Cardiovasc Intervent Radiol (2023) 46:901–910
https://doi.org/10.1007/s00270-023-03453-7

CLINICAL INVESTIGATION IMAGING

MRI- Versus CT-Guided Renal Tumor Cryoablation: Is There a Difference?

Roberto Luigi Cazzato[1] · Pierre De Marini[1] · Theo Mayer[1] · Loïc Leclerc[1] · Ian Leonard-Lorant[1] · Danoob Dalili[2,3] · Julia Weiss[1] · Guillaume Koch[1] · Pierre-Alexis Autrusseau[1] · Julien Garnon[1] · Hervé Lang[4] · Afshin Gangi[1,5]

Received: 16 January 2023 / Accepted: 22 April 2023 / Published online: 24 May 2023

Abstract

Purpose To compare procedure-related variables, safety, renal function, and oncologic outcomes in patients undergoing percutaneous cryoablation (CA) of renal tumors with MRI- or CT-guidance.

Materials and Methods Patient, tumour, procedure, and follow-up data were collected and analysed. MRI and CT groups were matched using a coarsened exact approach according to patient's gender and age, tumour grade, size and location. $P < 0.05$ was considered statistically significant.

Results Two-hundred fifty-three patients (266 tumors) were retrospectively selected. Following the coarsened exact matching 46 patients (46 tumors) in the MRI group and 42 patients (42 tumors) in the CT group were matched. There were no significant baseline differences between the two populations except for the duration of follow-up ($P = 0.002$) and renal function ($P = 0.002$).

On average MRI-guided CA lasted 21 min longer than CT-guided ones ($P = 0.005$). Following CA, complication rates (6.5% for MRI vs 14.3% for CT; $P = 0.30$) and GFR decline (mean − 13.1 ± 15.8%; range − 64.5–15.0 for MRI; mean − 8.1 ± 14.8%; range − 52.5–20.4; for CT; $P = 0.13$) were similar in both groups.

The 5-year local progression-free, cancer-specific and overall survivals in the MRI and CT groups were 94.0% (95% CI 86.3%–100.0%) and 90.8% (95% CI 81.3%–100.0%; $P = 0.55$), 100.0% (95% CI 100.0%–100.0%) and 100.0% (95% CI 100.0%–100.0%; $P = 1$), and 83.7% (95% CI 64.0%–100.0%) and 76.2% (95% CI 62.0%–93.6%; $P = 0.41$), respectively.

Conclusions Apart from increased procedural times associated with MRI-guided CA of renal tumors compared to CT-guidance, both modalities demonstrate similar safety, GFR decline and oncologic outcomes.

Keywords Cryoablation · Magnetic resonance imaging · Computed tomography · Kidney · Neoplasms

✉ Roberto Luigi Cazzato
gigicazzato@hotmail.com;
roberto-luigi.cazzato@chru-strasbourg.fr

[1] Service d'Imagerie Interventionnelle, Hôpitaux Universitaires de Strasbourg, 1, Place de L'hôpital, 67000 Strasbourg, France

[2] Academic Surgical Unit, South West London Elective Orthopaedic Centre (SWLEOC), Dorking Road, Epsom, London KT18 7EG, UK

[3] Department of Diagnostic and Interventional Radiology, Epsom and St Helier University Hospitals NHS Trust, Dorking Road, Epsom KT18 7EG, UK

[4] Service d'Urologie, Hôpitaux Universitaires de Strasbourg, 1, Place de L'hôpital, 67000 Strasbourg, France

[5] School of Biomedical Engineering and Imaging Sciences, King's College London, Strand London, London WC2R 2LS, UK

Introduction

Renal cancer is the 6th most diagnosed tumor worldwide [1], and the vast majority of diagnosed primary renal tumors measure less than 4 cm (i.e. T1a) [1]. The gold standard treatment for such small tumors remains partial

nephrectomy [1], but percutaneous cryoablation (CA) is increasingly emerging as an alternative to surgical treatment [1] because of its multiple advantages including the resistance of the urinary excretory tract to cold temperatures, the well-known analgesic effect of the cold favoring a smooth post-operative phase, and the real-time visibility of the ice ball granted by cross-sectional imaging, which favors the adaptation of the ablation zone to the size and shape of the target tumor [2].

CA is typically performed under computed tomography (CT) guidance [3, 4]; however, magnetic resonance imaging (MRI) is emerging as an alternative modality of guidance [5–7], yielding several theoretical advantages over CT such as its radiation-free nature, the availability of MRI-fluoroscopy permitting multiplanar, real-time control of needle advancement, and clearer delineation of the iceball as an area of signal void [8]. Aside from these theoretical technical advantages granted by MRI over CT, there is a paucity of data clearing comparing these two techniques of guidance in the context of renal tumor CA [9]. Accordingly, we conducted a retrospective study aiming at comparing clinical outcomes such as safety, renal function, and oncologic outcomes, as well as procedure-related variables in a population of patients with biopsy-proven localized renal tumors undergoing percutaneous MRI- or CT-guided CA.

Materials and Methods

This retrospective study was approved by the institutional review board with permission to perform chart review and a waiver of written informed consent. No industry funding was received.

