Ryan *et al. CVIR Oncology* (2025) 1:2
https://doi.org/10.1007/s44343-025-00001-7

CVIR Oncology

ORIGINAL RESEARCH

Open Access

Image guided energy-based ablation of T1 renal cell cancer: a ten-year single centre experience

James P. C. Ryan[1], Olwyn E. Lynch[2], Barry B. McGuire[2,3] and Colin P. Cantwell[1,3,4*]

Abstract

Purpose Image-guided energy-based tumour ablation (IGTA) with radiofrequency ablation (RFA), microwave ablation (MWA) and cryotherapy are curative local therapies for T1 renal cell carcinoma (RCC). The aim of this study is to evaluate the oncological outcomes and survival after IGTA of T1 RCC in our unit over a 10-year period.

Methods We retrospectively reviewed all patients with biopsy proven RCC who underwent IGTA of a T1 tumour between 1st March 2013 and 1st June 2023. Data collected included: patient demographics, tumour size and histology, pre and post procedure creatinine, ablation technique, complications, efficacy, disease free survival and overall survival (OS).

Results Fifty IGTAs were performed on 46 RCC (mean diameter 2.6 cm) in 45 patients. Complications occurred in 8% of procedures ($n=4/50$). Median clinical follow- up was 27.5 months (range 3—88). There was no significant change in creatinine due to IGTA. Primary efficacy of ablation was 94% (43/46 tumours). MWA had a lower primary efficacy than RFA (82% (14/17) vs 100% (28/28) respectively, ($p=0.02$)). Larger median RCC diameter was associated with failed primary efficacy in the MWA group (3.8 cm vs 2.4 cm respectively, $p=0.035$). OS was 97.4%, 88.5% and 88.5% at 1, 3 and 5 years respectively. Local tumour progression free survival was 100%, 95.2% and 95.2% at 1, 3 and 5 years respectively. Cancer specific survival at 5 years was 100%.

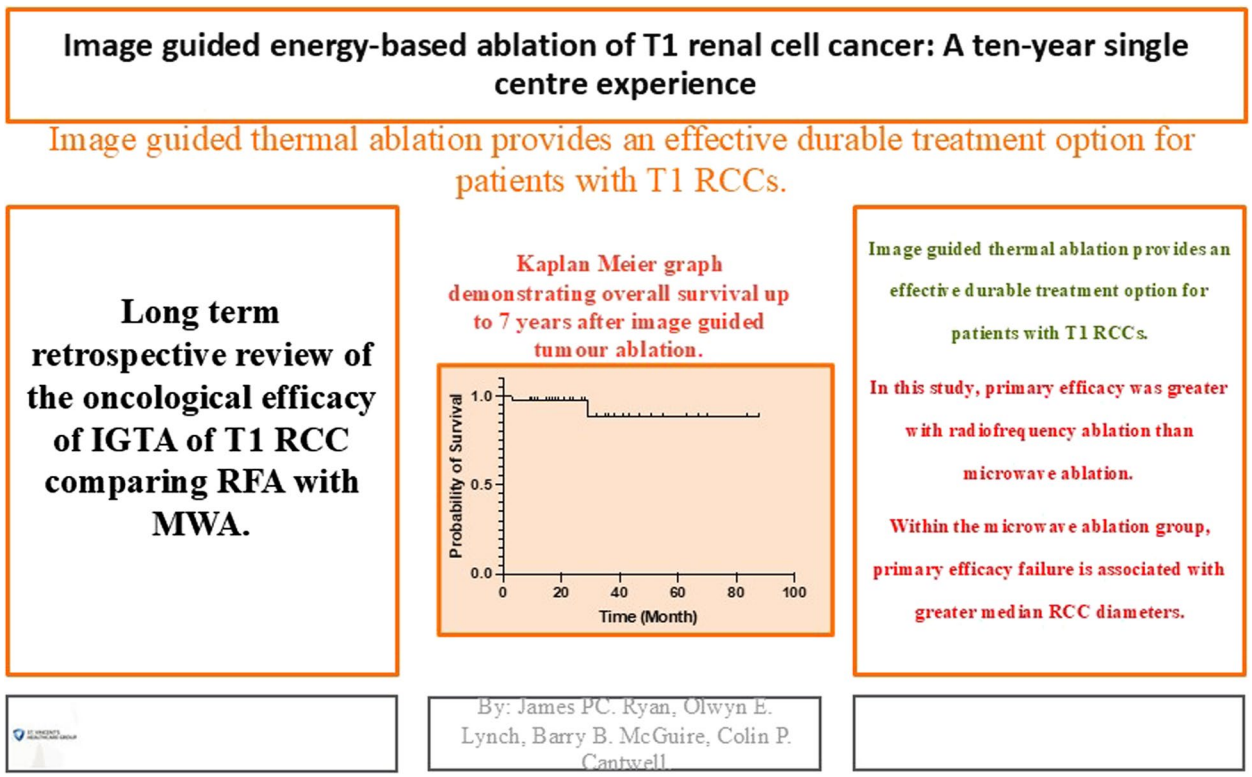
Conclusions IGTA provides an effective durable treatment option for patients with T1 RCCs. Primary efficacy was greater with RFA than MWA, although this may be influenced by the learning of curve for MWA during the study period. Primary efficacy failure in the MWA group is associated with greater median RCC diameters.

