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Partial Nephrectomy versus Percutaneous Cryoablation of Small Renal Cell Carcinomas: A Comparison of Adverse Events in a Prospective Multicenter Cohort Study

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ABSTRACT

Purpose: To assess and compare complications and readmissions after partial nephrectomy and percutaneous cryoablation of cT1 renal cell carcinoma (RCC).

Materials and Methods: Patients treated for cT1 RCC between 2019 and 2021 were prospectively and consecutively enrolled. Complications recorded within 30 and 90 days were graded according to the Clavien-Dindo classification, and percutaneous cryoablation was graded according to the Society of Interventional Radiology classification of adverse events. Major complications were defined as complications with a grade of ≥3 based on the Clavien-Dindo classification. Readmission within 30 days was recorded.

Results: The cohort included 86 partial nephrectomies and 104 cryoablations. The complication rate within 90 days was 23% after partial nephrectomy and cryoablation (P = .98), with major complication rates of 3% after partial nephrectomy and 10% after cryoablation (P = .15). The readmission rates were 14% and 11% after partial nephrectomy and cryoablation, respectively (P = .48). Double-J stents were associated with overall complications (odds ratio [OR], 9.88; 95% confidence interval [CI], 2.18–44.68; P = .003) and readmissions (OR, 5.39; 95% CI, 1.37–21.06; P = .015) after cryoablation. A high versus low radius-endophytic-nearness-anterior-location score (OR, 5.86; 95% CI, 1.08–31.81; P = .040) and endophytic location (OR, 7.70; 95% CI, 1.72–34.50; P = .008) were associated with a higher complication rate after cryoablation. The Charlson Comorbidity Index (CCI) was associated with major complications after partial nephrectomy (OR, 2.12; 95% CI, 1.05–4.30; P = .036).

Conclusions: Partial nephrectomy and cryoablation are comparable regarding complications within 90 days after treatment. Tumor complexity and double-J stents were associated with complications after cryoablation, and a high CCI was associated with complications after partial nephrectomy.

ABBREVIATIONS

CCI = Charlson Comorbidity Index, CI = confidence interval, GA = general anesthesia, OR = odds ratio, PS = performance status, RCC = renal cell carcinoma, RENAL = radius-endophytic-nearness-anterior-location

Renal cell carcinoma (RCC) accounts for approximately 2% of all newly diagnosed cancers worldwide (1). The increase in the incidental findings of small RCC has drawn attention to various treatment dilemmas (2). The recommended treatment option for RCC according to international guidelines is surgery (3). Two of the major concerns are ensuring curative oncological outcomes and minimizing complications caused by treatment. The latter emphasizes the importance of using minimally invasive treatments to mitigate treatment-related complications and nephron-

Appendix A and **Tables E1–E3** can be found by accessing the online version of this article on *www.jvir.org* and selecting the Supplemental Material tab.

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RESEARCH HIGHLIGHTS

- This prospective observational study compared the rates of complications between partial nephrectomy and cryoablation for the treatment of T1 renal cell carcinomas.
- No significant difference in the overall complication and readmission rates up to 90 days after treatment was noted.
- A double-J stent in place was associated with complications after percutaneous cryoablation.
- A high rate of late-onset complications after cryoablation warrants a minimum of 90 days of follow-up.

sparing treatment to minimize late-onset complications, such as chronic kidney disease and/or cardiovascular disease (4). Partial nephrectomy is currently the gold standard; however, during the past decade, new treatment options within the field of nephron-sparing treatment have emerged, including percutaneous cryoablation. An advantage of cryoablation is that it can be performed as an outpatient procedure and under sedation. Studies have shown that cryoablation is associated with lower complication rates than those of partial nephrectomy; however, the evidence is limited because of heterogeneity among studies (5). Thus, other potential advantages or disadvantages of cryoablation are yet to be further documented in larger protocol-driven comparative studies using a standardized reporting tool (6). Therefore, cryoablation is currently offered with caution to elderly patients, patients with a single kidney, or patients with comorbidities who are not fit for surgery (3). This poses a clinical treatment dilemma when advising patients who are not obvious candidates for partial nephrectomy or do not want to undergo major surgery because of other circumstances.

The overall aim of the present study was to assess and compare complications after partial nephrectomy and cryoablation of cT1 RCC in clinical practice.

MATERIALS AND METHODS

This comparative prospective cohort study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology guideline (7).

Ethical Considerations

Patients participated in the study after providing written and oral informed consent. The project was approved by the Danish Data Protection Agency (18/52479). The National Committee on Health Research Ethics deemed the project to be exempt from notification obligations (cf. case number 0182000-96). Data were stored in a Research Electronic Data Capture database in accordance with the Declaration of Helsinki (8). Furthermore, this study was registered at ClinicalTrials.gov: NCT04040530.

STUDY DETAILS

Study type: Prospective, observational, cohort study

Level of evidence: 3 (SIR-C)

Patient Selection

Prior to making treatment decisions, all patients were discussed at a conference by a multidisciplinary team, which included urologists, radiologists, pathologists, and oncologists. If a patient was a candidate for nephron-sparing treatment, the patient and urologist decided on the type of treatment on the basis of the principles of shared decision making (9). Thus, patients were not randomized, although allocation followed standard clinical practice. Multidisciplinary team conferences were carried out at both institutions. If a patient from Zealand University Hospital chose cryoablation, the patient was referred to Odense University Hospital. Partial nephrectomy was performed at both institutions.

Variables of Interest

The surgical complexity of each tumor was determined using the radius-endophytic-nearness-anterior-location (RENAL) nephrometry score (10) based on preoperative computed tomography/magnetic resonance images from the same radiologist with 17 years of experience. The radiologist was blinded to treatment type. Data regarding pathological subtype were based on the findings of biopsy performed before treatment for cryoablation and on postoperative tumor pathology for partial nephrectomy. All tumors were staged according to the American Joint Committee on Cancer (eighth edition) RCC tumor, node, metastasis staging system (11,12).