Patient Selection

All patients with renal tumors referred to our institution are routinely discussed in a multi-disciplinary tumor board. Based on patient's clinical characteristics (age, Eastern Cooperative Oncology Group-performance status [ECOG-PS], and comorbidities), expectations (preference for surgical or percutaneous treatment), and disease extension (kidney-confined tumor), the board refers patients for percutaneous or surgical treatment. When percutaneous treatment is selected, CA is systematically used.

CA for renal tumors was introduced in our center in May 2008; at that time only CT-guidance was available. Less than one year later (i.e., January 2009), MRI-guidance became available. Since then, renal tumor CA were scheduled either in the CT or the MRI unit according to the "first-room availability" principle (i.e., procedure is scheduled in the room presenting the first available slot to avoid any delay of treatment). Nevertheless, CT is invariably used for patients with established MRI contraindications (e.g., Body Mass index $\geq$ 35, non-MRI compatible indwelling devices).

The study population was selected by searching our radiology information system (Xplore; EDL, France) for all consecutive patients undergoing CA of renal tumors from the moment this procedure was introduced at our institution (May 2008) to December 2020. Three keywords ("cryoablation", "kidney", and "tumor") were simultaneously entered to identify the study population. Thereafter, the following exclusion criteria were applied to select the final study population: patients (a) having undergone MRI- and CT-guided CA (i.e. duplicate patients); (b) with cystic tumors and/or hereditary syndromes; (c) undergoing CA due to post-surgical tumor recurrence; (d) receiving total nephrectomy after CA; d) with follow-up $<$ 3 months; and (e) without primary and secondary technical efficacy (TE—i.e. no contrast enhancement or tumor enlargement at imaging follow-up $\leq$ 3 months). In particular, primary TE was calculated to take into account residual tumors detected 3 months within CA; and secondary TE was calculated to account for patients with residual tumors detected during the first 3 months after CA, and undergoing a second CA.

Percutaneous Cryoablation

CA were performed on primary biopsy-proven renal tumors by seven interventionalists with with $\geq$ 3 years' experience in renal CA. Procedures were performed on an inpatient basis under general anesthesia. Anticoagulants/antiplatelets were adjusted according to international standards [10].

Hydro- or carbo-dissection with fluids or carbon-dioxide respectively, were performed whenever a nearby non-target organ resided $<$ 1 cm away from the renal tumor. These maneuvers were performed through MRI-compatible (ITP, Bochum, Germany) 22G needles. CA were performed with argon-based systems and double 10-min freezing protocol. Iceball growth was intermittently monitored during freezing cycles with unenhanced CT images or T2-weighted sequences.

CT-Guided Cryoablation

Scanners from different manufacturers (Somatom, Siemens, Germany; Alphenix, Canon, Japan) were used. Axial CT images (with contrast-enhancement at the discretion of the operator) were acquired to plan needles' positioning. Hydro-dissection was performed with 5%-iodine diluted saline (Fig. 1); carbo-dissection by injecting sterile carbon-dioxide. Ultrasonographic guidance was not used to facilitate needles' placement.

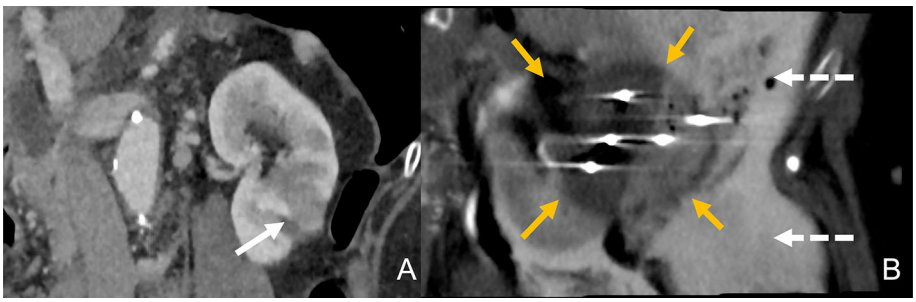

Fig. 1 **A** Coronal contrast-enhanced CT of a 77-year female patient demonstrating a left sided 2 cm primary renal tumour consistent with a biopsy-proven papillary carcinoma (arrow). **B** The patient underwent CT-guided cryoablation of the renal tumour; of note the large hypodense ice-ball (yellow arrows) covering the tumour on the coronal plane and the abundant hydro-dissection (dotted arrows) to protect the nearby non-target organs (colon, diaphragm, not showed since already spaced away). Hydro-dissection was achieved through injection of 5% contrast-diluted saline

CA was performed using two different machines (ICEFX or VISUAL ICE; Boston Sc, USA) and different 15–17G cryo-needles (IceSphere, IceRod, IceForce, Boston Sc, USA).

MRI-Guided Cryoablation

CA were performed on a 1.5T closed-bore MRI unit (MAGNETOM, Siemens, Germany; bore diameter 70 cm; bore length 140 cm). The MRI integrated body coil was used. Axial free-breathing T2-weighted sequences (BLADE, TE/TR 178/3420 ms, Flip angle 150°, field-of-view 400 × 400 mm, slice thickness 4 mm; HASTE, TE/TR 92/2000 ms, flip angle 180°, field-of-view 400 × 400 mm, slice thickness 4 mm) were acquired to plan needles' positioning. Hydro-dissection was performed with simple saline (Fig. 2). Carbo-dissection was not performed due to the unavailability of an MRI-compatible carbo-dissection system. All needles were positioned using continuous free-breathing multiplanar MRI-fluoroscopy (BEAT-IRTTT sequences, TE/TR 2.2/5.35 ms, flip angle 50°, field-of-view 400 × 400 mm, slice thickness 4 mm). CA was performed using one machine (VISUAL ICE MRI; Boston Sc, USA) and two different 17G cryo-needles (IceSeed, IceRod, Boston Sc, USA) providing oval-shaped iceballs with different sizes.

