Technology in Cancer Research & Treatment
Volume 22: 1-8

DOI: 10.1177/15330338231154994
journals.sagepub.com/home/tct
SAGE

Cone Beam Computed Tomography Image Fusion with Cross Sectional Images for Percutaneous Renal Tumor Ablation: Preliminary Data

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Abstract

Purpose: Percutaneous ablative treatments in the kidney are now standard options for local cancer therapy. Multimodality image guidance, combining two 3D image sets, may improve procedural images and interventional strategies. We aimed to assess the value of intra-procedural cone beam computed tomography (CBCT) with magnetic resonance (MR) or CT imaging fusion technique in the guidance of percutaneous microwave ablation (MWA) of renal neoplasms. **Materials and methods:** Fifteen patients (eight males, seven females, median age 65 years, median lesion size 20 mm) underwent percutaneous MWA for 15 renal tumors. All the procedures were performed in a dedicated angiography room setting; CBCT ablation planning capabilities included multimodality image fusion. Preoperative contrast-enhanced CT was available in 12 patients, whereas magnetic resonance imaging in the remaining. All patients were considered inoperable due to comorbidities, advanced age, and/or refusal to undergo surgery. Exclusion criteria were: tumors visible at unenhanced CBCT, metastatic disease, and uncorrected coagulopathy. Technical success and technical effectiveness were calculated. Procedural time, complications and recurrences were registered. **Results:** MWA under CBCT-guidance with fusion technique was technically successful in 14 out of 15 cases (93%). The median procedural time was 45 min. No procedure-related complications were reported. No enhancing tissue was visualized in the area of ablation at 1-month follow-up. All 15 cases were recurrence-free at last follow-up assessment (median follow-up of 12 months); no cancer-specific deaths were registered. **Conclusion:** CBCT-CT/MR image fusion is technically feasible and safe in achieving correct targeting and complete ablation of renal lesions. This approach bears the potential to overcome most of the limitations of unenhanced CBCT guidance alone; larger series are needed to validate this technique.

Keywords

renal tumor, ablation, microwave, fusion, cone beam, computed tomography, magnetic resonance imaging

Received: June 26, 2022; Revised: November 12, 2018; Accepted: January 18, 2023.

Introduction

Percutaneous ablative treatments, including radiofrequency ablation, microwave ablation (MWA), and cryoablation, are now performed as standard nephron-sparing options for local cancer therapy. Such procedures are currently considered viable alternatives in patients with small peripheral renal nodules (less than 3 cm in diameter), particularly for those patients who are not eligible for surgery due to multiple comorbidities, those with a solitary kidney, limited renal function, hereditary or multiple lesions.[1,2] In general, MWA offers some theoretical advantages over the other available

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technologies, which may result in a more reliable and predictable coagulative effect.[3] However, the choice among the different ablative approaches is often driven by the operator's preference and available technologies at each facility.

Image guidance is crucial to achieve a successful tumor ablation. Indeed, taking advantage of various imaging techniques in order to improve interventional procedures has become central to the work of the modern interventional radiologist.

Computed tomography (CT) guidance is regarded as optimal for renal ablation thanks to its ability to provide a detailed anatomy and precise depiction of the relationships between the target lesion and the surrounding structures, with the possibility to evaluate immediately the effectiveness of the treatment.[4] However, many interventional radiology units do not have access to a dedicated CT scanner. Cone-beam CT (CBCT), integrated with modern C-arms, may obviate this challenge.[5,6] This technology enables the acquisition of cross-sectional CT imaging with modern angiographic systems.[7]

Nowadays, thanks to the recent refinements of technology and constantly improving computing power, multimodality image guidance allows the combination of two 3D image sets to improve procedural images and interventional strategies.[8,9] Indeed, a technically challenging step of any ablative treatment is the precise localization of the tumor or the definition of the tumor margins, which may be better delineated on a modality or enhancement phase not immediately available during the procedure itself.

The aim of our study was to assess the value of intra-procedural fusion of CBCT with cross-sectional images (namely, CT or magnetic resonance imaging [MRI]) in the management of thermal ablation by MWs for renal cancer.