The patient's performance status (PS) and American Society of Anesthesiologists score were assessed before treatment (13,14). The Charlson Comorbidity Index (CCI) was calculated on the basis of information from the electronic medical record and cross-referenced with prescribed medication and patient-reported comorbidity (15). Furthermore, diabetes was assessed according to the CCI (eg, none, without complications, or with organ damage). Alcohol consumption was registered as none, under, or over the amount recommended by the Danish Health Authority, and smoking status was registered as no, yes, or former smoker. Postoperative complications were recorded within 30 and 90 days and graded according to the Clavien-Dindo classification (16). In addition, postoperative complications after cryoablation were reported according to the Society of Interventional Radiology (SIR) classification of adverse events (17–19). If a patient presented with complications of different grades and time intervals, only the complication with the highest grade was included. Major complications were defined as complications with a grade of ≥ 3 on the Clavien-Dindo classification. Finally, readmission within 30 days was recorded.

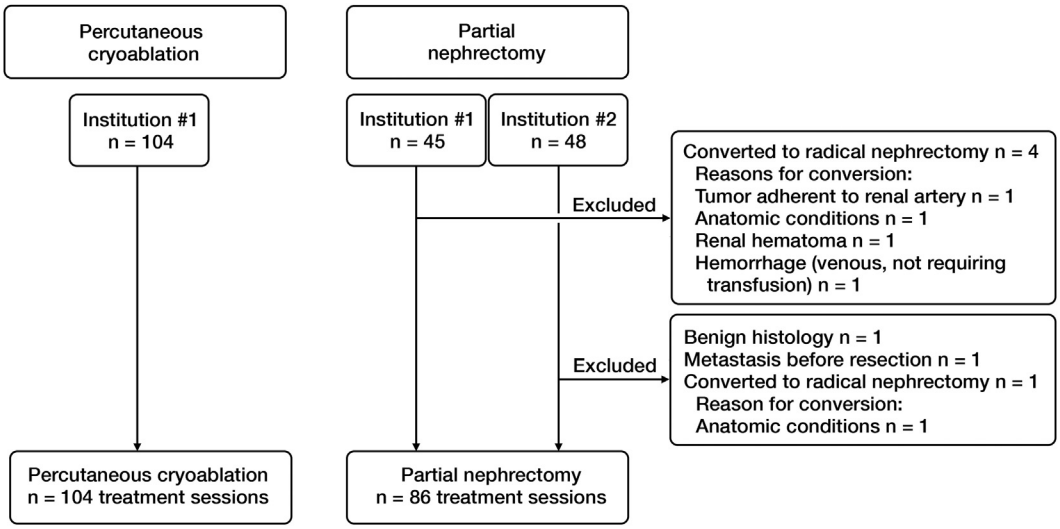

Figure 1. Flow diagram of study design. Institution #1 = Odense University Hospital; Institution #2 = Zealand University Hospital.

Patient Selection, Data Collection, and Pathological Evaluation

Patients aged ≥18 years with histologically verified primary RCC stage cT1N0M0 treated with partial nephrectomy or cryoablation at 2 university hospitals, Odense University Hospital or Zealand University Hospital, were prospectively and consecutively enrolled between June 2019 and February 2021. The time frame was based on an expectation of achieving a sample size large enough for a conclusion. The exclusion criteria were metastatic disease at the time of diagnosis, conversion from partial to radical nephrectomy, and salvage procedures. If patients were treated for a new tumor with nephron-sparing treatment during the inclusion period, with >3 months between each treatment, they were defined as 2 individual patients. A total of 187 patients and 194 tumors were treated in 190 sessions, which included 86 partial nephrectomies and 104 cryoablations (**Fig 1**). During the 104 cryoablation sessions, 1 patient underwent 2 procedures on 1 tumor because of an intraoperative complication that resulted in the first cryoablation being discontinued. Patients with multiple tumors and treatment sessions are described in **Table E1** (available online on the article's Supplemental Material page at *www.jvir.org*). Patients treated with cryoablation were significantly older ($P < .001$), had worse PS ($P < .001$), were more likely to experience chronic obstructive pulmonary disease ($P = .03$), have malignancies other than RCC ($P = .005$), and had a higher CCI than that of patients treated with partial nephrectomy ($P < .001$). Significantly more cT1b tumors were treated with partial nephrectomy (n = 32 vs n = 13, $P < .001$), and tumors treated with partial nephrectomy were significantly more exophytic than tumors treated with cryoablation ($P = .001$). Baseline patient, tumor, and treatment characteristics are shown in **Table 1**.

Procedures and Follow-Up

Partial nephrectomies were performed by 6 experienced urologists. Both robot-assisted partial nephrectomy and open partial nephrectomy were included. The 4-armed da Vinci Si robotic surgical system (Intuitive Surgical, Sunnyvale, California) was used to perform robot-assisted partial nephrectomy. The procedure has been previously described (20). Open partial nephrectomy was performed with the patient in a full-flank position with a subcostal incision. In both procedures, arterial clamping or off-clamp techniques were used according to the surgeon's preference, and endoscopic ultrasound was used to identify the margin of the tumor.

Cryoablation was performed by 2 radiologists, with 3 and 7 years of experience with cryoablation, under computed tomography guidance (Somatom Flash; Siemens Healthineers, Erlangen, Germany). Cases in which there was a risk of damaging the ureter during the procedure, a double-J stent was inserted. The procedure was performed before cryoablation and under general anesthesia (GA). The SIR reporting standard for image-guided tumor ablation was followed (17). The procedure is described in **Appendix A** (available online at *www.jvir.org*). All patients had a follow-up period of 90 days.

Statistical Analysis

Continuous variables were described as mean with standard deviation or median with interquartile range, depending on the empirical distributions judged visually by histograms, including approximating normal distributions. Descriptive statistics for categorical variables comprised of frequencies and respective percentages. Group comparisons were performed using unpaired t-tests (conservatively assuming unequal variances) or the Wilcoxon rank sum test for

Table 1. Baseline Patient, Tumor, and Treatment Characteristics for Patients Treated with Cryoablation or Partial Nephrectomy between June 2019 and February 2021