Data Collection

Chart review was performed with consensus by three interventional radiologists (ILL, LL, TM, of 1-, 2- and 3-years' experience, respectively, in percutaneous ablation) blinded to imaging and procedural data at the time of data collection. When doubts were raised, a third senior author (RLC. 8-years' experience) was summoned to resolve uncertainty through consensus.

Patient characteristics (age, sex, ECOG-PS, single kidney, number of renal tumors, previous nephrectomies, baseline glomerular filtration rate [GFR]); tumor characteristics (histology, size, location, RENAL score); procedural details (number of cryo-needles, use of dissection, procedure time, in-hospital stay duration, complications); and follow-up data (post-CA GFR, TE, local progression-free [LPFS], disease-free [DFS], metastasis-free [MFS], cancer-specific [CSS], and overall [OS] survivals were collected.

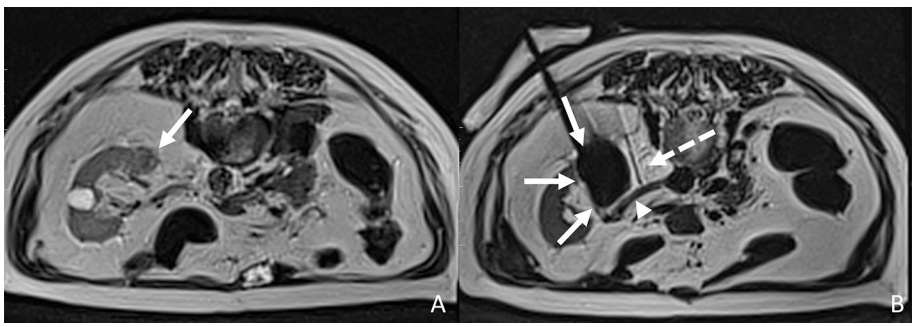

Fig. 2 **A** Axial T2 BLADE sequence of an 82-year male patient demonstrating a 2 cm renal tumour consistent with a biopsy-proven clear cell carcinoma (arrow) of the left kidney. **B** The patient underwent MRI-guided cryoablation of the renal tumour; of note on the axial T2 BLADE sequence the large signal void denoting the ice-ball (arrows) covering the tumour. Hydro-dissection with normal saline (dotted arrows) was used to space away the left renal artery (arrowhead), thus reducing the 'cold-sink' effect

Tumor size was measured as the largest diameter on the most recent cross-sectional imaging available 2–4 weeks before the procedure. Tumor location and RENAL score were assessed according to Kutikov et al. [11], and included evaluation of side of renal involvement (left/right), whether tumors were exophytic, endophytic, or intraparenchymal, and their location relative to the pyelic axis, and the polar renal lines.

Procedural time was calculated as the interval between first and last image acquisition on MRI or CT.

Complications were classified according to Clavien et al. [12] into minor (grade < 3) or major (grade ≥ 3).

LPFS was calculated in all cases reaching primary/secondary TE as the time interval between CA and the date of local progression with censoring at the last imaging follow-up for patients without local progression. DFS, MFS, CSS, and OS were respectively the time intervals between CA and appearance of any local recurrence, new kidney tumor, or distant metastasis; appearance of any distant metastasis; patient's death due to kidney cancer; and patient's death from any cause.

Statistical Analysis

Categorical variables are provided as absolute numbers and percentages; continuous variables as medians with interquartile ranges (IQRs). The Student t- (continuous variables) and the Chi squared (categorical variables) or Fischer's tests (when number of events was low) were used to compare MRI and CT groups. LPFS, MFS, and OS rates were estimated with the Kaplan–Meier method, and compared between the MRI and CT groups with the Log-Rank test. MRI and CT groups were matched using a coarsened exact matching by taking into account patient's sex and age, and tumour grade, size and location. $P < 0.05$ was considered to indicate a statistically significant difference. Statistical analysis was performed by using R v3.6.3 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Baseline Patient Characteristics

In the whole, 333 consecutive patients were identified by the retrospective search. After applying the exclusion criteria, 253 patients (266 tumors) were identified: 135 patients (139 tumors) underwent MRI-guided CA, and 118 patients (127 tumors) underwent CT-guided CA (Fig. 3, Table 1). Mean follow-up in the whole population was 36.0 ± 30.7 months (range: 0–137; median 25.5; IQR: 12–50 months).

After performing the coarsened exact matching, the final study population included 46 patients (46 tumors) receiving MRI-guided CA and 42 patients (42 tumors) receiving CT-guided CA (Table 2).

