ORIGINAL PAPER

sABLATE: a simplified ABLATE score for prediction of complications and outcome in percutaneous thermal ablation of renal lesions

Maurizio Papa1 · Pierpaolo Biondetti2 · Roberta Colombo2 · Anna Maria Ierardi2 · Salvatore Alessio Angileri2 · Gianpaolo Lucignani3 · Luca Boeri3 · Emanuele Montanari3 · Gianpiero Cardone4 · Paola Scagnelli1 · Gianpaolo Carrafiello2

Received: 22 April 2021 / Accepted: 23 May 2021 / Published online: 8 September 2021
© Springer Science+Business Media, LLC, part of Springer Nature 2021

Abstract
The aim of the study is to evaluate the performance of a simplified ABLATE score (sABLATE) in predicting complications and outcome with respect to RENAL, mRENAL, and ABLATE scores. This study included 136 renal lesions in 113 patients (M:F ratio = 2.5; mean age 70.8 years). 98 tumors underwent cryoablation at San Raffaele hospital between 01/2015 and 03/2020, while 37 underwent microwave ablation at San Paolo or Policlinico hospitals between 07/2016 and 03/2020. RENAL, mRENAL, ABLATE, and sABLATE scores were calculated using pre-procedural imaging. Data regarding complications and follow-up were registered. Mann–Whitney U test, ROC analyses, and logistic regression analyses were used for complications. Cox-regression analyses were performed for outcome. Mean tumor diameter was 23.2 mm. Mean and median RENAL, mRENAL, ABLATE, and sABLATE scores were 6.8 and 7, 6.9 and 7, 5.3, and 5, and 3.5 and 3, respectively. During a mean follow-up of 21.9 months (range 1–73), we registered 7 complications, 3 cases of residual disease, and 10 local tumor progressions. Mann–Whitney U test p values for complications for RENAL, mRENAL, ABLATE, and sABLATE were 0.51, 0.49, 0.66, and 0.056, respectively. ROC analyses for complications showed an AUC for RENAL, mRENAL, ABLATE, and sABLATE of 0.57, 0.57, 0.55, and 0.71, respectively. Regarding outcome, HR and p values of Cox-regression analyses were 1.30 and 0.36 for RENAL, 1.33 and 0.35 for mRENAL, 2.16 and 0.01 for ABLATE, 2.29 and 0.004 for sABLATE. sABLATE was the only score close to significance for complications, representing a progress even if not definitive. Regarding outcome, ABLATE confirmed its value, and sABLATE maintained validity despite being a simplification.

Keywords Ablation · Cryoablation · Microwave ablation · Renal cell carcinoma · Interventional oncology · Nephrometry

Introduction

The incidence of small renal masses has increased in recent decades [1]. A large proportion of these masses is represented by tumors and renal cell carcinoma (RCC) in particular, which has an annual incidence rate of 0.015% in men and of 0.007% in women in the USA [2].

The standard of care for clinical T1 RCC remains nephron-sparing partial nephrectomy, but the use of percutaneous thermal ablation, a widely diffused treatment modality in interventional oncology, has expanded [3]. The efficacy of percutaneous thermal ablation in this setting has already been demonstrated by numerous studies [4–6]. Its reported benefits include preservation of renal function, acceptable morbidity with few high-grade complications, and shorter in-hospital stay and recovery time when compared to partial nephrectomy [7, 8]. In terms of outcome, despite higher
rates of local recurrence, comparable rates of metastatic-free and disease-specific survival have been described for ablation in comparison to surgery [9–11]. Therefore, thermal ablation is currently included in major guidelines and it’s considered for selected patients as a less invasive alternative to surgery [12–14].

With the increasing use of thermal ablation in renal lesions, scores for predicting complications and outcome, in order to ultimately improve patient selection, are of interest. The RENAL nephrometry score [15], of surgical derivation, is one of the most widely used and standardized methods to assess complexity of renal masses, is based on anatomical tumor features assessed with cross-sectional imaging, and has been applied to percutaneous thermal ablation with conflicting results. An association between the score and complications or outcome has been reported by some studies [16–19], but not confirmed by others [20, 21]. Therefore, a modified RENAL score (mRENAL) was introduced briefly after, and had better prognostic value for outcome after radiofrequency ablation, but it differs from the original by only one parameter [22]. Recently, a new score was conceived by interventional radiologists, as challenges faced in percutaneous thermal ablation of renal lesions are different from those encountered by surgeons during partial nephrectomy. ABLATE score resulted better than RENAL and mRENAL in predicting relapses, but its evaluation was performed in a monocentric setting, using a single ablation technique (cryoablation); moreover, given its complexity, it may result of difficult use in everyday clinical setting.