Patient characteristics	Cryoablation (n = 101)	Partial nephrectomy (n = 86)	*P* value
Age (y), median (IQR)	69.4 (62.2–76.1)	63.6 (53.5–70.4)	<.001¶
Male sex, n (%)	72 (71)	65 (76)	.51
BMI, mean (SD)	29.3 (6.2)	28.7 (5.4)	.51
Smoking, n (%)			
Yes	21 (21)	21 (24)	.25
No	59 (58)	40 (47)	
Former	21 (21)	25 (29)	
Alcohol, n (%)			
None	34 (34)	20 (23)	.22
Under recommendations*	60 (59)	62 (72)	
Over recommendations*	7 (7)	4 (5)	
Performance status, n (%)			
0	55 (55)	71 (83)	<.001#
1	27 (27)	13 (15)	
2	18 (18)	2 (2)	
3	1 (1)		
ASA score, n (%)			
1	6 (6)	8 (9)	.11
2	47 (47)	50 (58)	
3	48 (48)	28 (33)	
CCI, median (IQR)	3 (2–5)	2 (1–3)	<.001¶
Diabetes n, (%)			
None	80 (79)	70 (81)	.67
Without complications	20 (20)	14 (16)	
Organ damage	1(1)	2 (2)	
Heart failure n, (%)			
Yes	7 (7)	2 (2)	.18
No	94 (93)	84 (98)	
COPD, n (%)			
Yes	15 (15)	4 (5)	.028#
No	86 (85)	82 (95)	
Other malignancy, n (%)			
None	66 (65)	73 (85)	.005#
Ongoing treatment	7 (7)	1 (2)	
Follow-up/ surveillance	28 (28)	12 (14)	
Symptoms, n (%)			
None	79 (78)	72 (84)	.34
Pain	3 (3)	2 (2)	.99
Gross hematuria	7 (7)	3 (4)	.35
Fatigue	1 (1)	4 (5)	.18
Weight loss	5 (5)	6 (7)	.76
Not recorded	8 (8)	2 (2)	.11
Other renal disease, n (%)			
Congenital	1 (1)	0	.99
History of urolithiasis	7 (7)	2 (2)	.18
Polycystic kidney disease	1 (1)	0	.99
Hereditary disease	0	1 (1)	.46

continued

Table 1. Baseline Patient, Tumor, and Treatment Characteristics for Patients Treated with Cryoablation or Partial Nephrectomy between June 2019 and February 2021 *(continued)*

Patient characteristics	Cryoablation (n = 101)	Partial nephrectomy (n = 86)	*P* value
Solitary functioning kidney	0	0	-
History of RCC	4 (4)	1 (1)	.38
Prior nephrectomy	6 (6)	0	.032#

Tumor characteristics	Cryoablation (n = 107)	Partial nephrectomy (n = 87)	*P* value
Tumor size, (cm), mean (SD)	3.1 (0.91) 1.5–5.8	3.7 (1.29) 1.7–7	.001**
Tumor placement			
Right/left	52/55	31/55	
Exophytic/endophytic, n (%)			
≥50% exophytic	51 (48)	57 (66)	.001#
<50% exophytic	40 (37)	29 (33)	
100% endophytic	16 (15)	1 (1)	
Nearness to sinus or collecting system, n (%)			
≥7 mm	24 (22)	20 (23)	.53
>4 mm	14 (13)	7 (8)	
≤4 mm	69 (64)	60 (69)	
RENAL score, median (IQR)	8 (6–9)	7 (6–9)	.32
RENAL score group, n (%)			
4–6 (low)	33 (31)	30 (34)	.46
7–9 (medium)	61 (57)	51 (59)	
10–12 (high)	13 (12)	6 (7)	
Multiple tumors, n (%)	8 (8)	1 (1)	.040#
Clinical tumor stage, n (%)			<.001††
cT1a	94 (89)	55 (63)	
cT1b	13 (12)	32 (37)	
Pathological tumor stage, n (%)			
pT1a	n/a	64 (74)	
pT1b	n/a	14 (16)	
pT2	n/a	3 (3)	
pT3a	n/a	6 (7)	
Histological subtype, n (%)			.11
Unclassified RCC	2 (2)	1 (1)	
Clear cell	68 (64)	63 (72)	
Papillary	29 (27)	12 (14)	
Chromophobe	5 (5)	7 (8)	
Multilocular cystic renal neoplasm	1 (1)	3 (3)	
Mucinous tubular and spindle cell carcinoma	1 (1)	0	
Epithelioid angiomyolipoma	0	1 (1)	
Insufficient specimen	1 (1)	0	

Treatment characteristics	Cryoablation (n = 104)	Partial nephrectomy (n = 86)
Anesthesia, n (%)		
Moderate sedation	96 (92)	n/a
GA	8 (8)	n/a
Number of probes/tumor, † n (%)		
2	33 (31)	n/a
3	44 (41)	n/a
4	21 (20)	n/a

continued

Table 1. Baseline Patient, Tumor, and Treatment Characteristics for Patients Treated with Cryoablation or Partial Nephrectomy between June 2019 and February 2021 *(continued)*

Treatment characteristics	Cryoablation (n = 104)	Partial nephrectomy (n = 86)	
5	5 (5)	n/a	
6	3 (3)	n/a	
7	1 (1)	n/a	
Hydrodisplacement, n (%)			
Yes	71 (68)	n/a	
No	33 (32)	n/a	
Double-J stent, n (%)			
Yes	16 (15)	n/a	
No	88 (85)	n/a	
Double-J stent dwell period, d, median (IQR)	60.5 (28–87.5)	n/a	
Outpatient procedure, n (%)			
Yes	97 (93)	n/a	
No	7 (7)	n/a	
Length of stay,‡ d, median (IQR)	2 (1–3)	2 (1–2)	.40
Procedure, n (%)			
Robot-assisted	n/a	80 (93)	
Open	n/a	2 (2)	
Converted from robotic to open	n/a	4 (5)	
WIT,§ min, median (IQR)	n/a	14.5 (10–18)	
Zero ischemia, n (%)	n/a	16 (20)	
Blood loss,‖ mL, median (IQR)	n/a	150 (100–350)	
Intraoperative transfusion, n (%)			.20
Yes	0	2 (2)	
No	104	84 (98)	

ASA = American Society of Anesthesiologists; BMI = body mass index; CCI = Charlson Comorbidity Index; COPD = chronic obstructive pulmonary disease; GA = general anesthesia; IQR = interquartile range; n/a = not applicable; RCC = renal cell carcinoma; RENAL score = radius-endophytic-nearness-anterior-location nephrometry score; SD = standard deviation; WIT = warm ischemia time.

*Based on the recommendation from the Danish Health Authority: female, <7 units per week, and male, <14 units per week.

†Based on 107 tumors.

‡Length of stay was defined as days admitted to the hospital after the day of treatment. Calculations based on 7 patients in the cryoablation group.

§Based on 82 of 86 procedures.

‖Based on 83 of 86 procedures.