Keywords Thermal ablation, Renal cell cancer, Survival analysis, Treatment outcome, Image guided therapy

*Correspondence:
Colin P. Cantwell
cpmcantwell@gmail.com
Full list of author information is available at the end of the article

© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

Graphical Abstract



Introduction

Renal cell carcinoma (RCC) incidence is increasing [1]. This is due to the increased use of CT and MR imaging resulting in the identification of asymptomatic early-stage renal tumours [2, 3]. New techniques have emerged in the last 40 years for treatment of RCC including tumour ablation and surgical technique. Now patients and physicians are considering treatment of smaller RCC due to better treatment options with favorable risk benefit profiles. This has led to a stage shift in the treatment of RCC, from large to small renal masses [3]. Management of T1 RCCs are dependent on several tumour and patient related factors, physician, and patient preference; and include active surveillance, nephron sparing surgery, image-guided tumour ablation (IGTA) and stereotactic radiotherapy [4].

Although IGTA options are often only considered in those too unfit for surgery, the oncological results are excellent, the complication rate extremely low, and it is minimally invasive facilitating rapid patient recovery [3, 5–8]. IGTA procedure volume is increasing, however urology referral for ablation is guarded due to the lack of level 1 evidence for its use [9]. This is reflected in the advice and the guidelines from the European Association of Urologists and American Urological Association [1, 10]. IGTA of T1 RCCs has been carried out for over 20 years, the long-term outcome data available on these patients has been limited to studies with small patient populations, which are generally retrospective and largely non-comparative [1, 5, 9, 11, 12].

The aim of our study was to evaluate oncological outcomes and survival after IGTA of T1 RCCs in our centre over the past 10 years.

Materials and methods

This retrospective single centre study obtained approval from the local ethics committee. Patient consent was not required due to the retrospective nature of this study and anonymisation of data. The Radiology Information System and Patient Archive and Communication System (RISPACS) was used to identify patients who underwent IGTA of RCC between 1st of March 2013 to 1st June 2023. The inclusion criteria were all patients who underwent primary IGTA of biopsy proven T1 RCC. Exclusion criteria were: metastatic RCC at the time of diagnosis, biopsy proven local recurrence in the nephrectomy bed,

incomplete ablation of a RCC due to technical or non-technical reasons, palliative treatment of RCC where the goal of treatment is to control symptoms such as haematuria. Figure 1, shows the total number of procedures reviewed with the inclusion and exclusion applied. One case was excluded for technical reasons as despite multiple attempts using hydro dissection to separate the large bowel which was closely related to the RCC, it was not possible to create enough space to allow safe thermal ablation of the lesion. One patient 8 years post IGTA developed an RCC in the contralateral kidney which was successfully treated with IGTA.

A data extraction form (Microsoft Excel, Microsoft) was developed in a pilot study to collect study data. The patient's electronic health record and radiology record were reviewed to record: patient demographics, Charlson Comorbidity Index Score, tumour histology, tumour diameter, pre-ablation and one month post-ablation blood serum creatinine level, IGTA technique, technical success, complications, length of stay, readmission and treatment for complication, primary efficacy, secondary efficacy, imaging and clinical follow up intervals, date of last clinical or imaging follow up, date of identification of local tumour recurrence, date of identification of metastatic disease, date of death and cause of death [13]. Complications were classified according to the Society of Interventional Radiology Adverse Event Classification System [14].