This study aims to evaluate the performance of a simplified and more objective version of the ABLATE score (sABLATE) in predicting complications and outcome in patients with renal lesions treated with percutaneous thermal ablation when compared to RENAL, mRENAL, and ABLATE score, in a larger number of patients, with different thermal ablation techniques and in a multicentric setting.

Materials and methods

Population

The institutional review boards, with waiver of informed consent, approved this retrospective observational multicentric study.

We included all patients with renal lesions treated with image-guided percutaneous thermal ablation in San Raffaele-Turro Hospital, Milan, from 01/2015 to 03/2020, and in either San Paolo Hospital or Policlinico Maggiore Hospital, Milan, from 07/2016 to 03/2020. Some of the subjects treated in San Raffaele-Turro Hospital have been previously reported [23].

Data collection and scores

Electronical medical records were retrospectively reviewed to assess patient demographics, tumor histology, and procedural details. Patient for whom adequate clinical data could not be reviewed and those treated for angiomyolipoma were excluded, as treatment intent in the latter case was cytoreductive and not eradicative.

For each patient, two radiologists reviewed pre-procedural cross-sectional imaging (contrast enhanced CT or MR) and calculated each of the following scores: RENAL, mRENAL, ABLATE, and sABLATE. Any disagreement was resolved by consensus review. Patients whose pre-procedural imaging could not be reviewed were excluded.

The RENAL nephrometry score assigns different points on the basis of the following anatomical tumor characteristics: maximum diameter (< 4 cm, 4–7 cm, > 7 cm), exophytic component (> 50%, < 50%, entirely endophytic), nearness to collecting system (< 4 mm, 4–7 mm, > 7 mm), and location (above/below polar line, crossing polar line, predominantly within or between polar lines) [15].

The mRENAL score differs from RENAL only by one parameter, as it utilizes different cut-off values for size (< 3 cm, 3–4 cm, > 4 cm) [22].

The ABLATE score is calculated on the basis of the following tumor features and procedural planning details: “axial dimension” (< 1 cm, 1–1.9 cm, 2–2.9 cm, 3–3.9 cm, 4–4.9 cm, 5–5.9 cm, 6–6.9 cm, > 7 cm), “bowel proximity” (< 5 mm, 5–15 mm, > 15 mm), “location/route” (medial, upper pole, anterior ± bowel interposition, route through lung, others), “angle of probe(s)” (axial plane parallel or perpendicular to bed, antero-posterior angle, cranio-caudal angle, both angles, > 1 probe with different angles), “touching” (tumor < 5 mm from ureter or pelvis, or touching renal sinus fat, collecting system, diaphragm, adrenal, renal vessels, spleen), “extra” (relapse tumor, lesion surrounded by cysts) [23].

ABLATE and sABLATE score criteria are reported in Table 1. The sABLATE score has no “bowel proximity” or “angle of probe(s)” components, maintains the same classes as ABLATE for the parameters “axial dimension” and “extra”, and presents modifications for “location/route” (lesion allowing direct approach, transhepatic route, abdominal wall proximity requiring hydro/pneumo-dissection, parenchymal organ or bowel or vessel proximity requiring hydro/pneumo-dissection, route through normal renal parenchyma < 1 cm or ≥ 1 cm, or route through lung) and “touching” (lesion contacting ureter, renal sinus fat, collecting system).

Changes in sABLATE were intended to simplify the score and make it more objective and reproducible. In particular, “angle of probe(s)” was eliminated as it was
operator-dependent rather than tumor-dependent, thus more variable.

**Pre-procedural evaluation and procedure**

Each patient was evaluated through history, physical examination, relevant laboratory exams, and a pre-procedural contrast-enhanced CT and/or MR which was used to evaluate tumor anatomic features and relationships. The decision to treat each patient with percutaneous thermal ablation was taken in a multidisciplinary setting where interventional radiologists were involved.