¶Wilcoxon rank sum test.

#Fisher exact test.

**A t-test with unequal variances.

††Chi-square test.

continuous variables. For categorical variables, the chi-square or Fisher exact tests were used; the latter was chosen when at least 1 cell frequency of a cross-tabulation was <5.

Inferential statistics on binary outcomes consisted of logistic regression analysis, stratified by procedure (percutaneous cryoablation vs partial nephrectomy). Univariate and multivariable regressions, adjusted for age and sex, were reported using odds ratios (ORs), respective 95% confidence intervals (CIs), and *P* values. Adjusted models included age and sex because these were considered potential confounding factors. The partial nephrectomy procedure (open, robot-assisted, and converted from robot-assisted to open) was omitted from the analyses because of the low number of open partial nephrectomies (n = 2) and converted from the robot-assisted partial nephrectomy group to the open partial nephrectomy (n = 4) group.

The level of statistical significance was set at 5%. All analyses were performed using STATA/BE 17.0 (StataCorp, College Station, Texas).

RESULTS

Complications

The overall complication rate was not significantly different between partial nephrectomy (20/86, 23%) and cryoablation (24/104, 23%) within 90 days ($P = .98$). All complications occurred within the first 30 postoperative days after partial nephrectomy, and 58% of complications occurred within the first 30 postoperative days after cryoablation. However, the difference in complications between cryoablation and partial nephrectomy within 30 days was not significant ($P = .08$).

There was no significant difference in the major complication rates between cryoablation (10/104, 10%) and partial nephrectomy (3/86, 3%) ($P = .15$), and the minor complication rates were also not significantly different between partial nephrectomy (17/86, 20%) and cryoablation (14/104, 13%) ($P = .32$) (**Table 2**). After cryoablation, minor complications included pain, skin infections, dehydration, urinary tract infection, hematomas, urine retention, and abscess (**Fig 2a–c**). Similar complications were observed after partial nephrectomy. Three cases with postoperative bleeding were treated conservatively.

The most common major complication after cryoablation was abscess (n = 5). Two of 5 patients who developed an abscess had received a prophylactic double-J stent. Two cases of postoperative bleeding leading to intensive care were reported; 1 was treated with selective embolization, and the other was treated conservatively. Two complications after cryoablation were classified as grade 3b on the Clavien-Dindo classification and grade D on the SIR adverse event classification owing to the need for GA to remove double-J stents: 1 case was because of displacement, and the other was because the patient experienced schizophrenia and was unable to cooperate in a removal procedure with local anesthesia. Major complications after partial nephrectomy included a case of small bowel obstruction treated with an exploratory laparotomy, reoperation because of postoperative bleeding resulting in radical nephrectomy and splenectomy, and a case of an abscess revised 3 times under GA. The details regarding all complications are shown in **Table E2** (available online at *www.jvir.org*).

Univariate analyses showed no statistically significant associations between patient characteristics and complications within 30 or 90 days or major complications (**Table E3**, available online at *www.jvir.org*).

Table 2. Adverse Events and Readmissions for patients treated with Cryoablation or Partial Nephrectomy between June 2019 and February 2021

Outcomes	Cryoablation (n = 104)	Partial nephrectomy (n = 86)	*P* value
Readmission within 30 d, n (%)	11 (11)	12 (14)	.48
Readmission time, d, median (IQR)	3 (1–6)	2.5 (2–5)	
Overall complications* within 30 d, n (%)	14 (13)	20 (23)	.08
Grade 1	3	2	
Grade 2	8	15	
Grade 3a	0	0	
Grade 3b	1	3	
Grade 4a	2	0	
Overall complications* within 90 d, n (%)	24 (23)	20 (23)	.98
Grade 1	3	2	
Grade 2	11	15	
Grade 3a	2	0	
Grade 3b	6	3	
Grade 4a	2	0	
Intraoperative complications		2 (2)	.99
Overall, n (%)	2 (2)	2	
Bleeding†	0	0 n/a	
Suspicion of organ perforation	1		
Skin injury	1		
Overall postoperative complications, n (%)			.32
Minor‡	14 (13)	17 (20)	.15
Major§	10 (10)	3 (3)	
Overall adverse events‖ within 30 d, n (%)	14 (13)	n/a	
Grade 1	2		
Grade 2	9		
Grade 3	3		
Grade 4	0		
Grade 5	0		
Overall adverse events‖ within 90 d, n (%)	24 (23)	n/a	
Grade 1	2		
Grade 2	10		
Grade 3	12		
Grade 4	0		
Grade 5	0		

IQR = interquartile range; n/a = not applicable.
*According to the Clavien-Dindo classification (16).
†Demanding blood transfusion.
‡Minor overall postoperative complications were indicated by a Clavien-Dindo grade of 1–2.
§Major overall postoperative complications were indicated by a Clavien-Dindo grade of 3–4.
‖Graded according to the Society of Interventional Radiology classification of adverse events (19).

In the cryoablation group, multivariable logistic regression, adjusted for sex and age, revealed a significant difference between patients with a high RENAL score and those with a low RENAL score and complications within 30 days (OR, 5.86; 95% CI, 1.08–31.81; $P = .040$), Similarly, a significant difference was found between patients with an endophytic tumor and those with a ≥50% exophytic tumor and complications within 30 days (OR, 7.70; 95% CI, 1.72–34.50; $P = .008$). Double-J stents were statistically significantly associated with complications within 90 days (OR, 9.88; 95% CI, 2.18–44.68; $P = .003$) and major complications (OR, 12.8; 95% CI, 2.52–65.26; $P = .002$).

After partial nephrectomy, a significant association between CCI and major complications, adjusted for sex, was observed (OR, 2.12; 95% CI, 1.05–4.30; $P = .036$) (Table 3).

Readmission within 30 Days

The rate of readmissions within 30 days among patients treated with cryoablation was 11%, and that after partial nephrectomy was 14%. The median time of readmissions was 3 versus 2.5 days after cryoablation and partial nephrectomy, respectively (Table 2).

Univariate analyses showed no statistically significant associations between patient characteristics and readmission after cryoablation (Table E3, available online at *www.jvir.org*).

In the cryoablation group, multivariable logistic regression, adjusted for sex and age, suggested a statistically significant association between double-J stents and readmission (OR, 5.39; 95% CI, 1.37–21.06; $P = .015$) (Table 3).