Ablation protocol

Patients were referred by the urology service for ablation after discussion at the urology multidisciplinary team meeting. The panel consisted of at least two urologists, one interventional radiologist and their supporting teams. All patients had either image-guided percutaneous radiofrequency, microwave or cryoablation depending on operator choice. If the RCC was within 1.5 cm of the ureter cryoablation was selected. All procedures apart from one case were performed under general anaesthesia with computed tomography (CT) and ultrasound (US) planning and targeting by one of three fellowship trained interventional radiologists with 5–8 years experiences in IGTA of renal and hepatic masses.

IGTA was performed with curative intent. IGTA was planned to observe a circumferential 0.5 cm margin of treatment surrounding the tumour.

Radiofrequency ablation was performed with an internally cooled 17-gauge cluster electrode (70 ml/min 4C saline) with a 2.5 cm active tip (Medtronic) and 12-min impedance control ablation program. The number of probe placements depended on the tumour size.

Microwave ablation was performed with an internally cooled 14-gauge antenna (2450 MHz, HS Amica generator, Amica V4 antenna). The type of microwave program used depended on tumour size measured on the CT performed before ablation, power (40 or 60 or 100W) and exposure time (5, 10 or 15 min) were adapted in accordance with the theoretical ablation dimensions as specified by the manufacturer.

Cryotherapy was performed with a 14-gauge cryoprobe (Galil) and two freeze thaw cycles with two applicators placed 1 cm apart from each other and 1 cm from the tumour treatment margin. Intraprocedural treatment monitoring and modification was only performed only for cryotherapy.

Assessment of immediate response was not performed. Ancillary procedures were performed in 8% including hydrodissection.

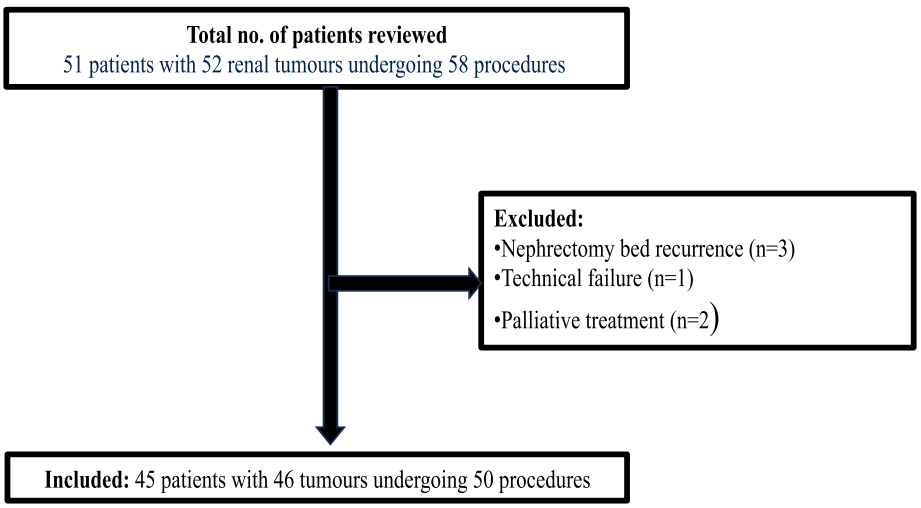


Fig. 1 Flowchart of patient selection with inclusion criteria applied

Imaging follow-up

Imaging follow-up was performed with multiphasic renal CT or contrast-enhanced MRI at 3, 6, 9 and 12 months and then annually. This protocol was followed within the confines of the limitation of radiological resources.

Peri-operative and oncologic outcomes are defined below as per the recommendations by Ahmed et al. [15]:

Technical success – Satisfactory completion of the treatment protocol as per the radiologist performing the procedure. This refers to the consultants perception of the success of the treatment protocol in treating the RCC at the time of the procedure.
Primary efficacy – Successful eradication of the tumour on initial CT or MRI after the initial procedure.
Secondary efficacy - Successful eradication of the tumour on initial CT or MRI after the second procedure.
Residual unablated tumour - Residual tumour enhancement on initial follow up imaging.
Local tumour progression free survival (LTPFS) - The proportion of patients who at a specified time point after primary ablation survived without local tumour progression after the initial follow up imaging documented adequate ablation.
Complications - Any unexpected departure from an expected postprocedural course.
Cancer specific survival (CSS) - The proportion of patients who at specified time point after primary ablation did not die of RCC (reported on a procedure basis).
Overall survival (OS) - The proportion of patients who at a specified time point after primary ablation did not die of any cause.