A pre-procedural or intra-procedural biopsy before ablation was performed with the following exceptions: when the patient had a history of ipsilateral and/or contralateral renal lesion with the same imaging features and of known

| Variable | Classes | Points | Variable | Classes | Points |
|----------|---------|--------|----------|---------|--------|
| A Axial dimension | < 1 cm | 0 | A Axial dimension | < 1 cm | 0 |
| | 1–1.9 cm | 1 | | 1–1.9 cm | 1 |
| | 2–2.9 cm | 2 | | 2–2.9 cm | 2 |
| | 3–3.9 cm | 3 | | 3–3.9 cm | 3 |
| | 4–4.9 cm | 4 | | 4–4.9 cm | 4 |
| | 5–5.9 cm | 5 | | 5–5.9 cm | 5 |
| | 6–6.9 cm | 6 | | 6–6.9 cm | 6 |
| | ≥ 7 cm | 7 | | ≥ 7 cm | 7 |
| B Bowel proximity | > 15 mm | 0 | L Location/route | Direct route | 0 |
| | 5–15 mm | 1 | | Route through liver | 1 |
| | < 5 mm | 3 | | Hydro/Pneumo-dissection for abdominal wall proximity | 1 |
| L Location/route | Route through liver | 1 | Hydro/Pneumo-dissection for parenchymal organ, bowel or vessel proximity | 3 |
| | Anterior without bowel interposition | 1 | Route through normal renal parenchyma (< 1 cm) | 3 |
| | Upper pole | 1.5 | Route through normal renal parenchyma (≥ 1 cm) | 5 |
| | Medial | 2 | Route through lung | 8 |
| | Anterior with bowel interposition | 3 | Touching Collecting system | 1 |
| | Any other | 0 | Renal sinus fat | 3 |
| A Angle of probe(s) | Axial route, parallel or perpendicular to bed | 0 | T Touching | Ureter | 5 |
| | AP angle | 0.5 | E Extra | Surrounded by cysts | 1 |
| | CC angle | 1 | | Recurrent lesion | 3 |
| | AP and CC angles | 2 | | | |
| | Every additional needle with different approach | 0.5 | | | |
| T Touching | Abdominal wall | 1 | | | |
| | Spleen | 1 | | | |
| | Diaphragm | 1.5 | | | |
| | Adrenal walls | 1.5 | | | |
| | Collecting system | 1.5 | | | |
| | Renal sinus fat | 2 | | | |
| | IVC, renal artery or vein | 2 | | | |
| | < 5 mm from ureter or pelvis | 3 | | | |
| E Extra | Surrounded by cysts | 1 | | | |
| | Recurrent lesion | 2 | | | |

_AP_ antero-posterior; _CC_ cranio-caudal; _IVC_ inferior vena cava
histology, as high pathologic correlation has been demonstrated for initial and recurrent masses [24]; when the ablation procedure was judged complex for technical and/or patient-related factors, and performing a biopsy could have compromised the entire procedure (i.e., when a biopsy-derived hemorrhage could have limited a correct visualization of the target lesion, or when a patient could tolerate to be lying still only a very limited amount of time due to his/her clinical conditions).

Each patient had international normalized ratio within normal limits per institutional criteria and platelet count of >50,000/μl on the day of the procedure.

Each procedure was performed under deep conscious sedation. A single prophylactic dose of intravenous antibiotics was administered in each case according to the routine standards of each institution.

Depending on the institution availability and operator preference, ablations were performed either with cryoablation (Visual ICETM Cryoablation System—Boston Scientific) or microwave ablation (EmprinTM Microwave Ablation System—Covidien). For cryoablation, 1 to 4 cryoprobes were used, depending on each case (IceSeedTM, IceSphereTM or IceRodTM—Boston Scientific), with eventual repositioning for 1 or more probes to cover large lesions. Microwave ablation was always performed with 1 antenna, with eventual repositioning to cover large lesions. Antenna type, ablation power, and ablation time were chosen on the basis of vendor specifications.

Depending on operator preference and institution availability, ultrasound (either Arietta V70—Hitachi Aloka Medical, or EPIQ 5—Philips Medical Systems), CT (either LightSpeed VCT-64—GE Medical Systems, or Brilliance-64—Philips Medical System), or cone-beam CT (CBCT, either Innova-4100—GE Healthcare, or Allura Clarity Xper FD20—Philips Healthcare) were used as imaging guidance.

None of the patients received concomitant agents, combination therapies, or concurrent therapies.

Complications and outcome

Complications occurring within hospital stay or the first month post procedure were registered according to the Clavien-Dindo classification [25].