DISCUSSION

In this prospective study, a similar overall complication rate of 23% was observed for partial nephrectomy and cryoablation, including major complication rates of 3% after partial nephrectomy and 10% after cryoablation. This finding deviates from those of previous retrospective studies (21–23) that demonstrated a lower overall complication rate after cryoablation of 7.8%–12.9%. However, in one of the largest studies, Schmit et al (21) did not account for complications beyond 30 days. When only considering complications within 30 days, the results from this study are comparable with those reported by Schmit et al (21). In the present study, 6 patients developed a delayed abscess more than 30 days after treatment, among these 6 cases, 5 were graded as a major complication. The number of abscesses contrasts with the finding of Schmit et al (21), who reported 1 case of 398 procedures, although possibly because of the limited follow-up of 30 days. In addition, a newly published retrospective study (24) from the same institution as the present study reported fewer cases of patients developing an abscess (2%), all of which occurred 30 days after surgery (24). A plausible reason could be that the use of cryoablation has increased since the aforementioned retrospective study, partially because of an increase in patient requests and an increase in the level of experience leading

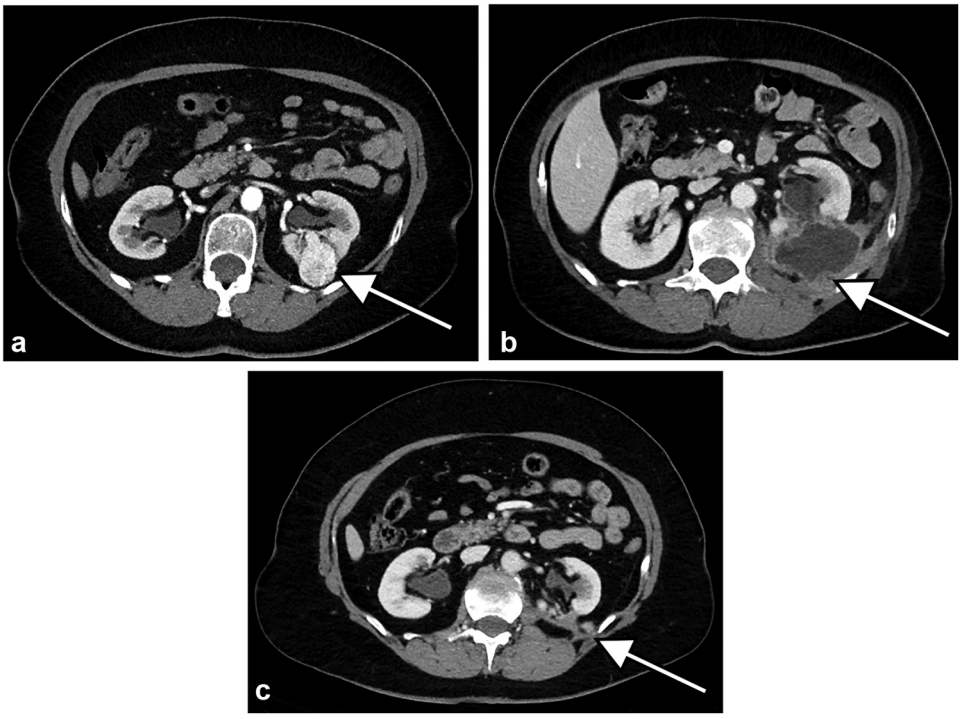

Figure 2. (a) A 64-year-old woman with a 4-cm left-sided clear cell renal cell carcinoma depicted on the contrast-enhanced computed tomography (CT) image (arrow). Uncomplicated cryoablation was performed using 4 needles and hydrodissection to protect the muscles and ribs. The patient had symptoms of infection 35 days after cryoablation, and initial CT imaging showed a well-ablated renal tumor, with fluid collection unsuitable for drainage (image not shown); the patient was treated with intravenous antibiotics twice over 3 months after cryoablation. **(b)** The abscess (arrow) was observed to have increased in size on the contrast-enhanced CT image, and the patient was treated with ultrasound-guided drainage 4 months after cryoablation. **(c)** Contrast-enhanced CT performed 2 years after cryoablation showed a well-treated renal tumor (arrow), with no sign of local recurrence or infection.

to the treatment of more complex tumors and fragile patients. Furthermore, data from this study showed that major complications, including the development of an abscess, after cryoablation occur later than after partial nephrectomy, which calls for a longer follow-up when reporting complications for cryoablation. Regarding the results for major complications after cryoablation within 30 days, the present study showed a rate of 2.9% compared with the rate of 7.5% reported by Schmit et al (21). Furthermore, the rate of major complications within 30 days after cryoablation in this study is comparable with the rate of major complications after percutaneous microwave ablation of 2.2% recently reported by Yu et al (25). When accounting for major complications within 90 days, the difference in the complication rate between partial nephrectomy (3%) and cryoablation (10%), although not significant ($P = .15$), was considered clinically relevant.

Bhindi et al (26) reported complication rates of 15% and 31% after cryoablation and partial nephrectomy, respectively, in patients with a single kidney. Bhindi et al (26) performed several adjunctive procedures to cryoablation to reduce complications in selected tumors, whereas only hydrodisplacement and double-J stents were used in selected cases in the present study,. In addition, in the same study (26), only 3% of partial nephrectomies were robot-assisted, whereas 93% of partial nephrectomies were robot-assisted in the present study, which may have contributed to the lower complication rate after partial nephrectomy. The type of partial nephrectomy was omitted from the analyses because the results would have been too imprecise considering that only 2 patients had open operation and 4 were converted to open operation in this study.

In the literature, the results from laparoscopic cryoablation are often combined with those from percutaneous cryoablation (27). Novara and Ficarra (28) argued against laparoscopic cryoablation being considered a less invasive procedure compared with robot-assisted partial nephrectomy for elderly patients with severe comorbidities given the need for GA. In the present study, 92% of the cryoablation procedures were performed under sedation; however, 15% required GA for the insertion of a double-J stent before cryoablation. Even though insertion of a double-J stent requires a shorter period of GA than that required by robot-assisted partial nephrectomy, it is an additional invasive procedure for the patient to undergo.