Procedure-Related Results

A similar number of cryo-needles was used for MRI- and CT-guided CA (MRI: mean 3.3 ± 0.7; range 2.0–5.0; median 3.0; IQR 3.0–4.0; CT: mean 3.2 ± 0.9; range 2.0–6.0; median 3.0; IQR 2.0–4.0; $P = 0.35$). Dissection maneuvers were comparably applied whilst treating 31 tumors under MRI-guidance and 30 tumors under CT-guidance (31/46 [67.0%] vs 30/42 [71.0%]; $P = 0.68$). In the CT-guided group, hydro-dissection was used for 17 tumors (17/42 [40.5%]), carbo-dissection for 11 tumors (11/42 [26.2%]), and a combination of both these techniques for 2 tumors (2/42 [4.8%]).

On average MRI-guided CA lasted 21 min. more than CT-guided ones (MRI: mean 141.5 ± 41.0 min; range 64.0–212.0; median 135.5; IQR 110.8–173.8; CT: mean 120.4 ± 27.3 min; range 75.0–178.0; median 120.0; IQR 95.0–142.5; $P = 0.005$). The length of the in-hospital stay was similar for patients receiving MRI-guided CA and CT-guided ones (MRI: mean 3.0 ± 1.6 days; range 2.0–11.0; median 3.0; IQR 2.0–3.0; CT: mean 3.8 ± 2.0 days; range 3.0–13.0; median 3.0; IQR 3.0–4.0; $P = 0.06$).

Overall, 3 patients in the MRI group (3/46 [6.5%]) experienced procedure-related complications versus 6 patients in the CT group (6/42 [14.3%]; $P = 0.30$). Complications in the MRI group were all minor; complications in the CT group were minor for 5 patients (5/42; 11.9%) and major for one patient (1/42; 2.4%). Complications are listed in Table 3.

Follow-up Results

Following CA, GFR decreased for both the MRI and CT groups (nadir GFR in the MRI group: mean 60.8 ± 24.3 ml/min/1.73 m^2; range 9.0–93.0; median 65.5; IQR 42.2–80.0; nadir GFR in the CT group mean 52.5 ± 12.0 ml/min/1.73 m^2; range 25.0–82.0; median 60.0; IQR 44.0–60.0; $P = 0.044$). Compared to the baseline, GFR declined more in the MRI group compared to the CT group, despite such difference was not statistically significant (mean maximal GFR variation in the MRI group: − 13.1 ± 15.8%; range − 64.5–15.0; median − 9.0; IQR − 21.1–0.0; mean GFR variation in the CT group: mean − 8.1 ± 14.8%; range − 52.5–20.4; median 0.0; IQR − 14.0–0.0 in the CT group; $P = 0.13$).

Primary TE was 100.0% (46/46 patients) in the MRI group versus 95% (40/42 patients) in the CT group ($P = 0.22$). Patients not reaching primary TE in the CT