Materials and Methods

Study Design

This is a retrospective observational study. The study was conducted at Policlinico di Milano Fondazione IRCCS Ca' Grand (University Hospital of Milan affiliated with the University of Milan. The Institutional Review Board of the Policlinico di Milano approved the study (radint 11/2020; prot. 11/2020; approved on the 11th of July 2020), and written informed consent was obtained from the patients before the procedure.

Patients

From January 2019 to January 2020, 15 patients (eight males, seven females, median age 65 years, range 55-77 years) underwent 15 percutaneous MWA sessions for 15 renal tumors. The median size of the treated lesions was 20mm (range 13–35 mm). Patient and tumor characteristics are detailed in Table 1.

Patient history was analyzed, and images were completely reviewed by a multidisciplinary team, composed of a Urologist, Oncologist, and Interventional Radiologist.

Treatment options were discussed among the experts involved, and a consensus was achieved; the procedure was consequently proposed to the patient and indications, risks, and benefits of the treatment were discussed.

All selected patients had neoplastic disease that was judged to be inoperable on the basis of co-morbidities, advanced age, and/or refusal to undergo surgery. Tumors of the series presented were histologically ascertained, even if in some cases they were defined on the basis of increase in size or change in contrast-enhancement characteristics during follow up. Cystic lesions were characterized under the Bosniak v2019 classification system.[10] The lesions to be treated were assessed by the RENAL nephrometry[11] and ABLATE[12] scores aimed at predicting the risk of adverse events and relapses.

In the present series, only tumors which were not evident at unenhanced CBCT were included, therefore exophytic lesions or tumors with a definite cystic component or intra-lesional calcifications, identified by unenhanced CBCT, were excluded from the study.

Other exclusion criteria were: metastatic disease and uncorrected coagulopathy. Ongoing anticoagulant or antiplatelet therapies were discontinued at least 7 days before the ablation, and low molecular weight heparin was started when necessary.

All patients had preoperative CT or MR examination, carried out not more than 1 month previously.

Inclusion and exclusion criteria are summarized in Table 2.

Procedure

All the procedures were performed with the same angiographic unit (Allura Xper FD20, Philips Healthcare, Best, The Netherlands) equipped with C-arm CBCT (XperCT, Philips Healthcare).

This system allows CT contrast-enhanced scans (CECT) or previously performed MRI (Figure 1A-C) to be loaded and merged with a CBCT volume archived on a workstation as raw files. This process takes about 2–3 min with well-trained personnel.

Each patient was placed in the prone position and pre-procedural unenhanced CBCT was obtained with a 240 rotation of the C-arm in 5.2 s acquiring 312 projection images at 60 frames/s.[13] The projection images were automatically transferred via fiber optic connection to a dedicated 3D workstation where 3D volumetric reconstruction was performed and visualized within 15 s. The final CBCT volume presented with a field of view of $25 \times 25 \times 19$ cm^3 and an isotropic voxel size of 0.6 mm (matrix size $= 384 \times 384 \times 291$, 4×4 binning).

Whenever possible, patients were asked to hold their breath or breathe shallowly in order to avoid breathing artifacts during acquisition to simulate as much as possible CT/MRI acquisition.

In 12 cases, diagnostic CT was imported into the dedicated workstation and fusion imaging (FI) software was used to register the CT with unenhanced CBCT. In the remaining cases, the same procedure was carried out importing diagnostic MRI (the optimal sequences to identify the lesions to be treated were selected in each case, usually axial T2-weighted images, TSE/FSE sequences).

Target point and entry point were drawn using the antenna navigation software (XperGuide) considering the site of the tumor on CT or MRI (Figure 2A-C). The operator indicated the entry point and target point and the system automatically

Table 1. Patients' Characteristics and Procedural Data.