A high RENAL score was significantly associated with more complications within 30 days after cryoablation compared with a low RENAL score. Sisul et al (29) also found RENAL score to be a predictor for complications after cryoablation, and Schmit et al (21) stated that nearness

Table 3. Logistic Regression of Complications and Readmissions Based on Patient and Tumor Characteristics by Group

Percutaneous cryoablation		
Outcomes	**Unadjusted OR (95% CI)**	**Adjusted[§] OR (95% CI), *P* value**
Overall postoperative complications within 30 d		
High RENAL score group*	8.00 (1.59–40.20)	5.86 (1.08–31.81),.040
100% endophytic†	9.62 (2.28–40.67)	7.70 (1.72–34.50),.008
Overall postoperative complications within 90 d		
Double-J stent‡	7.55 (1.88–30.29)	9.88 (2.18–44.68),.003
Major complications		
Double-J stent‡	7.55 (1.88–30.29)	12.8 (2.52–65.26),.002
Readmission within 30 d		
Double-J stent‡	5.69 (1.50–21.58)	5.39 (1.37–21.06),.015
Partial nephrectomy		
	Unadjusted OR (95% CI)	**Adjusted[‖] OR (95% CI)**
Major complications		
CCI	2.10 (1.06–4.17)	2.12 (1.05–4.30),.036

CCI = Charlson Comorbidity Index; CI = confidence interval; OR = odds ratio; RENAL score = radius-endophytic-nearness-anterior-location nephrometry score.
*A high RENAL score compared with a low RENAL score.
†100% endophytic compared with ≥50% exophytic.
‡Having a double-J stent compared with not having a double-J stent.
§Logistic regression adjusted for sex and age.
‖Logistic regression adjusted for sex (age included in the CCI).

to the renal sinus, tumor diameter, and an increased number of probes were significant factors in predicting major complications after cryoablation. This study found that the endophytic properties of the tumor were significantly associated with overall complications within 30 days; however, Schmit et al (21) found these properties to be a predictor for major complications only, and Breen et al (30) did not find such tumor properties to be associated with any complications.

Receiving a double-J stent increases the risk of infection and discomfort for the patient (31). This study showed that double-J stent placement was also associated with complications within 90 days, major complications, and readmissions after cryoablation. Several studies have shown that double-J stents pose a high risk of urinary tract infection (31,32). Furthermore, patients with comorbidities are predisposed to complications linked to double-J stents, which are more prevalent in patients choosing cryoablation (31). The use of a double-J stent is recommended when there is a risk of damaging the ureter; however, the stent should be removed as soon as possible after cryoablation. Because cryoablation is a treatment typically offered to patients who are frail and have comorbidities, it is worth considering the increased risk of a major postoperative complication if the patient has a tumor that requires a double-J stent.

Chandrasekar et al (2) have recently presented their findings on the complex nature of treatment decision making for patients with localized RCC. Results from the present study, which reported a similar rate of complications after cryoablation to that after partial nephrectomy, contribute to the current body of knowledge and clinical observations needed to make appropriate treatment decisions for individual patients. In the present study, the best treatment option was determined for each individual patient on the basis of shared decision making after a multidisciplinary team conference. More studies are needed within this subject area, including active surveillance as an alternative treatment strategy and a consideration of the current clinical guidelines (3).

The nonrandomized design of the present study contributed to the risk of selection bias, considering the heterogeneity of comorbidity, age, and PS score across treatment groups. However, if the study had been randomized, several patients would have been excluded because they were not considered to be surgical candidates. Such an approach would have limited the results by only benefiting a narrow group of patients in the clinical decision-making process. Another limitation was the sample size, which reduced the number of events in some outcome variables. In addition, the sample size resulted in wide CIs that affected the precision and limited the generalizability of the results. Furthermore, cryoablation was performed at a single site, which is another limitation of the study. However, the data were prospectively collected and driven by a predefined protocol. Moreover, the cohort represents consecutively treated patients from 2 highly specialized institutions, covering one third of the population in Denmark treated with nephron-sparing procedures for RCC. Furthermore, all patients in this study were discussed at a multidisciplinary team conference, and treatment decisions were reached on the basis of shared decision making, which ensured a solid foundation for the decision-making process. The multidisciplinary team approach minimized selection bias because of the

surgeon's technical preferences; however, because cryoablation was only implemented as a treatment at 1 of the institutions, this selection bias could not be eliminated.

In conclusion, similar complication rates were found after partial nephrectomy and cryoablation. Even though patients in the cryoablation group had a higher CCI, were older, and had a worse PS, none of these patient characteristics were associated with complications or readmission after cryoablation. Tumor complexity and double-J stent requirements were associated with complications after cryoablation, whereas a high CCI was associated with complications after partial nephrectomy.

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APPENDIX A

A Technical Note With a Full Description of Computed Tomography–Guided Cryoablation

Cryoablation was performed under computed tomography (CT) guidance. During the inclusion period (June 2019 to February 2021), sedation was the preferred form of anesthesia, using intravenous dexmedetomidine and remifentanil combined with local anesthesia with lidocaine and bupivacaine. No standard antibiotic prophylaxis was applied before or during the cryoablation procedure. In cases where there was a risk of damaging the ureter during the procedure, a double-J stent was inserted. The procedure was performed before cryoablation (1 day or up to 14 days before treatment). The double-J stent insertion was performed under general anesthesia, and all patients received perioperative antibiotic prophylaxis, according to an individual urine culture report or the national infection hygiene guidelines.

The patient was placed in a prone or lateral decubitus position opposite the renal tumor. To protect the vital organs and nerves close to the tumor, hydrodisplacement was performed according to international recommendations (17) using an 18-cm, 18-gauge percutaneous entry thin wall needle (Cook, Bloomington, Indiana) with 2% iodine-based saline solution.

The cryoprobes were inserted percutaneously under CT-fluoroscopy guidance (continuous rotation) (2 × 128-channel/slice Siemens Somatom Flash system; Siemens Healthcare, Erlangen, Germany). An argon-based cryoablation system (ICEfx system; Boston Scientific, Minneapolis, Minnesota) with 14-gauge or 17-gauge sealed cryoprobes was used. Percutaneous cryoablation was performed with a double 10-minute freeze, with an 8-minute thaw period in between. An expanding ice ball covered the entire tumor and exceeded the tumor circumference by a minimum 5-mm margin. Sequential CT scans were obtained at 4 and 8 minutes into each freezing cycle to identify the ice ball, evaluate needle position, and monitor for potentially intraoperative complications. The indication of technical success was evaluated after the completion of the procedure.

