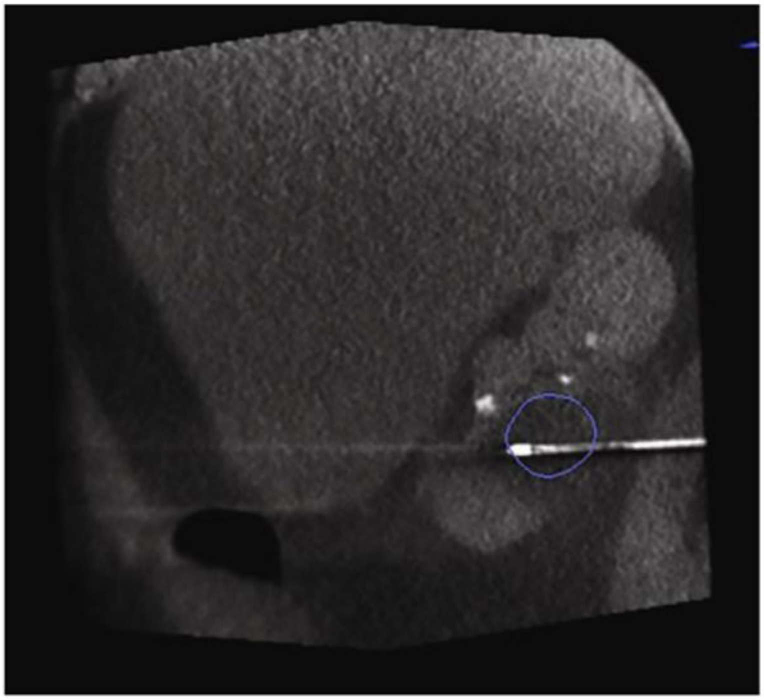

Figure 5.

CBCT during ablation showing the iceball is visible around the probe.

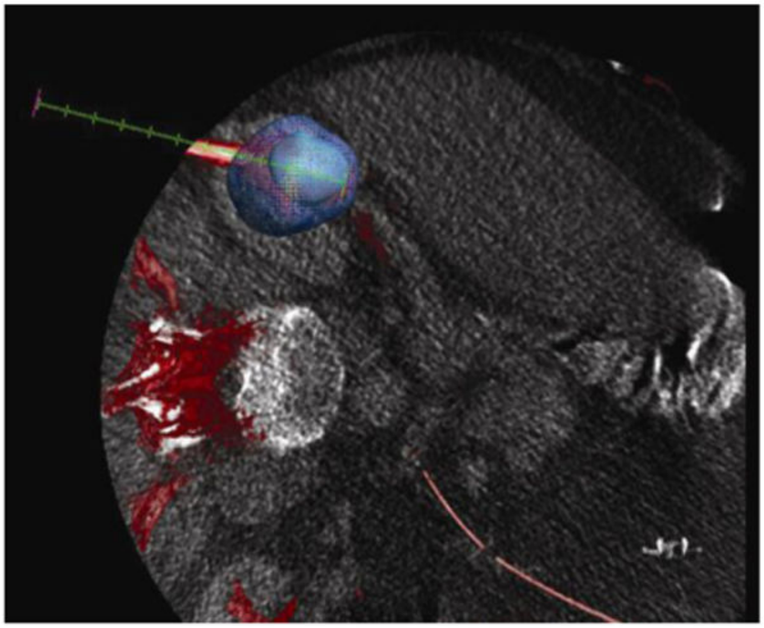

Figure 6.

The iceball is segmented (outer mesh blue circle) and the tumor is also segmented (inner mesh teal circle). The post ablation CBCT is registered to pre-procedure CBCT and both images are fused. A CBCT histogram is displayed showing the ablation zone encompasses the tumor and an adequate safety margin. The probe and virtual needle path (green line) are also displayed.

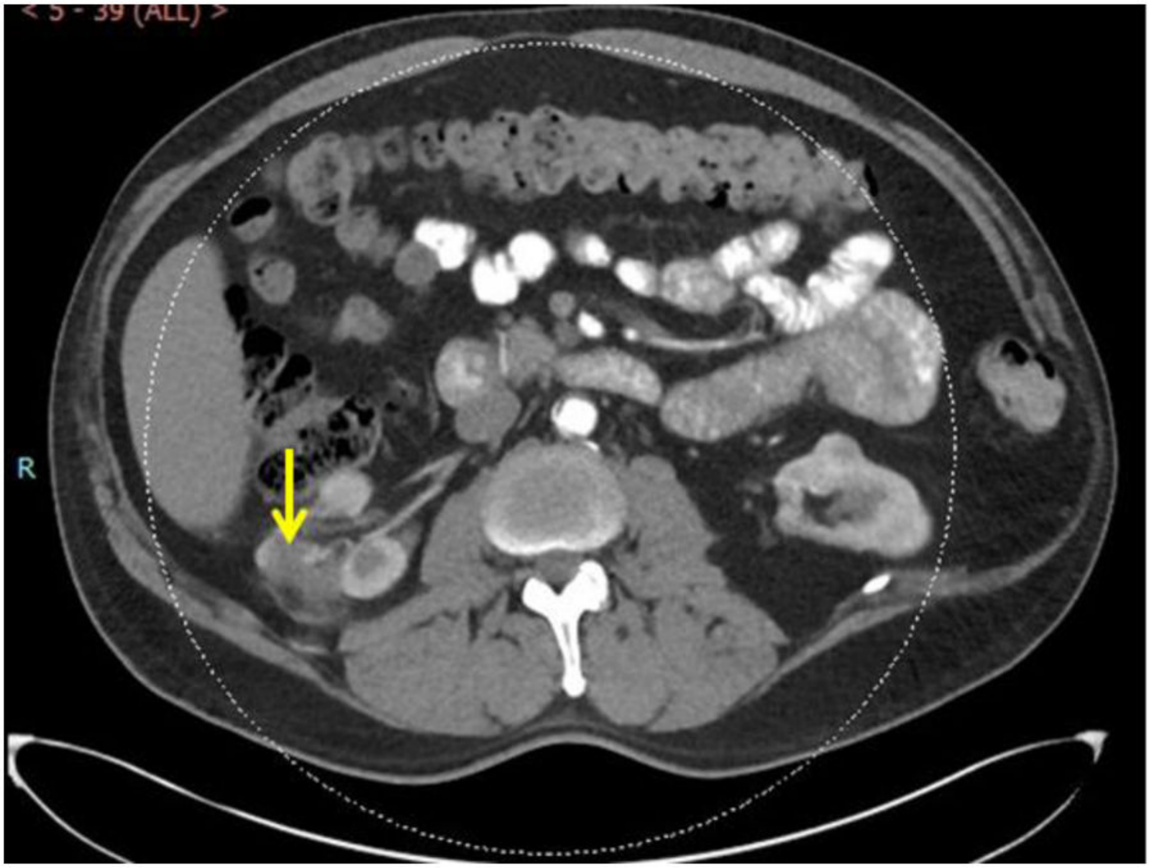

Figure 7.

There is no sign of viable tumor on contrast enhanced CT 12 months post procedure (yellow thick arrow).