Pt	Age, sex	Side	Size (mm)	Histology	RENAL score	ABLATE score	Procedural time (min)	DAP TOT (Gy cm^2)	FU (months)	TS	TE	LTP	CSD	note
1	65,M	L	28	clear cell RCC	p6	5	60	64.15	6	yes	yes	no	no	
2	70,M	L	14	clear cell RCC	p8	6.5	50	60.10	12	yes	yes	no	no	
3	77,F	R	15	chromophobe RCC	a8	8	45	56.45	6	yes	yes	no	no	
4	68,M	R	21	clear cell RCC	p7	7	60	62.44	18	yes	yes	no	no	
5	65, M	L	20	clear cell RCC	p7	6	50	61.02	14	yes	yes	no	no	
6	75,M	L	22	clear cell RCC	a5	6.5	45	53.07	20	yes	yes	no	no	
7	55,F	L	35	oncocytoma	p8	7	45	52.16	9	yes	yes	no	no	
8	58,F	L	21	Bosniak III cyst	p7	7	50	52.58	12	yes	yes	no	no	
9	62,M	R	19	clear cell RCC	p9	7.5	40	50.13	12	yes	yes	no	no	
10	59,F	R	20	clear cell RCC	p10	6	45	49.49	9	yes	yes	no	no	
11	74,M	L	15	clear cell RCC	p7	6.5	40	50.27	12	yes	yes	no	no	
12	70,F	R	13	clear cell RCC	p8	7	45	50.01	15	yes	yes	no	no	
13	63,M	L	25	Bosniak III cyst	p7	8.5	50	51.19	18	yes	yes	no	no	
14	58,F	R	18	clear cell RCC	p7	3	45	56.78	18	yes	yes	no	no	
15	60,F	L	20	clear cell RCC	p6	5.5	75	68.67	15	no	yes	no	no	2 positioning of the antenna

Abbreviations: Pt, patient; FU, follow-up; TS, technical success (ablation completed according to the study protocol); TE, technical effectiveness; LTP, local tumor progression (recurrence at the site of ablation); CSD, cancer-specific death (during observation period); DAP tot, total dose area product; RCC, renal cell carcinoma.

Table 2. Inclusion and Exclusion Criteria of Patients Undergoing the Procedures.

Inclusion criteria

Renal tumors considered inoperable (co-morbidities, advanced age, and/or refusal to undergo surgery);
Tumors which were histologically ascertained, or increasing in size, or changing in contrast-enhancement characteristics over time;
Tumors not evident at unenhanced CBCT.

Exclusion criteria

Tumors visible at unenhanced CBCT (exophytic renal lesions, or with a definite cystic component, or intra-lesional calcifications);
Metastatic disease;
Uncorrected coagulopathy;
Unavailable preoperative CT or MR examinations (performed less than 1 month prior ablation).

Abbreviations: CBCT, cone beam computed tomography; MR, magnetic resonance.

calculated the path. This tool allows cross-sectional DICOM data (CT or MRI) to be used to plan the needle trajectory. CBCT and real-time fluoroscopic images were automatically merged and the C-arm identified two different views: the "entry point" (in which entrance and target were overlapped) and "progression view" (perpendicular to the entry point view).

In lesions closer to the calyxes, or to the principal arteries/veins, the MW antenna was advanced step by step toward the lesion during consecutive CBCT checks, in order to avoid incidental puncture of these important structures.

A final contrast-enhanced CBCT identifying the tumor was used to visualize the antenna, in order to check the correct position within the target (Figure 3A, B).

Safety air-dissection was performed for any lesion close to the bowel (Figure 4A, B).

Contrast enhanced CBCT was obtained with intra-venous injection of 50–70 mL of contrast media (Visipaque 320 mgI/mL, GE Healthcare, Princeton, NJ, USA) with a 10 s C-arm rotation time in both the arterial and portal phases (Dual-Phase CBCT). A pre-arranged delay of 35–40 s from injection was established for the arterial phase and a delay of 50–60 s for the portal phase, respectively.

The CBCT acquisition parameters were the same as the unenhanced CBCT.

At the end of the procedure, a new unenhanced CBCT was obtained to assess the absence of immediate complications (Figure 5).