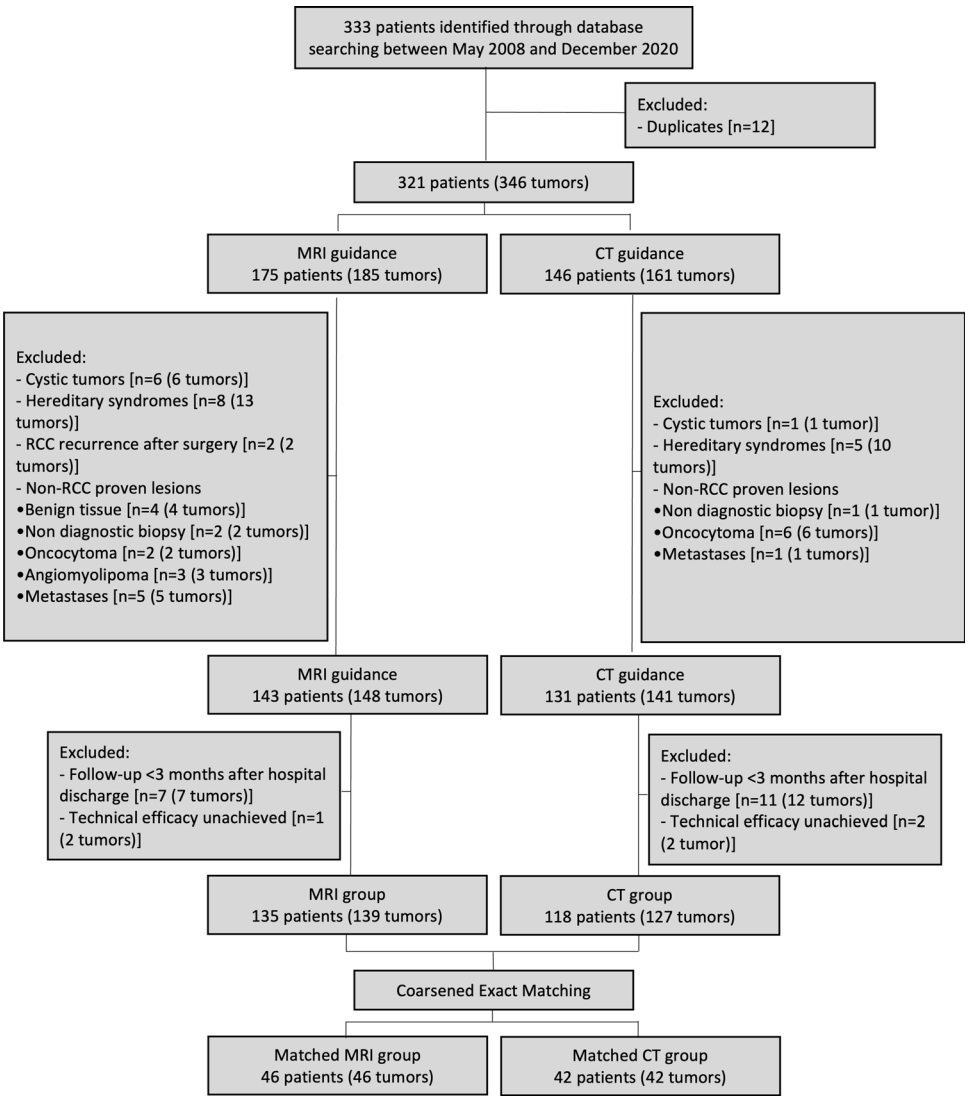

Fig. 3 Study summary flowchart. Of notice only patients without primary and secondary technical efficacy were excluded from the final study population. Duplicates were patients receiving CT and MRI cryoablation

group were subsequently retreated with CA, thus allowing complete secondary TE (42/42 patients [100.0%]. LPFS was similar for MRI and CT groups with 5-year LPFS rates of 94.0% (95% CI 86.3%–100.0%) and 90.8% (95% CI 81.3%–100.0%; $P = 0.55$), respectively (Fig. 4). The other oncologic outcomes are listed in Table 4.

Discussion

This study aimed at comparing two similar populations presenting with primary, biopsy-proven renal tumors undergoing percutaneous MRI- or CT-guided CA. The intent of the study was to reveal whether the modality of guidance could impact safety and others procedure-related variables, as well as renal function, and oncologic outcomes, by matching two homogeneous sub-populations (MRI vs CT) according to multiple patients' and tumours' features.

There was no significant association between the type of guidance and impact on patient' safety, renal function impairment, nor oncologic outcomes (LPFS, DFS, MFS, CSS, OS). Only the duration of the intervention was affected by the modality of guidance where MRI resulted in interventions lasting on average 21 min longer than those performed with CT. Overall, these results compare favorably with Bhagavatula et al [9] who compared percutaneous MRI- and CT-guided CA of T1 renal tumors in 307 patients. In their series, despite the absence of matching to select the two subpopulations, 5-year estimates of LPFS, DFS, CSS and OS were similar in both groups (LPFS, DFS, CSS and OS: 94%, 92%, 100%, 88%, and 95%, 90%, 98%, 85%, respectively for the MRI and CT groups); which is in line which with our 5-year estimates of LPFS, DFS, CSS and OS of 94.0%, 88.7%, 100%, 83.7%,

Table 1 Unmatched population

Patients	MRI group (N = 135)	CT group (N = 118)	P-value
Age (years)			0.35
Mean ± SD (range)	72.2 ± 11.1 (34.0–91.0)	70.9 ± 11.2 (35.0–89.0)	
Median (IQR)	73.0 (66.5–80.0)	72.0 (66.0–79.0)	
Gender			0.49
Male	98 (73.0%)	81 (69.0%)	
Female	37 (27.0%)	37 (31.0%)	
ECOG-PS			0.64
≤ 2	125 (93.0%)	111 (94.0%)	
> 2	10 (7.4%)	7 (5.9%)	
Previous renal surgery	43 (32.0%)	32 (27.0%)	0.41
Single kidney	30 (22.0%)	26 (22.0%)	0.97
Baseline renal function (ml/min/1.73m^2)			< 0.001
Mean ± SD (range)	67.7 ± 24.0; (11.0–138.0)	54.8 ± 14.2 (0.0- 107.0)	
Median (IQR)	72.0 (50.0–90.0)	60.0 (49–60.0)	
Tumors	MRI Group (N = 139)	CT Group (N = 127)	
Size (mm)			0.13
Mean ± SD (range)	27.0 ± 9.3 (6.0–60.0)	28.9 ± 11.5 (7.0–60.0)	
Median (IQR)	26.0 (20.0–32.5)	28.0 (20.5–35.0)	
RENAL score			0.05
≤ 6	81 (58.0%)	89 (70.0%)	
> 6	58 (42.0%)	38 (30.0%)	
Histology			0.08
Clear cell	104 (75.0%)	34 (81.0%)	
Papillary	24 (17.0%)	7 (17.0%)	
Chromophobe	4 (2.9%)	1 (2.0%)	
Other	7 (5.0%)	1 (0.8%)	
ISUP score			0.78
ISUP ≤ 2	119 (86.0%)	107 (84.0%)	
ISUP > 2	9 (6.5%)	11 (8.7%)	
Other than RCC/papillary	11 (7.9%)	9 (7.1%)	

SD Standard deviation; *IQR* Interquartile ranges; *ECOG-PS* Eastern Cooperative Oncology Group-performance status; *ISUP* International Society of Urological Pathology; *RCC* Renal cell carcinoma

and 90.8%, 81.0%, 100%, 76.2% for the MRI and CT groups, respectively. Moreover, similarly to Bhagavatula et al [9], in our series MRI-guided CA lasted more than CT-guided CA (21 min. in our series vs 13 min in Bhagavatula et al.). Yet contrary to Bhagavatula et al [9], our series specifically analyzed the safety of MRI- and CT-guided CA. Although, the total complication rate in the MRI group was lower than that in the CT group (i.e., 6.5% vs 14.3%), such difference was not statistically significant. When analyzing the type of procedure-related morbidity, we noted 2.2–4.8% of various haemorrhagic events (e.g. haematuriaa, hematoma) across both groups. Most of these events were self-limiting and minor, and only one patient (2.4%) in the CT group presented with an active bleeding requiring embolization. These data are in line with large series reporting up to 3.2% of hemorrhagic events after renal CA, with only a minority requiring active treatment [13]. Accordingly, haemorrhagic complications seem almost unavoidable in a minority of renal CA, and may depend on physical puncturing of hyper vascular tumours in a hyper vascular organ [14].