Follow-up imaging was performed generally with contrast-enhanced CT or MR at 1 month, 6 months, 12 months post procedure, and yearly thereafter; variations applied in single cases were judged necessarily from health providers. Follow-up time for each patient was intended as the time between intervention and the last imaging study available. Two radiologists evaluated follow-up scans to assess for outcome, and literature criteria were used to define treatment success [26]. In particular, residual disease corresponded to the persistence of vital tissue at the margins of the ablation volume at the first follow-up scan, while local tumor progression was defined as the appearance of tumoral tissue within the ablation zone after at least one contrast-enhanced follow-up study demonstrating absence of viable tissue within the target tumor and surrounding ablation margin.

Statistics

The performance of sABLATE score in predicting complications and outcome in our population was compared to those of RENAL, mRENAL, and ABLATE.

The difference between the mean values of patients with and without complications, for each of the 4 scores, was evaluated with Mann–Whitney U test. Receiver operating characteristic (ROC) analyses were then used to assess the accuracy of each score in predicting complications. Subsequently, logistic regression analyses were performed for each score to find significant association with complications.

Regarding outcome, due to the low number of events, residual disease and local tumor progression were considered together at statistical analysis. Outcome analyses were performed selecting lesions with malignant histology only. Cox-regression analyses were performed for prediction of residual disease or local tumor progression on the basis of the 4 scores. To maximize comparability between hazard ratios, all indices were standardized to have a mean of zero and standard deviation of one. A 5% significance level was used (p < 0.05).

Results

Population

In the centers and during the time aforementioned, we treated a total of 151 lesions in 125 patients. We eliminated 2 tumors in 2 patients because of paucity of clinical data, 2 tumors in 1 patient due to lack of adequate imaging, while 11 lesions in 9 subjects were eliminated as they resulted angiomyolipomas. Therefore, the cohort of this study was composed by 136 lesions in 113 patients with 71.7% (n = 81/113) being males and 28.3% (n = 32/113) females (M:F ratio 2.5). Mean and median age of population were 70.8 and 74 years, respectively (range 34–89). The main patient- and tumor-related features are reported in Table 2.

Mean and median tumor diameters were 23.2 and 23 mm (range 7–51). Tumors were local recurrences of previous treated lesions in 14.7% (n = 20/136) of cases, with the remainder 85.3% (n = 116/136) representing new lesions.

Prior to ablation, 65.4% (n = 89/136) of lesions were biopsied, while in 8.8% (n = 12/136) patient biopsy was not performed as it was judged high-risk due to patient...
status or anatomical factors; the remainder 25.7% (n = 35/136) of lesions were found in patient with previous histological characterization of ipsilateral or contralateral renal tumors with the same imaging features. The majority of tumors were clear cell renal cell carcinomas (RCCs, 52.2%, n = 71/136), followed by papillary RCCs (14%, n = 19/136), oncocytomas (11%, n = 15/136), and chromophobe RCCs (6.6%, n = 9/136); non-diagnostic samples occurred in 7.3% cases (n = 10/136). Lesions with certified malignant histology, therefore, represented 72.8% of total (n = 99/136).

Procedure

Cryoablation was used to treat 98 (72%) lesions; in particular, 1 probe was used in 33 cases, 2 in 26, 3 in 25, 4 in 12, and 5 in 2. The remainder 38 (28%) lesions underwent microwave ablation with a single antenna. An example of cryoablation is illustrated in Fig. 1. As guidance, CT was used in the majority of cases (76.5%, n = 104/136), while US in 6.6% (n = 9/136), CBCT in 2.9% (n = 4/136), US and CT in 14% (n = 19/136).

Complications and outcome

We registered 7 complications during treatment of 7/136 lesions (5.1%) in 7 patients. According to Clavien-Dindo, complications were graded as follows: 3 grade I cases, all minor anemization episodes for which only a day of prolonged observation was decided; 3 grade IIIa cases, with angiography being performed in all of them and embolization needed in two; 1 grade IV case, a retroperitoneal hemorrhage requiring blood transfusions and embolization, with an acute renal failure on background chronic renal failure. Table 3 reports mean and median values of the 4 scores, calculated for groups with and without complications, and groups with and without residual disease/local tumor progression.

Mann–Whitney U test didn’t show significant differences between the groups for any score, although sABLATE was

Mean and standard deviation values of RENAL, mRENAL, ABLATE, and sABLATE scores, calculated for the total number of renal lesions, were 6.8 (±1.8), 6.9 (±1.8), 5.3 (±2.5), and 3.5 (±2.4), respectively.