Statistical analysis

All analysis was completed using Statistical Package for the Social Sciences, version 29 (SPSS v29). Categorical variables are reported as proportions and quantitative variables are reported by their mean and range. Baseline categorical variables were compared using a Pearson's Chi square test for independent samples; one-way analysis of variance was used to compare continuous variables. A Wilcoxon Signed Rank test was used to compare pre and post procedure creatinine. A P value of < 0.05 was considered significant.

Results

Patient demographics and tumour characteristics are summarized in Table 1. The IGTA technique, length of stay and complications are categorized in Table 2.

Table 1 Patient and tumour characteristics

Patient characteristics	Mean (range) or proportion (%)
Age (years)	70.1 (45–85)
Gender	
Male	34 (74)
Female	12 (26)
Charlson comorbidity index score	5.4 (2–10)
Mean renal tumour Size	2.6 cm (1.5—5.2 cm)
Radiological stage	
T1a	42 (91.3)
T1b	4 (8.7)
Renal cell cancer subtype	
Clear cell low grade	25 (54.3)
Clear cell high grade	2 (4.3)
Chromophobe	10 (21.7)
Papillary	5 (10.8)
Unclassified	3 (6.5)
Oncocytic RCC	1 (2.2)

Note: One patient underwent treatment for 2 separate RCC 8 years apart

Table 2 Image-guided energy based thermal ablation technique used and peri-procedural outcomes

	Median (range) or number of cases (%)
Ablation technique	
Radiofrequency	28 (60.8)
Microwave	17 (36.9)
Cryoablation	1 (2.2)
Complication rate per procedure ($n = 50$)[a]	4 (8)
A	0
B	0
C	2 (4)
D	2 (4)
E	0
F	0
Length of stay (days)	1 (0–13)
Technical success	50 (100)
Primary efficacy	43/46 (94)
Secondary efficacy	45/46 (98)

[a] Complications classified according to the Society of Interventional Radiology Adverse Event Classification System

Primary technical success was achieved in 100% of procedures ($n = 46/46$). Primary efficacy was achieved in 94% (43/46 tumours). Three patients (Patient A, B, C) had residual disease; two of the three patients (Patient A and B) had a successful second ablative procedure. Patient A had a 2.8 cm endophytic lesion in the interpolar region

of the left kidney, abutting the collecting system. This was initially treated with MWA at 100 watts for 5 min. Patient B had 3 cm endophytic lesion abutting the collecting system in the interpolar region of the left kidney. This was initially treated with MWA at 100 watts for 10 min. The second ablation procedures were performed between 11 and 20 months post the first ablation procedure. Patient C had a 4.8 cm RCC which required a third ablation which was performed at 25 months post the first ablative procedure. Residual disease was seen on subsequent follow up imaging and the patient developed pulmonary metastases and was palliated. Follow up ablative procedures were performed at the above times, due to issues with access to CT and the patient's significant co morbidities.

Median length of stay was one day (range 0–13 days).

Complications occurred after 8% of ablation procedures (4/50). Complications were classified according to the Society of Interventional Radiology Adverse Event Classification System (Table 2) [14]. The four patients with complications had radiofrequency ablation as their treatment modality and all were considered major complications. One patient had an intra-procedure pneumothorax that required a chest drain insertion. The second patient had an intra-procedure haemothorax requiring a chest drain, resulting in a prolonged inpatient stay (13 days). This was identified at the end of the procedure and a drain placed at that time. The third patient developed a perinephric collection at 3 months post ablation that resulted in ipsilateral mild hydronephrosis treated with image-guided collection drainage and antibiotic treatment as an inpatient. One patient developed acute urinary retention post procedure likely because of general anaesthesia resulting in insertion of a urinary catheter and subsequent successful trial without catheter 48 h later. The patient did not develop haematuria post procedure.

There was no statistically significant difference in mean pre-procedure blood serum creatinine and creatinine one-month post-procedure ($p=0.37$).