Ablation

Before the beginning of each procedure, local anesthesia of the access site was achieved with a subcutaneous injection of a 10-mL solution of 2% Lidocaine (Lidocaina, 2%, Angelini SpA, Rome, Italy). Each patient was kept in a state of moderate sedation through intravenous administration of a combination of midazolam (Ipnovel, Roche, Milan, Italy) (0.07–0.08 mg/kg), propofol (Propofol Kabi 10 mg/mL, Fresenius Kabi Italy S.r.L) (0.5–2.0 mg/kg/h) and fentanyl (Fentanest 0.1 mg/2 mL, Pfizer Italy, S.r.L.) (1-2 lg/kg).

Heart rate, electrocardiographic trace, oxygen saturation, respiratory frequency, and blood pressure were continuously monitored throughout the procedure.

During the entire ablation session, patients were monitored by an anesthesiologist. Adequate antibiotic prophylaxis was achieved with intravenous administration of 2 g of cefazolin sodium (Ancef,

Figure 1. Pre-procedural CT shows the location of a small tumor: unenhanced CT (A), arterial phase (B), venous phase (C).

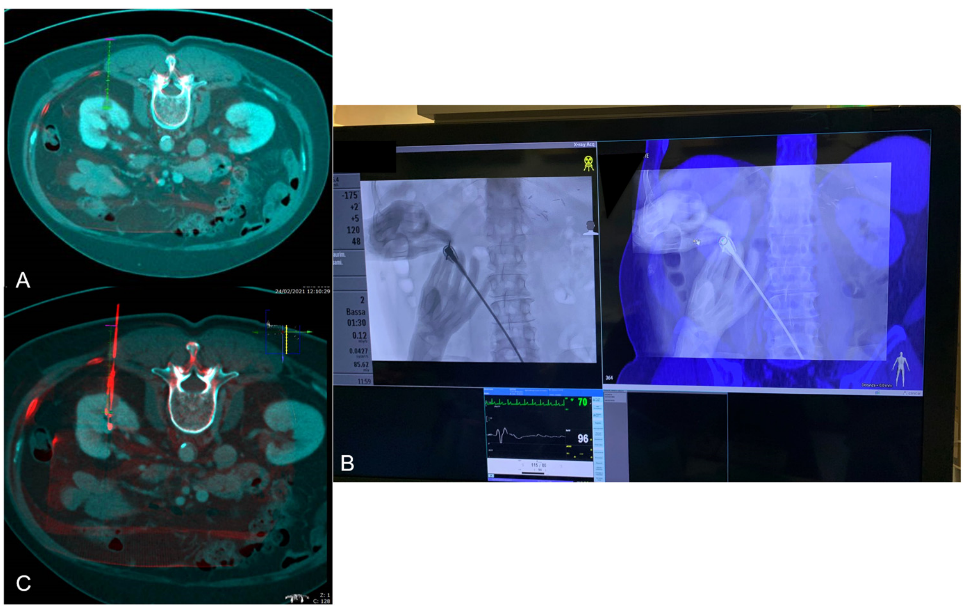

Figure 2. Target point and entry point were drawn using the antenna navigation software (XperGuide) on the merged image (A); under fluoroscopic guidance, the antenna was positioned following the path drawn (B); further CBCT scan was obtained to check the position of the antenna (C).

SmithKline Beecham Pharmaceuticals, Philadelphia, PA, USA) given immediately before the beginning of the procedure.

MWA was carried out using a 2450-MHz generator that delivers a maximum power of 100 W coupled with an internally cooled antenna with single-body fiberglass construction that reduces the risk of antenna breakage during placement (Emprint/Covidien, Boulder, CO, USA), a pump for efficient antenna cooling to minimize thermal conductivity for increased control and predictability and a remote temperature probe that verifies tissue temperature in real-time and triggers automatic ablation shut-off when a pre-set tissue temperature is achieved.

In all cases, only one antenna was used.

Outcomes

Technical success (TS) was defined as the possibility to deploy the antenna within the target lesion, as verified by the contrast-enhanced CBCT performed before the ablation.