Table 2

| Patient- and tumor-related data                                      |        |
|---------------------------------------------------------------------|--------|
| Total subject number, n                                             | 113    |
| Age mean and range, y                                               | 70.8 (34–89) |
| Gender, n (%)                                                       |        |
| Male                                                                | 81 (71.7) |
| Female                                                              | 32 (28.3) |
| M:F ratio                                                           | 2.5    |
| Total tumor number, n                                               | 136    |
| Tumor size mean and range, mm                                      | 23.2 (7–51) |
| Tumor type, n (%)                                                   |        |
| New                                                                 | 116 (85.3) |
| Recurrence of previous tumor                                       | 20 (14.7) |
| Tumor histology, n (%)                                              |        |
| Clear-cell RCC                                                      | 71 (52.2) |
| Papillary RCC                                                       | 19 (14) |
| Oncocytoma                                                          | 15 (11) |
| Chromophobe RCC                                                     | 9 (6.6) |
| Non-diagnostic                                                      | 10 (7.3) |

F female; M male; n number; RCC renal cell carcinoma; y years

Fig. 1 Abdominal contrast-enhanced CT image (a) demonstrates a renal tumor in the right kidney of a 57-year-old male. RENAL, mRENAL, ABLATE, and sABLATE scores were 8, 8, 4.5, and 3, respectively. The lesion was biopsied before procedure and resulted a clear-cell renal carcinoma; intra-procedural coronal (b) and axial (c) CT images show the positioning of 3 cryoprobes with a transhepatic approach. Abdominal contrast-enhanced fat-suppressed axial T1-weighted MR image at 1 month post procedure (d) shows the ablation zone with no enhancing tissue within, suggesting effective treatment result. Abdominal axial T2-weighted MR image at 3 years post procedure (e) shows the normal shrunken appearance of the ablation zone; although the ablation zone may exceed the original tumor size immediately after procedure, it’s expected to observe its involution during a longer follow-up, and this phenomenon is usually more pronounced with cryoablation.
the closest to significance ($p$ values: RENAL = 0.51, mRENAL = 0.49, ABLATE = 0.66, sABLATE = 0.06). ROC plots for complications for each score are illustrated in Fig. 2. The area under curve (AUC) for sABLATE resulted higher in value, but not reaching a statistically significant difference with respect to the other scores. Logistic regression analyses failed to demonstrate any significant association between the scores and the occurrence of complications. Similarly to what observed for the Mann–Whitney $U$ test, despite not reaching significance ($p < 0.05$), sABLATE was the only score that resulted lower than a 10% threshold (RENAL: $p = 0.29$, OR 1.31; mRENAL: $p = 0.23$, OR 1.33; ABLATE: $p = 0.60$, OR 1.10; sABLATE: $p = 0.07$, OR 1.35).

During a mean follow-up time of 21.9 months (range 1–73), we registered 3 cases of residual disease (2.2%) at a mean time of 33.3 days after procedure (range 10–90) and 10 cases of local tumor progression (7.3% of total cohort, $n = 10/136$; 10.1% of malignant lesions, $n = 10/99$) at a mean time of 13.1 months (range 3–41). An example is illustrated by Fig. 3. All of these cases were retreated with thermal ablation, except for 2 patients that underwent surgery (1 partial and 1 total nephrectomy), and 1 patient who decided for follow-up. Mean and median values of the 4 scores, calculated for groups with and without residual disease or local tumor progression, are reported in Table 3.

At Cox-regression analyses, ABLATE and sABLATE scores were significantly associated with the occurrence of residual disease/local tumor progression, with the latter score demonstrating the highest hazard increase associated with each standard deviation increase (RENAL: $p = 0.36$, HR = 1.30; mRENAL: $p = 0.35$, HR = 1.33; ABLATE: $p = 0.01$, HR = 2.16; sABLATE: $p = 0.004$, HR = 2.29).

### Table 3

| Score   | Variable, mean (SD) | Complications | No       | Yes       |
|---------|---------------------|---------------|----------|-----------|
| n       | 129                 |               |          |           |
| RENAL   | 6.8 (1.7)           | 7.3 (1.8)     |          |           |
| mRENAL  | 6.9 (1.8)           | 7.4 (1.9)     |          |           |
| ABLATE  | 5.3 (2.6)           | 5.6 (2.1)     |          |           |
| sABLATE | 3.4 (2.4)           | 5.3 (2.8)     |          |           |

| Score   | Variable, mean (SD) | Residual disease or local tumor progression | No       | Yes       |
|---------|---------------------|---------------------------------------------|----------|-----------|
| n       | 123                 |                                             |          |           |
| RENAL   | 6.7 (1.7)           | 7.8 (1.8)                                   |          |           |
| mRENAL  | 6.8 (1.8)           | 7.8 (1.7)                                   |          |           |
| ABLATE  | 5.0 (2.5)           | 7.6 (1.8)                                   |          |           |
| sABLATE | 3.2 (2.3)           | 6.4 (1.9)                                   |          |           |