Clinical follow-up

Median follow up was 27.5 months (range 3—88 months). Three patients died during the follow up period from causes unrelated to RCC: COVID-19 pneumonitis, cerebrovascular accident and decompensated liver disease at 4, 29 and 31 months respectively. Follow up to 5 years was achieved in 6 patients. OS was 100%, 95.2% and 95.2% at 1 year, 3 and 5 years respectively (Fig. 2). CSS was 100% at 5 years.

LTPFS was 100%, 95.2% and 95.2% at 1 year, 3 and 5 years respectively (Fig. 3). Local tumour progression was identified in one patient at 28 months. His initially imaging and biopsy demonstrated a 5 cm high grade clear cell RCC. This patient developed local recurrence and chest metastasis at 28 months follow up. He was subsequently referred to medical oncology for consideration of chemotherapy.

Cryotherapy was used in a single case in our institution. In this case, length of stay was 1 day and at 48 months follow up, there was no evidence of local or distant recurrence.

Comparison of energy-based ablation techniques

Table 3 compares patient demographics, tumour size and periprocedural outcomes between RFA and MWA groups. Primary efficacy was greater in the RFA group compared to the MWA group, [100% ($n=28/28$) v 82.4% ($n=14/17$), $p=0.02$]. There was no statistically significant difference in tumour size or pathology, complication rate or length of stay between the MWA and RFA groups. Larger mean RCC diameter was associated with failed primary efficacy in the MWA group ($n=17$) [3.8 cm (2.8—5 cm) vs 2.4 cm

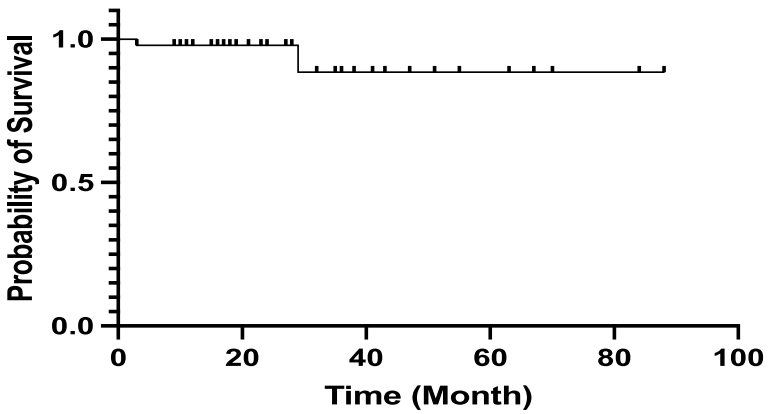


Fig. 2 Kaplan Meier graph demonstrating overall survival up to 7 years after image guided tumour ablation

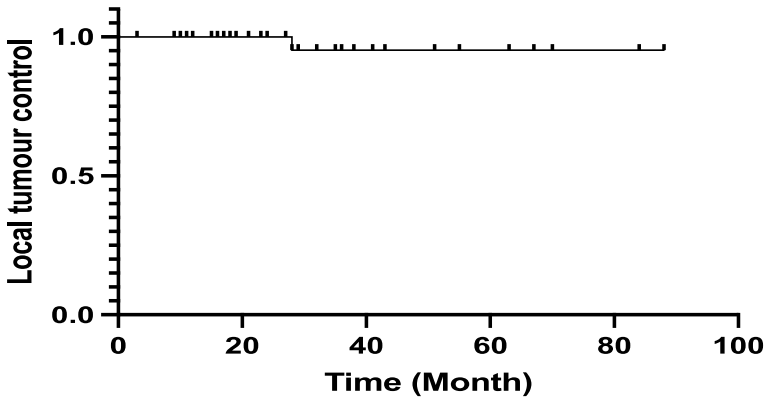


Fig. 3 Kaplan Meier graph demonstrating local tumour control up to 7 years after image guided tumour ablation

Table 3 A comparison of microwave ablation (MWA) and radiofrequency ablation (RFA) group demographics, tumour characteristics and peri-procedural outcomes