However, in the MRI group, there were no cases of iatrogenic injury to non-target organs lying nearby the ablation zone, but one pneumothorax was noted in the CT group. Although not statistically significant, one may speculate that avoiding injury to non-target organs

Table 2 Matched population

Patients	MRI Group ($N = 46$)	CT Group ($N = 42$)	P-value
Age (years)			0.85
Mean ± SD (range)	72.8 ± 8.0 (51.0–86.0)	72.4 ± 8.8 (49.0–86.0)	
Median and IQR	73.0 (69.2–79.8)	73.5 (68.2–79.8)	
Gender			0.62
Male	36 (78.0%)	31 (74.0%)	
Female	10 (22.0%)	11 (26.0%)	
ECOG-PS			0.72
≤ 2	41 (89.0%)	39 (93.0%)	
> 2	5 (11.0%)	3 (7.0%)	
Previous renal surgery	13 (28.0%)	14 (33.0%)	0.61
Single kidney	8 (17.0%)	13 (31.0%)	0.14
Baseline renal function (ml/min/1.73m^2)			0.002
Mean ± SD (range)	70.1 ± 26.4; (11.0–138.0)	56.6 ± 10.6 (32.0–84.0)	
Median (IQR)	77.0 (50.0–90.0)	60.5 (58.0–60.0)	
Tumors	MRI Group ($N = 46$)	CT Group ($N = 42$)	
Size (mm)			0.75
Mean ± SD (range)	26.0 ± 6.1 (15.0–40.0)	26.4 ± 6.4 (12.0–42.0)	
Median (IQR)	26.0 (20.2–30.0)	25.5 (22.0–31.0)	
T1			
a (≤ 40 mm)	46 (100%)	41 (98%)	0.48
b (> 40 mm)	0 (0%)	1 (2.0%)	
Affected kidney			0.24
Right	22 (48.0%)	25 (60.0%)	
Left	24 (52.0%)	16 (38%)	
Transplanted kidney	0 (0%)	2 (2.0%)	
Location relative to the renal parenchyma			0.88
Exophytic $\geq 50\%$	31 (67.0%)	28 (67.0%)	
Exophytic $< 50\%$	13 (28.0%)	11 (26%)	
Entirely endophytic	2 (5.0)	3 (7.0%)	
Location relative to the pyelic axis			0.40
Anterior	20 (43.0%)	22 (52.0%)	
Posterior	26 (57.0%	20 (48.0%)	
Location relative to the kidney poles			
Pole of kidney			0.57
Above upper renal line	12 (26.0%)	15 (33.0%)	
In between polar lines	17 (37.0%)	12 (29.0%)	
Below inferior renal line	17 (37.0%)	15 (36.0%)	
RENAL Score			0.61
≤ 6	34 (74.0%)	33 (79.0%)	
> 6	12 (26.0%)	9 (21.0%)	
Distance to renal sinus			0.14
Mean ± SD (range)	1.4 ± 0.7 (1.0–3.0)	1.2 ± 0.6 (0.0–3.0)	
Median and IQR	1.0 (1.0–2.0)	1.0 (1.0–1.0)	
Histology			0.78
Clear cell	36 (78.0%)	34 (81.0%)	
Papillary	9 (20.0%)	7 (17.0%)	
Chromophobe	0 (0%)	1 (2.0%)	
Mucinous tubular and spindle cell carcinoma	1 (2.0%)	0 (0%)	

Table 2 continued

Patients	MRI Group ($N = 46$)	CT Group ($N = 42$)	P-value
ISUP score			1
ISUP ≤ 2	44 (96.0%)	40 (95.0%)	
ISUP > 2	1 (2.0%)	1 (2.5%)	
Other than RCC/papillary	1 (2.0%)	1 (2.5%)	
Follow-up			0.002
Mean $\pm$ SD (range)	30.6 $\pm$ 19.6 (4.0–83.0)	51.4 $\pm$ 37.3 (3.0–131.0)	
Median (IQR)	28.0 (12.2–43.0)	48.5 (18.2–74.0)	

SD Standard deviation; *IQR* Interquartile ranges; *ECOG-PS* Eastern Cooperative Oncology Group-performance status; *ISUP* International Society of Urological Pathology; *RCC* Renal cell carcinoma

Table 3 Complications in the study population

	Complication	No	Grade	N. of days until complication occurred	Management
MRI group	Hematuria	1 (2.2%)	I	1	Spontaneous resolution
	Frostbite	1 (2.2%)	I	1	Local care
	Isolated fever	1 (2.2%)	I	2	Antipyretics
CT group	Retroperitoneal hematoma	1 (2.4%)	IIIA	3	Embolization
	Hematuria	1 (2.4%)	I	1	Spontaneous resolution/Urinary catheter
	Transient renal failure	2 (4.8%)	II	1	Hydration
	Acute pulmonary edema	1 (2.8%)	II	0	Diuretics
	Pneumothorax	1 (2.4%)	I	1	Spontaneous resolution