$mRENAL$ modified RENAL; $n$ number; $sABLATE$ simplified ABLATE; $SD$ standard deviation;

![Fig. 2](image-url) Receiver operating characteristic (ROC) plots for complications. ROC plots for complication calculated for a RENAL, b mRENAL, c ABLATE, and d sABLATE scores. $AUC$ area under curve; $ROC$ Receiver operating characteristic.
We registered 7 deaths at a mean time post procedure of 17 months (range 2–29) for causes non-related to renal tumors.

**Discussion**

In this multicentric study, we compared the performance of four different scores in predicting complications and outcome of patients treated with percutaneous thermal ablation of renal tumors using different ablation modalities (either cryoablation or microwave ablation). The scores we evaluated are all based on anatomical tumor-related features that can be derived from pre-procedural cross-sectional imaging (CT or MRI), but two of them are of surgical derivation (RENAL and mRENAL scores), while the remainder two (ABLATE and sABLATE scores) have been developed specifically for interventional radiology, taking into account that the challenges faced from surgeons during a nephrectomy aren’t the same as those encountered by interventional radiologists while performing an ablation percutaneously. In particular, this study was aimed to evaluate the simplified ABLATE score (sABLATE), that we created by reorganizing some of the criteria of the previously reported ABLATE [23], in order to make it simpler and more objective but trying not to lose its efficacy. The results show that among the four scores, sABLATE was the closest to a significant association with complications, and that both ABLATE and sABLATE were significantly associated with residual disease or local tumor progression. Moreover, regarding outcome, sABLATE, despite being a simplified version of ABLATE, not only maintained validity but performed better than its “original” version. As a key factor to improve the efficacy of every treatment is patient selection, the identification of pre-procedural factors which can predict complications and outcome in patients with renal masses undergoing percutaneous thermal ablation is of interest.

This study confirms that percutaneous thermal ablation is safe and well-tolerated, as we registered an overall complication rate of 5.1% ($n = 7/136$), composed by 3 Clavien-Dindo grade I cases and 4 grade III-IV cases, which is similar to recent experiences in literature [27–31]. We didn’t register any death related to renal tumor during the study observation time. The different types of statistical analyses we performed for complications (Mann–Whitney $U$ test, ROC analyses and logistic regression) were concordant, and showed that no score reached statistical significance, but the results for sABLATE were close to reach it. Therefore, it seems that sABLATE performs better than the other scores, but given the fact that the statistical evaluation may have been limited by the low number of events, further larger studies are needed for confirmation. Percutaneous thermal ablation was also efficacious, as we registered a residual disease rate of 2.2%, and a local tumor progression rate of 7.3% and 10.1% for all and malignant lesions, respectively, during a mean follow-up time of 21.9 months (range 1–73). These data are similar to what has been previously reported [29, 31–33]. In this study we focused on lesions, not patients, and on the efficacy of single procedures, not of cumulative treatments; thus, no outcomes such as secondary efficacy were calculated nor compared. Nevertheless, all residual or recurrent lesions were retreated with thermal ablation, except for 2 patients that underwent surgery and 1 patient who decided for follow-up. Of note, all cases of residual disease or local tumor progression were clear-cell RCC. This is concordant with previous studies which demonstrated an association between worse ablation outcome and this type of histology, and it might be kept in mind for further scores development.
Cox-regression analyses showed that among the four scores, ABLATE and sABLATE were significantly associated with residual disease/local tumor progression, with sABLATE having the highest hazard increase for each standard deviation increase. We thus confirm the value of ABLATE score in predicting residual or recurrent disease after ablation, which had been already reported, this time in a multicentric setting, with different ablative techniques and in a larger cohort. Despite being the result of a simplification, sABLATE maintained validity in this setting, and whether it performs better than its original version will have to be assessed by further research.

This study has several limitations. The retrospective nature may have caused selection and reporting bias. There was no clearly defined algorithm used to select ablation modality. The heterogeneity of tumors types treated, and ablation techniques used, may limit validity. Not all lesions were biopsied before ablation, and some biopsies were non-diagnostic. The small number of events registered on one hand forced us to consider residual disease and local tumor progression together at statistical analyses, on the other might have impaired to some extent the analyses too. As this is a preliminary report, the score has not been tested in a group of patients independent to the group used to develop the score, and it will need to be tested in the future in other series.