After cryoablation, all patients were observed in a recovery ward for 1 hour and observed afterward for 2–3 hours and discharged in the event of no immediate complications. All patients were offered a consultation 14 days after surgery in the outpatient clinic. The follow-up protocol consisted of CT scans or magnetic resonance imaging of the kidneys at 3, 6, and 12 months, followed by CT scan or magnetic resonance imaging of the kidneys plus full chest and abdomen annually up to 5 years after surgery.

Table E1. Description of Patients with 2 Tumors, Treated in the Same Session or in >1 Session with <90 Days between, and Patients Developing New Tumors Requiring Treatment >90 Days after the First Treatment within the Inclusion Period

Patients with 2 tumors treated in the same session (n = 5)

Treatment date	Treatment type	Tumor placement Left/right	Comment
August 2019	Cryoablation	Right	Two independent tumors, 1.8 and 2.2 cm, in the right kidney. Both clear cell adenocarcinomas. Former pT3aN0M0 clear cell adenocarcinoma, Fuhrman grade 2, Leibovich score of 6 in the left kidney. Treated with RN on the left side 5 weeks before cryoablation.
October 2019	Cryoablation	Bilateral	Two tumors, 2.5 cm right and 2.0 cm left. Both tumors were PRCCs. Previous 3.5-cm PRCC in the left kidney treated with cryoablation in 2017.
April 2020	Cryoablation	Right	Two independent tumors, 2.0 and 2.5 cm. Both tumors were PRCCs. Previous PRCC in the left kidney treated with cryoablation in 2017 and bilateral tumors treated with cryoablation in 2019. No genetic disposition to PRCC.
May 2020	Partial nephrectomy	Left	Two independent tumors, 2.0 and 4.0 cm, in the left kidney, treated with partial nephrectomy at ZUH.
January 2021	Cryoablation	Right	Two independent tumors, 2.8 and 2.0 cm, in the right kidney. Both tumors were PRCCs. Former pT1b PRCC left treated with radical nephrectomy in 2020.

Patients with bilateral tumors treated in >1 session <90 d after the first treatment (n = 4)

First treatment	Second treatment	Time between (d)	Comment
Cryoablation	Cryoablation	7	Treated in 2 sessions because of tumor placement.
Cryoablation	Partial nephrectomy/radical nephrectomy	40	Converted to radical nephrectomy and, therefore, only included in data with the first treatment.
Cryoablation	Partial nephrectomy	26	Had an endophytic 2.5-cm tumor in the left kidney treated with cryoablation and an exophytic 2.5-cm tumor in the right kidney treated with partial nephrectomy. Both tumors were clear cell adenocarcinomas.
Cryoablation	Cryoablation	28	Procedure in 2 steps because the need for a double-J stent to treat the second tumor was discovered after surgery.

Patients developing new tumors requiring treatment
Treated >90 d after the first treatment within the inclusion period (n = 2)

First treatment	Second treatment	Time between (d)	Comment
Cryoablation	Cryoablation	322	Had a 4.0-cm tumor in the right kidney treated with cryoablation in 2019 and a 3.5-cm tumor on the left side treated with cryoablation in 2020. Both tumors were PRCCs; however, the first tumor was type 2, and the second was type 1. Retrospectively, the second tumor was visualized on CT back in 2019.
Cryoablation	Cryoablation	189	Treated for 2 tumors in both sessions, October 2019 and April 2020; see under patients with 2 tumors were treated in the same session.

CT = computed tomography; PRCC = papillary renal cell carcinoma; RN = radical nephrectomy; ZUH = Zealand University Hospital.

Table E2. Description of Postoperative Complications after Partial Nephrectomy and Cryoablation, within 30 and 90 Days

Postoperative complications after partial nephrectomy

Postoperative complications <30 d	Grade	Comments
Pain	1	Increasing pain located in the right side of the abdomen 7 d after robot-assisted partial nephrectomy on the right side. CT imaging showed a small subcutaneous hematoma at the port site, located where the patient experienced the most pain.
Insufficient healing	1	Insufficient healing of cicatrice after robot-assisted partial nephrectomy and pain in relation to this. Conservatively treated by the patient's general practitioner.
Pain	2	Severe pain on the day of robot-assisted partial nephrectomy. The patient was given a diagnosis of prolapse before surgery. Treated with an epidural for pain relief.
Infection	2	Fever, shortness of breath, and sharp chest pain the day after robot-assisted partial nephrectomy. Radiography showed pneumonia. Treated with IV antibiotics.
Infection	2	Presenting with pain and fever 9 d after robot-assisted partial nephrectomy. CT showed a small perirenal hematoma. Treated with IV antibiotics. Experienced poor emptying of the bladder and LUTS immediately after robot-assisted partial nephrectomy, treated with a urethral catheter. Therefore, treatment supplemented with an alpha-blocker. Fully recovered 14 d after robot-assisted partial nephrectomy.
Infection	2	Readmitted with fever 2 d after robot-assisted partial nephrectomy. Treated with IV antibiotics.
Infection	2	Fever 2 d after robot-assisted partial nephrectomy. Treated with IV antibiotics and discharged with PO antibiotics.
Infection	2	Urinary tract infection with dysuria and pollakiuria. Treated with relevant PO antibiotics.
Infection	2	Readmitted with fever 2 d after robot-assisted partial nephrectomy. Treated with IV antibiotics.
Urosepsis	2	Fever and gross hematuria 3 d after robot-assisted partial nephrectomy. Was discharged with a urethral catheter owing to insufficient emptying of the bladder. A small hematoma on CT was suspected as the focus of infection. Treated with IV antibiotics for 5 d. The patient had the urethral catheter until 14 d after surgery, at which point it was removed. Hereafter, the patient fully recovered.
Skin infection	2	Skin infection in relation to the port near the umbilicus. Treated with PO antibiotics. Fully recovered 3 wk after robot-assisted partial nephrectomy.
Skin infection	2	Skin infection in relation to the camera port, 11 d after robot-assisted partial nephrectomy. Treated with PO antibiotics.
Bleeding	2	Bleeding 1 d after robot-assisted partial nephrectomy. Treated conservatively with blood transfusion.
Bleeding	2	Readmitted 2 d after robot-assisted partial nephrectomy with pain. CT angiography showed bleeding. Treated conservatively with blood transfusion.
Bleeding	2	Presenting with urine retention because of gross hematuria 13 d after robot-assisted partial nephrectomy. CT showed a small subcapsular hematoma in relation to the pelvis. The patient's ATA, which he received for the treatment of apoplexia, was stopped. Was treated conservatively with bed rest and a urethral catheter.
Urine retention	2	Developed urine retention the day after robot-assisted partial nephrectomy Was discharged with a urethral catheter. This was removed 1 wk later by the general practitioner.
Infection and urine retention	2	Developed urine retention 3 d after robot-assisted partial nephrectomy. Treated with a urethral catheter for 3 d. Ten days later, treated for urinary tract infection with PO antibiotics.
Infection, pain, and dyspnea	2	Severe pain the day after robot-assisted partial nephrectomy. CT showing a small bleed and hematoma. Conservatively treated with an intramuscular quadratus lumborum block. Two days later, readmitted with dyspnea and urinary tract infection treated with PO antibiotics and positive expiratory pressure.
Bleeding	3b	Reoperation on POD 3 because of severe bleeding. Resulting in radical nephrectomy and splenectomy. Furthermore, the patient tested positive for coronavirus disease 2019 at admission without symptoms.
Abscess	3b	Fever and infection in the cicatrice 10 d after open partial nephrectomy. CT showed abscess. First US-guided drainage but was insufficient. Therefore, drainage under GA 20 d after partial nephrectomy. In all, revised 3 times under GA between 3 and 4 wk after open partial nephrectomy. Fully recovered 3 mo after partial nephrectomy. CT at 6 mo showed full remission of the abscess.
Ileus/small bowel obstruction	3b	Severe abdominal pain and vomiting a few days after being discharged after open partial nephrectomy. CT showed small bowel obstruction and an incarcerated hernia. The patient had an exploratory laparotomy, where the hernia was loosened without any complications. Fully recovered after 14 d.