	RFA	MWA	*P* value
Number of tumours	28	17	
Number of patients	27	17	
Mean patient age (years)	73.5	65	*P* = 0.019
Male sex (percentage)	21 (75)	13 (76.5)	
Charlson comorbidity index score	5.4	6	*P* = 0.9
Mean tumour diameter in centimetres (range)	2.4 (1.5—5.2)	2.7 (1.6 – 4.8)	*P* = 0.9
Radiological stage			
T1a	27 (96.4%)	14 (82.4%)	*P* = 0.25
T1b	1 (3.5%)	3 (17.6%)	
Tumour subtype			
Clear cell	13 (46.4%)	13 (76.5%)	*P* = 0.5
Chromophobe	8 (28.5%)	2 (11.8%)	
Papillary	4 (14.3%)	1 (5.9%)	
Oncocytic	1 (3.6%)	0 (0%)	
Undifferentiated	2 (6.9%)	1 (5.9%)	
Complication number (rate)	4 (14%)	0 (0%)	*P* = 0.37
Length of stay (days)	2.1 (0–13)	0.93 (0–1)	*P* = 0.6
Technical success (rate)	28 (100%)	17 (100%)	
Primary efficacy (rate)	28 (100%)	14 (88.2%)	*P* = 0.02
Overall efficacy [≥ 1 treatment] (rate)	28 (100%)	16 (94.1%)	*P* = 0.19

Note: One patient underwent cryotherapy which is not included in the comparative analysis

(1.7 – 4.8 cm), $p=0.035$]. Of note, only 3 out of the 17 patients who underwent MVA failed primary efficacy.

Discussion

IGTA is an effective treatment for RCC. The primary efficacy is 94% (43/46) in our series. The primary efficacy is like other published series with rates greater than 90% [2, 3, 5–7].

There are limited studies comparing the outcomes of different ablative techniques in RCC [16]. In this study we compared our primary efficacy outcome in RFA and MWA groups. Our patients experienced a significantly higher primary efficacy with RFA when compared to MWA {100% vs 88% respectively ($p=0.02$)}. There was no statistically significant difference in tumour characteristics or patient demographic between the RFA and MWA group. This result is contrary to a meta-analysis of pooled outcomes of 508 MWA and 1750 RFA/cryo-ablation of RCC that concluded that the primary efficacy between

the two groups were not significantly different [17]. Aarts et al. also found no significant difference between the primary efficacy of RFA and MWA for the treatment of T1a RCC {92% (80/87) v 91% (92/101) respectively} [18].

There is an inverse relationship between increasing RCC diameter and primary efficacy of IGTA. In our cohort, primary efficacy in the MWA group was significantly lower with greater mean RCC diameters (3.8 cm vs 2.4 cm respectively, $p=0.045$). This result is in a small subset of patients ($n=17$) with only 3 patients not achieving local control on their first treatment, however it is in keeping with current literature. Lam et al. reported that increasing tumour size in a T1a RCC cohort was a predictor of primary efficacy failure (HR 2.256; 95% CI = 1.46–3.51; $p<0.001$) [11]. Wah et al. found that tumour size (< 3 cm) was a significant indicator of primary efficacy success ($p<0.001$) [5]. Similarly, when comparing different stages of RCC, Psutka et al. found a statistically significant difference in residual tumour rates between RFA of T1a and T1b tumours {5.6% v 19.1% ($p=0.0085$)} [19].

We commenced using MWA for IGTA of RCC as an alternative to RFA and cryoablation in our institution in 2018. MWA was presented by manufacturers as an ablative technology that was less susceptible to heat sink effect when used in the thermal ablation of liver tumours, could deliver more energy in a shorter period of time, and hence treat a larger renal tumour in a shorter period of time with a single microwave antenna [20].

Prior to the introduction of MWA, radiologists used RFA and cryoablation to treat T1 RCC. They were familiar with the shape and diameters of ablation zones produced by each system. Like with the introduction of any new technology, there is a learning curve for operators using MWA. At the time of introduction of MWA, manufacturers lacked in-vivo treatment charts for the operator to plan therapy in the kidney. The radiologist relied on treatment charts performed on ex-vivo animal liver. The MWA antenna produces a non-spherical ablation zone different to RFA and cryoablation. The distal margin of treatment is proximal to the antenna tip in MWA and extends beyond the electrode tip in RFA and cryoablation [20]. These factors may have impacted the primary efficacy of our MWA group.