In conclusion, none of the scores demonstrated significant differences in average between patients with and without complications, but sABLATE was close to significance, representing a progress toward the right direction in this setting, even if not definitive. ABLATE score confirmed its validity in predicting residual disease or local tumor progression in a multicentric setting with different ablative modalities and a larger cohort. sABLATE, despite being a simplified score, maintained validity and whether it performs better than its original version will have to be assessed by further research.

Acknowledgements We thank Giacomo Mason, PhD, who provided statistical support and expertise for this research.

Author contributions We declare that all authors have significantly contributed to all the steps of this research project, from ideation to final manuscript review. All authors have read and agreed to the submitted version of the manuscript.

Funding No funding was received for conducting this study.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no conflict of interest to declare that are relevant to the content of this article.

Ethical approval Ethical approval was given by IRBs/ Ethical approval was waived by IRB in view of the retrospective nature of the study and all the procedures performed were part of the routine care. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent to participate Waived by IRB for this retrospective study, which is observational and didn’t modify the routine care in any way.

Consent for publication Waived by IRB as no identifying information is present in the current study.

References

1. Hollingsworth JM, Miller DC, Daignault S, Hollenbeck BK. Rising incidence of small renal masses: a need to reassess treatment effect. J Natl Cancer Inst. 2006;98(18):1331–4.
2. Znaor A, Loriot-Tieulent J, Laversanne M, Jemal A, Bray F. International variations and trends in renal cell carcinoma incidence and mortality. Eur Urol. 2015;67(3):519–30.
3. Shah PH, Alom MA, Leibovich BC, et al. The temporal association of robotic surgical diffusion with overtreatment of the small renal mass. J Urol. 2018;200(5):981–8.
4. Iannuccilli JD, Dupuy DE, Beland MD, Machan JT, Golijanin DJ, Mayo-Smith W. Effectiveness and safety of computed tomography-guided radiofrequency ablation of renal cancer: a 14-year single institution experience in 203 patients. Eur Radiol. 2016;26(6):1656–64.
5. Yang Y, Shen S, Chen F, et al. Outcome of radiofrequency ablation over partial nephrectomy for small renal mass. Int J Clin Exp Med. 2015;8(11):20670–4.
6. Trudeau V, Larcher A, Boehm K, et al. Comparison of postoperative complications and mortality between laparoscopic and percutaneous local tumor ablation for T1a renal cell carcinoma: a population-based study. Urology. 2016;89:63–8.
7. Larcher A, Trudeau V, Sun M, et al. Population-based assessment of cancer-specific mortality after local tumour ablation or observation for kidney cancer: a competing risks analysis. BJU Int. 2016;118(4):541–6.
8. Yu J, Zhang G, Liang P, et al. Midterm results of percutaneous microwave ablation under ultrasound guidance versus retroperitoneal laparoscopic radial nephrectomy for small renal cell carcinoma. Abdom Imaging. 2015;40(8):3248–56.
9. Pierorazio PM, Johnson MH, Patel HD, et al. Management of renal masses and localized renal cancer: systematic review and meta-analysis. J Urol. 2016;196(4):989–99.
10. Thompson RH, Atwell T, Schmit G, et al. Comparison of partial nephrectomy and percutaneous ablation for cT1 renal masses. Eur Urol. 2015;67(2):252–9.
11. Whitson JM, Harris CR, Meng MV. Population-based comparative effectiveness of nephron-sparing surgery vs ablation for small renal masses. BJU Int. 2012;110(10):1438–43.
12. Campbell S, Uzzo RG, Alfat ME, et al. Renal mass and localized renal cancer: AUA guideline. J Urol. 2017;198(3):520–9.
13. Finelli A, Ismaila N, Bro B, et al. Management of small renal masses: American society of clinical oncology clinical practice guideline. J Clin Oncol. 2017;35(6):668–80.
14. Motzer RJ, Jonasch E, Agarwal N, et al. Kidney cancer, version 2.2017: clinical practice guidelines in oncology. JNCCN J Natl Compr Cancer Netw. 2017;15(6):804–34.
15 Kutikov A, Uzzo RG. The R.E.N.A.L. nephrometry score: a comprehensive standardized system for quantitating renal tumor size, location and depth. J Urol. 2009;182(3):844–53.