Primary technical effectiveness (TE) represented the absence of residual viable tumor, assessed by using RECIST criteria[14] at contrast-enhanced CT or MRI performed one month following treatment; secondary TE was defined as complete ablation after any retreatment.

Local tumor progression was defined as tumor recurrence in the site of thermal ablation or rather growth of the tumors or

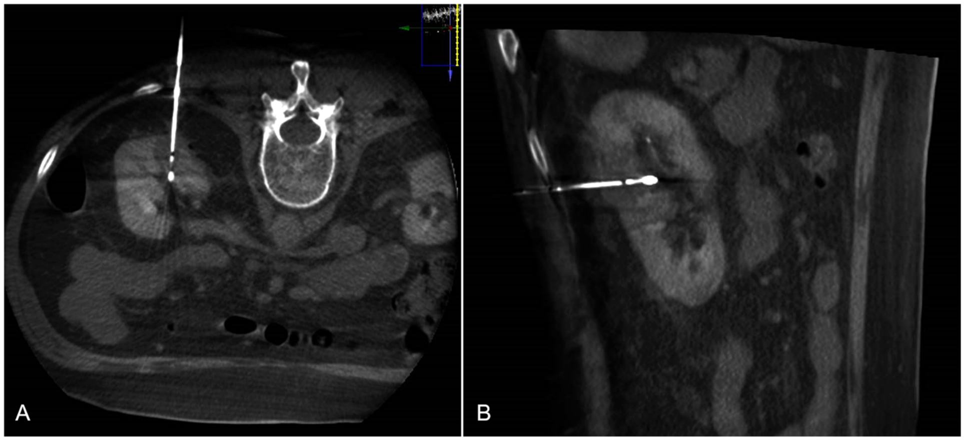

Figure 3. Final contrast-enhanced CBCT identifying the tumor was used to visualize the antenna, in order to check the correct position within the tumor itself: axial (A) and sagittal (B) views.

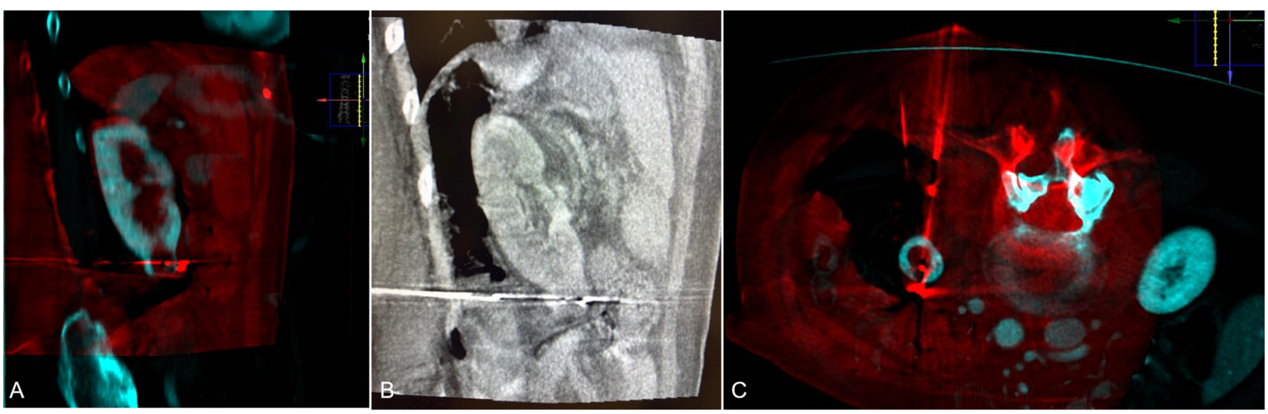

Figure 4. Fusion image obtained after air dissection to sunder the kidney from the colon (A); contrast-enhanced CBCT obtained to check the correct position of the antenna: coronal (B) and axial view (C).