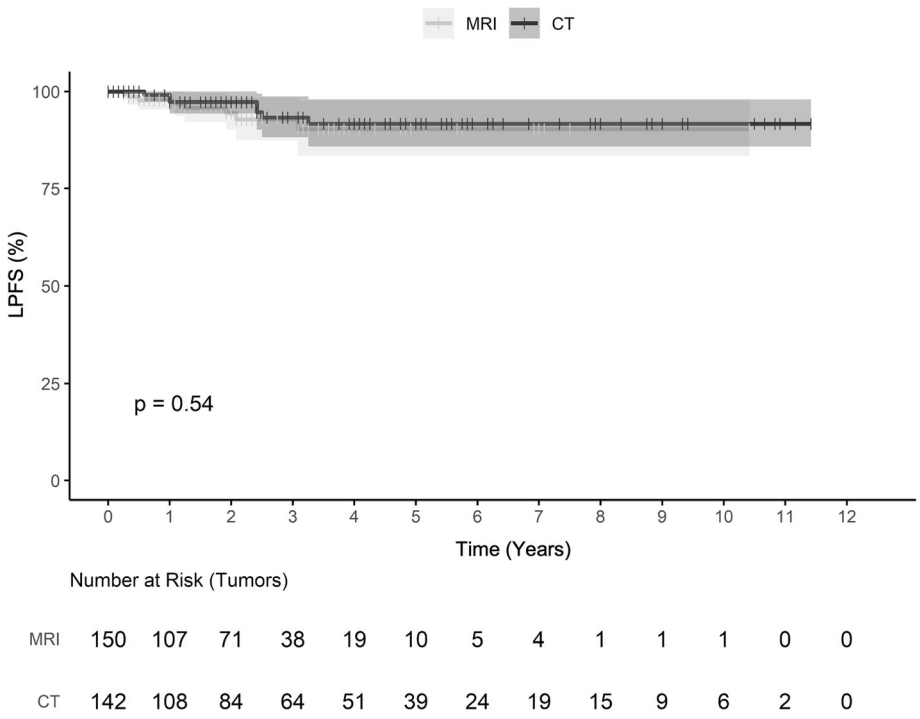

Fig. 4 Kaplan-Meir curves showing the local progression free survival in the MRI and CT groups

Table 4 5-year oncologic outcomes in the study population

	MRI Group (N = 46) (95% CI)	CT Group (N = 42) (95% CI)	P-value
5-year DFS	88.7% (78.7%–100.0%)	81.0% (69.0%–95.0%)	0.24
5-year MFS	97.7% (93.4%–100.0%)	92.0% (83.7%–100.0%;	0.3
5-year CSS	100.0% (100.0%-100.0%)	100.0% (100.0%-100.0%)	1
5-year OS	83.7% (64.0%–100.0%)	76.2% (62.0%–93.6%)	0.41

DFS disease-free survival; *MFS* metastasis-free survival; *CSS* cancer-specific survival; *OS* overall survival

(including pneumothorax, that has been reported as the second most frequent complication in a large series of renal CA [13]) may be more dependent on imaging guidance as, superior visualization of the margins of the iceball on MRI, systematic use of multiplanar MRI fluoroscopy, and high contrast resolution granted by this modality may contribute to lower the risk of iatrogenic injuries. Accordingly, one potential advantage of MRI guidance compared with CT, may be the reduction of non-haemorrhagic complications involving nearby organs, including pneumothoraxes, bowel and pyelo-ureteral junction injuries, whose cumulative rates of occurrence in CT-guided series' are 0.8–5.8% [13, 15–20].

Limitations of our study include the monocentric retrospective nature, which precluded direct prospective randomization of the study population. Nevertheless, the final two sub-populations resulting from the matching could be considered homogeneous given the numerous parameters utilized in the matching process. However, using such a matching method led to a large loss of patients from the initial sampled population; this could have potentially impeded reaching the statistical significance when comparing the MRI and CT populations, especially in terms of procedure-related morbidity. Accordingly, larger prospective studies are definitively needed to understand whether MRI-guidance could potentially lower non-hemorrhagic complications compared to CT-guidance. Furthermore, following data collection, no assessment of the inter- and intra-observer variability was conducted. Lastly, CA were always performed by experienced operators thus hindering description of the learning curves expected for CT and MRI-guided procedures.

In conclusion, compared to CT-guidance one should expect longer CA procedures when MRI-guidance is utilized to treat renal tumors. Aside from this, the modality of imaging guidance has no impact on procedure-related safety, renal function and 5-year oncologic outcomes.

Funding This study was not supported by any funding.

Declarations

Conflict of interest Authors have no conflicts of interest to disclose.

Ethical Approval For this type of study formal consent is not required.

Informed Consent For this type of study informed consent is not required.

Consent for Publication For this type of study consent for publication is not required.