Patient factors influence IGTA primary efficacy. Patients referred for IGTA in our cohort had multiple comorbidities which influenced the type of anaesthesia and the doses of conscious sedation. One patient in our study illustrates this phenomenon. The patient had a stage T1b RCC (4.8 cm in diameter), was medically unsuitable for general anaesthesia and IGTA was performed with conscious sedation with poor analgesic effect. The poor efficacy of sedation made ablation challenging and ultimately this treatment failed.

Studies of ablation and surgery for RCC are all affected by selection bias as surgical pathway favour surgery and guidelines such as the European Association of Urology recommend partial nephrectomy (PN) as first line treatment for the management of T1 RCC [1]. Therefore, IGTA is often reserved for frail, co-morbid or elderly patients unfit for surgery. Thompson et al. also retrospectively compared groups 1057 partial nephrectomies, 180 RFA and 187 cryoablation of T1 RCC. They found that the patients in the partial nephrectomy group were younger ($p<0.001$) and had a lower Charlston co-morbidity Index score ($p<0.001$) than the other two groups [21]. The mean age in our cohort was 70 years (range 45–85 years) and the average Charlston comorbidity index score was 5.5 corresponding to approximately 21% 10-year survival. This highlights the relatively frail group of patients that are currently being treated with IGTA. Similar population demographics have been reported by other institutions. Psutka et al. who evaluated long term outcomes of 185 patients after RFA of T1 RCC, had a median age of 74 in their cohort [19]. Zagoria et al. had similar patient demographics in their series of 41 patients undergoing RFA, with a median age of 72 [12].

Representative surgical and oncology societies criticize IGTA of RCC in guidelines due to a lack of medium- and long-term outcome data [1, 10]. Herein, we present 5-year survival statistics and Kaplan Meier charts to 7 years. 5-year OS, local tumour progression free survival and CSS of 89%, 95% and 100% respectively in this cohort are comparable to other studies [5–7]. Lorber et al. in their cohort of only pT1a RCC treated with thermal ablation had a 5-year OS of 98% [7]. Wah et al. found OS and CSS at 5 years to be 75.8% and 97.9% respectively [5]. Marshal et al. found that CSS and local tumour progression free survival at 5 years to be 92% and 92% respectively [6]. Lorber et al. in their cohort of pT1a RCC treated with thermal ablation had a 5-year CSS of 100% [7].

Our complication rate of 8% is similar to that in the literature. A systematic review by Castellana et al. included 2258 thermal ablations, suggests an overall complication rate of 16% and major complication rate of 3% [17].

This study has limitations. This is a small, single center retrospective observational single-arm study. There was selection bias of the modality used to treat RCC in our hospital as outlined earlier in the discussion.

In conclusion, IGTA provides an effective durable treatment option for patients with T1 RCCs. Primary efficacy was greater with RFA than MWA, although this may be influenced by the learning of curve for MWA during the study period. Primary efficacy failure in the MWA group is associated with greater median RCC diameters.

Acknowledgements
None.

Authors' contributions
James PC Ryan: Conceptualization, Investigation, Software, Validation, Formal analysis, Data Curation, Writing—Original Draft, Visualization. Olwyn E Lynch: Investigation, Validation, Data Curation, Writing—Original Draft, Visualization. Barry B McGuire: Conceptualization, Writing—Review & Editing, Supervision. Colin P Cantwell: Methodology, Writing—Review & Editing, Supervision, Project administration.

Funding
No grant funding or other financial support was received by any author during the creation of the work.

Data availability
Data will be made available on request.

Declarations

Ethics approval and consent to participate
Ethics approval was received from the institutional Research Board and consent to participate was achieved at patient counselling before the procedure.

Consent for publication
All participants have given consent for publication.

Competing interests
The authors declare no conflict of interest or competing interest.

Author details
[1]Department of Radiology, St. Vincent'S University Hospital, Elm Park, Dublin 4 D04 T6F4, Ireland. [2]Department of Urology, St. Vincent'S University Hospital, Dublin, Ireland. [3]Royal College of Surgeons of Ireland, Dublin, Ireland. [4]University College Dublin, Dublin, Ireland.