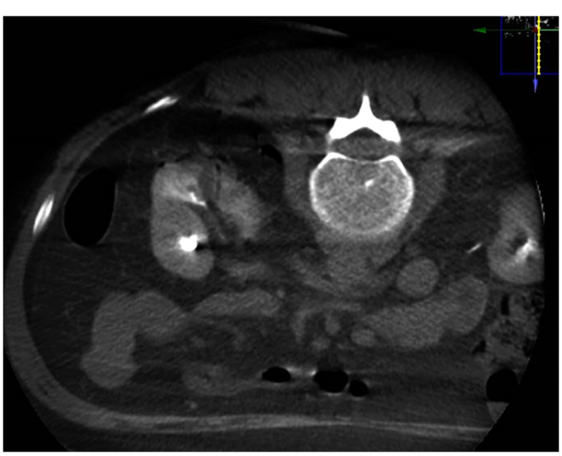

Figure 5. Final unenhanced CBCT acquired to assess the absence of immediate complications.

focal enhancement within or around the tumors in CT or MR scans during imaging follow-up.[14,15]

Procedural time was measured from anesthesia induction to the patient awakening.

Complications were graded according to the SIR (Society of Interventional Radiology) classification system.[16]

The first imaging follow-up, using with the same pre-operative modality, was performed after 1 month. Following that, CT or MRI were performed after 3, 6, 12 months, and then yearly.

Follow-up length was calculated from the first treatment until the last imaging evaluation.

Variables were reported as median with range.

Results

MWA of renal tumors with fusion technique was technically successful in 14 out of 15 cases (93%). In one case, merging between pre-procedural unenhanced CBCT and MRI image was not feasible because of the patient moving during the procedure. Therefore, the antenna was positioned only on the basis of anatomical landmarks; two deployments of the device (the second advancing the antenna 5–7 mm ahead) were judged necessary by the operator to completely cover the lesion presumably. 1-month CT scan showed complete ablation of the tumor in this case.

The median procedural time was 45 min (range 40–75 min).

No procedure-related complications were reported.

Technical efficacy with fusion technique at 1 month was reached in all patients (100%): no enhancing tissue was visualized in the area of ablation at follow-up examination.

No patient needed a further ablation during the follow-up duration (12 months, range 6–18 months).

All 15 cases were recurrence-free at last follow-up assessment; no cancer-specific deaths were registered.

Discussion

This study represents a preliminary experience on the role of intra-procedural CBCT-CT/MR fusion imaging for guiding percutaneous renal ablation. This approach proved to be feasible and safe in the cohort of patients involved in this study; no major complications were observed, and all procedures were successfully performed in a single session. No recurrence/residual disease was registered during the available follow-up.

Although percutaneous thermal ablation is generally deemed safe, it can be complicated with unintended thermal injury to the surrounding organs. Advances in oncologic interventional procedures have increased the need for accurate 3D characterization of vessels and adjacent structures. Therefore, correct targeting still represents one of the most challenging issues.

Ultrasonography (US) is still considered the guidance method of choice for percutaneous interventional procedures, as it provides real-time imaging, is widely available and inexpensive, and does not use ionizing radiation. However, compared to multidetector CT and MR, it has lower contrast resolution and a narrower field of view, strongly affected by the presence of gas, body size and patient habitus.

Whenever available, conventional CT remains key for successful percutaneous renal ablation; however, the ideal scenario of having a conventional CT or a hybrid suite dedicated to interventional oncology treatments is viable only in few referral cancer facilities. Instead, CBCT has gained increasing popularity as a more affordable compromise for combining real-time fluoroscopy and angiography with multisectional CT-like images, and is now widely used in disparate interventions in cancer patients.[3,7,17] The CBCT images, alone or potentially fused to previously acquired imaging (eg, MRI or CT), may be used to determine a target and accurately plan a path for a device. The selected virtual path can be displayed simultaneously on real-time fluoroscopy in addition to the fused image (namely previous 3D dataset), thus allowing precise image-based navigation in the angiography suite.[18] Moreover, the possibility to repeat a CBCT acquisition with the same conditions immediately after treatment may be useful to obtain a safe ablation zone, and promptly assess the coverage of the desired area (MDCT at 1 month is mandatory to verify whether the tumor is completely or partially ablated); furthermore, it may be helpful in excluding early complications.