References

1. Ljungberg B, Albiges L, Abu-Ghanem Y, et al. European Association of Urology guidelines on renal cell carcinoma: the 2022 update. Eur Urol. 2022. https://doi.org/10.1016/j.eururo.2022.03.006.
2. Cazzato R, Garnon J, Ramamurthy N, et al. Percutaneous image-guided cryoablation: current applications and results in the oncologic field. Med Oncol. 2016;33:1–6.
3. Borgbjerg J, Bylling T, Andersen G, Thygesen J, Mikkelsen A, Nielsen TK. CT-guided cryoablation of renal cancer: radiation burden and the associated risk of secondary cancer from procedural- and follow-up imaging. Abdom Radiol. 2020;45(11):3581–8. https://doi.org/10.1007/s00261-020-02527-1.
4. Zhong J, Gallagher M, et al. Radiation dose reduction in CT-guided cryoablation of renal tumors. Diagn Interv Radiol. 2021;27(2):244–8. https://doi.org/10.5152/dir.2021.19548.
5. Cazzato RL, De Marini P, Leonard-Lorant I, et al. Safety and oncologic outcomes of magnetic resonance imaging-guided cryoablation of renal cell carcinoma: a 10-year single-center experience. Invest Radiol. 2021;56(3):153–62. https://doi.org/10.1097/RLI.0000000000000719.
6. De Marini P, Cazzato RL, Garnon J, et al. Safety and oncologic efficacy of percutaneous MRI-guided cryoablation of intraparenchymal renal cancers. Diagn Interv Imaging. 2021;102(9):531–8. https://doi.org/10.1016/j.diii.2021.04.002.
7. Silverman SG, Tuncali K, vanSonnenberg E, et al. Renal tumors: MR imaging–guided percutaneous cryotherapy—initial experience in 23 patients. Radiology. 2005;236(2):716–24. https://doi.org/10.1148/radiol.2362041107.
8. Cazzato R, Garnon J, Shaygi B, et al. How to perform a routine cryoablation under MRI guidance. Top Magn Reson Imaging. 2018. https://doi.org/10.1097/RMR.0000000000000158.
9. Bhagavatula SK, Tuncali K, Shyn PB, Levesque VM, Chang SL, Silverman SG. Percutaneous CT- and MRI-guided cryoablation of cT1 renal cell carcinoma: intermediate- to long-term outcomes in 307 patients. Radiology. 2020;296(3):687–95. https://doi.org/10.1148/radiol.2020200149.
10. Hadi M, Walker C, Desborough M, et al. CIRSE standards of practice on peri-operative anticoagulation management during interventional radiology procedures. Cardiovasc Intervent Radiol. 2021;44(4):523–36. https://doi.org/10.1007/s00270-020-02763-4.

11. Kutikov A, Uzzo RG. The RENAL nephrometry score: a comprehensive standardized system for quantitating renal tumor size, location and depth. J Urol. 2009;182(3):844–53. https://doi.org/10.1016/j.juro.2009.05.035.
12. Clavien PA, Barkun J, de Oliveira ML, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg. 2009;250(2):187–96. https://doi.org/10.1097/SLA.0b013e3181b13ca2.
13. Garnon J, Van Strijen MJ, Nielsen TK, et al. Safety of percutaneous renal cryoablation: an international multicentre experience from the EuRECA retrospective percutaneous database. Eur Radiol. 2019;29(11):6293–9. https://doi.org/10.1007/s00330-019-06191-y.
14. Kakarala B, Frangakis CE, Rodriguez R, Georgiades CS. Hemorrhagic complications of percutaneous cryoablation for renal tumors: results from a 7-year prospective study. Cardiovasc Intervent Radiol. 2016;39(11):1604–10. https://doi.org/10.1007/s00270-016-1419-x.
15. Blute ML Jr, Okhunov Z, Moreira DM, et al. Image-guided percutaneous renal cryoablation: preoperative risk factors for recurrence and complications: *RISK FACTORS FOR RECURRENCE AFTER PERCUTANEOUS CRYOABLATION*. BJU Int. 2013;111(4b):E181–5. https://doi.org/10.1111/j.1464-410X.2012.11538.x.
16. Breen DJ, King AJ, Patel N, Lockyer R, Hayes M. Image-guided cryoablation for sporadic renal cell carcinoma: three- and 5-year outcomes in 220 patients with biopsy-proven renal cell carcinoma. Radiology. 2018;289(2):554–61. https://doi.org/10.1148/radiol.2018180249.
17. Okhunov Z, Moreira DM, del Junco M, et al. predictors of complications after percutaneous image-guided renal cryoablation for T1a renal cortical neoplasms. J Endourol. 2017;31(1):7–13. https://doi.org/10.1089/end.2016.0684.
18. Kim EH, Tanagho YS, Bhayani SB, Saad NE, Benway BM, Figenshau RS. Percutaneous cryoablation of renal masses: Washington University experience of treating 129 tumours: Percutaneous cryoablation of renal masses. BJU Int. 2013;111(6):872–9. https://doi.org/10.1111/j.1464-410X.2012.11432.x.
19. Kim EH, Tanagho YS, Saad NE, Bhayani SB, Figenshau RS. Comparison of laparoscopic and percutaneous cryoablation for treatment of renal masses. Urology. 2014;83(5):1081–7. https://doi.org/10.1016/j.urology.2013.10.081.
20. Pickersgill NA, Vetter JM, Kim EH, et al. Ten-year experience with percutaneous cryoablation of renal tumors: tumor size predicts disease progression. J Endourol. 2020;34(12):1211–7. https://doi.org/10.1089/end.2019.0882.