Received: 4 February 2025 Accepted: 4 March 2025
Published online: 08 April 2025

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;82:399–410.
2. Katsanos K, Mailli L, Krokidis M, et al. Systematic review and meta-analysis of thermal ablation versus surgical nephrectomy for small renal tumours. Cardiovasc Intervent Radiol. 2014;37:427–37.
3. Park BK, Gong IH, Kang MY, et al. RFA versus robotic partial nephrectomy for T1a renal cell carcinoma: a propensity score-matched comparison of mid-term outcome. Eur Radiol. 2018;28:2979–85.
4. Rühle A, Andratschke N, Siva S, et al. Is there a role for stereotactic radiotherapy in the treatment of renal cell carcinoma? Clin Transl Radiat Oncol. 2019;18:104–12.
5. Wah TM, Irving HC, Gregory W, et al. Radiofrequency ablation (RFA) of renal cell carcinoma (RCC): experience in 200 tumours. BJU Int. 2014;113:416–28.
6. Marshall HR, Shakeri S, Hosseiny M, et al. Long-Term Survival after Percutaneous Radiofrequency Ablation of Pathologically Proven Renal Cell Carcinoma in 100 Patients. J Vasc Interv Radiol. 2020;31:15–24.
7. Lorber G, Glamore M, Doshi M, et al. Long-term oncologic outcomes following radiofrequency ablation with real-time temperature monitoring for T1a renal cell cancer. Urol Oncol. 2014;32:1017–23.
8. Zhou W, Herwald SE, McCarthy C, et al. Radiofrequency ablation, cryoablation, and microwave ablation for T1a renal cell carcinoma: a comparative evaluation of therapeutic and renal function outcomes. J Vasc Interv Radiol. 2019;30:1035–42.
9. Abu-Ghanem Y, Fernández-Pello S, Bex A, et al. Limitations of available studies prevent reliable comparison between tumour ablation and partial nephrectomy for patients with localised renal masses: a systematic review from the European Association of Urology Renal Cell Cancer Guideline Panel. Eur Urol Oncol. 2020;3:433–52.
10. Campbell SC, Clark PE, Chang SS, et al. Renal mass and localized renal cancer: evaluation, management, and follow-up: AUA Guideline: Part I. J Urol. 2021;206:199–208.
11. Lam CJ, Wong NC, Mauricevoss, et al. CUAJ-Original Research Lam et al Surveillance post-radiofrequency ablation for small renal masses Surveillance post-radiofrequency ablation for small renal masses: Recurrence and followup. Epub ahead of print 2020. https://doi.org/10.5489/cuaj.6374.
12. Zagoria RJ, Pettus JA, Rogers M, et al. Long-term outcomes after percutaneous radiofrequency ablation for renal cell carcinoma. Urology. 2011;77:1393–7.
13. Charlson ME, Pompei P, Ales KL, et al. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis. 1987;40:373–83.
14. Khalilzadeh O, Baerlocher MO, Shyn PB, et al. Proposal of a New Adverse Event Classification by the Society of Interventional Radiology Standards of Practice Committee. J Vasc Interv Radiol. 2017;28:1432-1437.e3.
15. Ahmed M, Solbiati L, Brace CL, et al. Image-guided tumor ablation: standardization of terminology and reporting criteria–a 10-year update. J Vasc Interv Radiol. 2014;25:1691-1705.e4.
16. Aarts BM, Gomez FM, Lopez-Yurda M, et al. Safety and efficacy of RFA versus MWA for T1a renal cell carcinoma: a propensity score analysis. Eur Radiol. 2022;33:1040.
17. Castellana R, Natrella M, Fanelli G, et al. Efficacy and safety of MWA versus RFA and CA for renal tumors: a systematic review and meta-analysis of comparison studies. Eur J Radiol. 2023;165. Epub ahead of print. https://doi.org/10.1016/J.EJRAD.2023.110943.
18. Aarts BM, Gomez FM, Lopez-Yurda M, et al. Safety and efficacy of RFA versus MWA for T1a renal cell carcinoma: a propensity score analysis. Eur Radiol. 2023;33:1040–9.
19. Psutka SP, Feldman AS, McDougal WS, et al. Long-term oncologic outcomes after radiofrequency ablation for T1 renal cell carcinoma. Eur Urol. 2013;63:486–92.
20. Hoffmann R, Rempp H. Clasen S [Microwave tumor ablation. New devices, new applications?]. Radiologe. 2012;52:22–8.
21. Thompson RH, Atwell T, Schmit G, et al. Comparison of partial nephrectomy and percutaneous ablation for cT1 renal masses. Eur Urol. 2015;67:252–9.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.