This is why CBCT fusion imaging has previously been employed for precise guiding of percutaneous thermal ablations mainly for liver and kidney applications.[5,19–22]

Monfardini et al.[19] described the use of CBCT-guidance for radiofrequency ablation of renal tumors in 14 patients. In 2 lesions, pre-acquired CBCT was co-registered with real-time US to enable US-CBCT fusion image guidance. All the procedures were carried out successfully, with a primary technical efficacy achieved in 19/21 ablations at 1 month (90.1%), and in all patients after a second session of treatment.

In another series with heterogeneous histologies and technical approaches, Abi-Jaoudeh et al.[5] treated in multiple sessions 16 lesions, also including some RCCs. The authors exploited a software that was analogous to that used in the present work, and which allowed the guidance under CBCT images fused to MR, positron emission tomography (PET)-CT or contrast-enhanced CT.

CE-CBCT registration was retrospectively applied by Solbiati et al.[21] to ablate liver lesions through MW application in 30 patients. This method showed the potential to decrease patient risk and discomfort associated with retreatment of partially ablated tumors.

In our series, the largest ever reported on fusion imaging-guided renal ablation, it was always possible to achieve a precise registration of the CBCT images with the previously acquired MDCT or MR images.

Fusion imaging may prove to be useful for guiding interventional procedures for several reasons. Indeed, although CBCT provides fast generation of volumetric images with lower radiation dose as compared to MDCT, the two datasets differ with respect to many features. MDCT and CBCT are both imaging modalities based on radiation and computed tomography technology; however, the images generated differ with regard to many parameters, including the field-of-view, susceptibility to motion artifacts, different signal-to-noise ratios, and image resolution.[17,21]

CBCT fused to MR images, instead, may help in case the use of iodinated contrast media is contraindicated, or the lesions to be targeted are visible only at MR imaging.[18]

In this study, we have applied the fusion image guidance to percutaneous ablation of renal tumors through MWs. This last modality utilizes dielectric hysteresis to produce heat, inducing cellular death via coagulation necrosis. MWA may carry some advantages over the other available technologies, including higher intra-tumoral temperatures, larger ablation zones, shorter coagulation time, possibility of simultaneous multi-probe application, optimal heating of cystic lesions and tumors close to the vessels, and less procedural pain.[23,24] These features may result in a more predictable and reliable ablation.[3,25] In our series, we also used MWs to successfully ablate two cystic lesions classified as Bosniak III, confirming our previous experience in this field.[25]

Currently, the only possibility to verify the correct position of the antenna is a CBCT carried out after intravenous administration of contrast media. The consolidation of merging unenhanced CBCT acquisitions and pre-procedural CT or MRI images could allow us to perform the procedure without using iodinated contrast media. This would be a great advantage, especially considering the number of CT or MRI examinations these patients will undergo during follow-up.

Our experience has shown the need for patient cooperation, particularly in staying still during the procedure.

Furthermore, the procedures can only be completed in a reasonable amount of time if the staff has received adequate training (preparation and positioning of the patient, technical possibility to perform CBCT as many times as necessary with the rotation of the C-arm around the patient).

Some limitations of the present work must be disclosed; notably, the small number of patients, the limited follow-up duration, and the retrospective study design. Thus, our results should be regarded as preliminary, since future research is needed to thoroughly explore the safety profile and oncological outcomes of this alternative approach.

Conclusion

This preliminary experience has shown that CBCT-CT/MR image fusion can be technically feasible and safe as an image guidance modality for achieving correct targeting and complete ablation of renal lesions. This approach bears the potential to overcome the majority of the limitations of CT or US guidance alone.

Consent for Publication

Consent for publication was obtained for every individual person's data included in the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

This retrospective study was conducted at Policlinico di Milano Fondazione IRCCS Ca' Grand (University Hospital of Milan affiliated with the University of Milan). The Institutional Review Board of the Policlinico di Milano approved the study (radint 11/2020; prot. 11/2020; approved on the 11th of July 2020). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Funding

This study was funded by Italian Ministry of Health, Current research IRCCS.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

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