16 Schmit GD, Thompson RH, Kurup AN, et al. Usefulness of R.E.N.A.L. nephrometry scoring system for predicting outcomes and complications of percutaneous ablation of 751 renal tumors. J Urol. 2013;189(1):30–5.

17 Camacho JC, Kokabi N, Xing M, et al. R.E.N.A.L. (radius, exophytic/endophytic, nearness to collecting system or sinus, anterior/posterior, and location relative to polar lines) nephrometry score predicts early tumor recurrence and complications after percutaneous ablative therapies for renal cell carcinoma: a 5-year experience. J Vasc Interv Radiol. 2015;26(5):686–93.

18 Sisul DM, Liss MA, Palazzi KL, et al. RENAL nephrometry score is associated with complications after renal cryoablation: a multi-center analysis. Urology. 2013;81(4):775–80.

19 Ierardi AM, Puliti A, Angelieri SA, et al. Microwave ablation of malignant renal tumours: intermediate-term results and usefulness of RENAL and mRENNAL scores for predicting outcomes and complications. Med Oncol. 2017;34(5):97.

20 Kim EH, Tanagho YS, Bhayani SB, Saad NE, Benway BM, Figenshau RS. Percutaneous ablation of renal masses: Washington University experience of treating 129 tumours. BJU Int. 2013;111(6):872–9.

21 Seideman CA, Gahan J, Weaver M, et al. Renal tumour nephrometry score does not correlate with the risk of radiofrequency ablation complications. BJU Int. 2013;112(8):1121–4.

22 Gahan JC, Richter MD, Seideman CA, et al. The performance of a modified RENAL nephrometry score in predicting renal mass radiofrequency ablation success. Urology. 2015;85(1):125–9.

23 Papa M, Suardi N, Losa A, et al. ABLATE: a score to predict complications and recurrence rate in percutaneous treatments of renal lesions. Med Oncol. 2020;37(4):26.

24 Rothman J, Crispen PL, Wong YN, Al-Saleem T, Fox E, Uzzo RG. Pathologic concordance of sporadic synchronous bilateral renal masses. Urology. 2008;72(1):138–42.

25 Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg. 2004;240(2):205–13.

26 Ahmed M, Solbiati L, Brac CL, et al. Image-guided tumourablation: standardization of terminology and reporting criteria-A 10-year update. J Vasc Interv Radiol. 2014;25(11):1691-1705.e4.

27 Zargar H, Atwell TD, Cadeddu JA, et al. Cryoablation for small renal masses: selection criteria, complications, and functional and oncologic results. Eur Urol. 2016;69(1):116–28.

28 Klapperich ME, Abel EJ, Ziemlewicz TJ, et al. Effect of tumor complexity and technique on efficacy and complications after percutaneous microwave ablation of stage T1a renal cell carcinoma: a single-center, retrospective study. Radiology. 2017;284(1):272–80.

29 De Cobelli F, Papa M, Panzeri M, et al. Percutaneous microwave ablation versus cryoablation in the treatment of T1a renal tumors. Cardiovasc Interv Radiol. 2020;43(1):76–83.

30 Maciolek KA, Abel EJ, Posieliski NM, et al. Tumor location does not impact oncologic outcomes for percutaneous microwave ablation of clinical T1a renal cell carcinoma. Eur Radiol. 2019;29(11):6319–29.

31 Zhou W, Herwald SE, McCarthy C, Uppot RN, Arellano RS. 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(7):1035–42.

32 Kim DK, Won JY, Park SY. Percutaneous cryoablation for renal cell carcinoma using ultrasound-guided targeting and computed tomography-guided ice-ball monitoring: radiation dose and short-term outcomes. Acta radiol. 2019;60(6):798–804.

33 Yamanaka T, Yamakado K, Yamada T, et al. CT-guided percutaneous cryoablation in renal cell carcinoma: factors affecting local tumor control. J Vasc Interv Radiol. 2015;26(8):1147–53.

34 Beksac AT, Rivera-Sanfeliz G, Dufour CA, et al. Impact of tumor histology and grade on treatment success of percutaneous renal cryoablation. World J Urol. 2017;35(4):633–40.

35 Haddad MM, Schmit GD, Kurup AN, et al. Percutaneous cryoablation of solitary, sporadic renal cell carcinoma: outcome analysis based on clear-cell versus papillary subtypes. J Vasc Interv Radiol. 2018;29(8):1122–6.

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