Postoperative complications after cryoablation

Postoperative complications <30 d	Grade†/‡	Comments
Pain	1/B	One day after cryoablation, in contact with the emergency room owing to severe pain and insecurity. US of the kidney without suspicion of acute bleeding. Treated with PO morphine, and fully recovered 3 d after treatment.
Pain	1/B	Severe pain the night after cryoablation. Treated with morphine and observed for 1 d. Fully recovered a few days later.
Dehydration	1/C	Fifteen days after cryoablation, readmitted because of poor general condition and severe dehydration. Treated with IV fluids. Recovered to baseline after 1 wk of hospitalization. Had a prophylactic double-J stent, removed 61 d after cryoablation.
Skin infection	2/C	Skin infection treated with PO antibiotics 12 d after cryoablation. Fully recovered after treatment.
Infection	2/C	Developed fever of 40°C 4 d after cryoablation. Urinary tract infection was suspected on urinalysis. The patient was treated with PO antibiotics 3 times over the following 2 mo. On CT after 1 mo, slight suspicion of an infection in the

continued

Table E2. Description of Postoperative Complications after Partial Nephrectomy and Cryoablation, within 30 and 90 Days *(continued)*

Postoperative complications after cryoablation

Postoperative complications <30 d	Grade†/‡	Comments
		cryoablation cavity. Because of a good clinical response to antibiotics, CT was repeated 1 mo later, showing regression of the suspected infected area. Renography showed a decrease in function from 41% before cryoablation to 25% 3 mo after cryoablation.
Infection and hematoma/bleeding	2/C	Had an ureteropelvic junction obstruction on the right side scheduled to a Hynes-Anderson operation. On that account and owing to tumor location, the patient had bilateral double-J stents inserted on the day of cryoablation on the left side. Developed hematuria immediately after treatment, probably because of a prostatic bleed during insertion of the double-J stents. Was readmitted 4 d after cryoablation because of pain, fewer, and gross hematuria. CT showed a 11-cm × 9-cm × 5-cm retroperitoneal hematoma on the right side. Conservative treatment with pain relief and IV antibiotics.
Skin infection	2/C	Skin infection treated with PO antibiotics 7 d after cryoablation. Fully recovered after treatment.
Urine retention/ hematuria	2/C	Developed acute urine retention with gross hematuria immediately after cryoablation under sedation. Was shortly unconscious and, therefore, treated with atropine. Was treated with a urethral catheter and discharged after 2 d. Was known to have LUTS and prostate cancer before cryoablation.
Infection	2/C	Fever, positive urine culture, and pain localized to the treated kidney 15 d after cryoablation. CT showed no signs of infection. Treated with PO antibiotics.
Infection	2/C	Treated with PO antibiotics because of dysuria. Urine culture showing urinary tract infection. No history of LUTS and urinary tract infection before cryoablation.
Urosepsis	2/C	Fever and pollakiuria 9 d after cryoablation. Underwent cystoscopy 3 d before this infection because of a history of urinary tract infection. Was treated with IV antibiotics.
Urosepsis and hematuria	3b/D	Severe hematuria and fever the day after cryoablation. Infection treated with IV antibiotics and hematuria conservatively with a urethral catheter until clear urine. The patient had known renal agenesia, ureterocele, and hydronephrosis on the right side before cryoablation. Therefore, had a prophylactic double-J stent before cryoablation. Postprocedural CT showed hydronephrosis and a displaced double-J stent, which was changed under GA.
Bleeding	4a/D	Renal bleeding 7 d after cryoablation treated with selective embolization. Needed intensive care for 6 d, including the need for hemodialysis because of acute renal failure. Received several blood transfusions. CT showed perirenal hematoma after 3 mo and regression after 6 mo. Had no need for dialysis after discharge. Received AC treatment because of a mechanical heart valve. AC was paused according to guidelines before cryoablation.
Bleeding	4a/D	Developed bleeding the night after cryoablation. The patient presented with severe pain, and CT showed subcapsular hematoma. Conservatively treated with blood transfusions and intensive care. CT 1 mo after treatment showed regression, and magnetic resonance imaging 5 mo later showed total remission.
Postoperative complications 30–90 d	**Grade†/‡**	**Comments**
Hematuria and urinary tract infection	2/C	Acute urine retention owing to hematuria and urinary tract infection 50 d after cryoablation. Treated with a urethral catheter and PO antibiotics. Also experienced urine retention a few days after cryoablation and treated with antibiotics for urinary tract infection several times in the period. Furthermore, examined with CT and cystoscopy without finding any other cause of hematuria. Fully recovered 3 mo after cryoablation.
Abscess*	2/D	Infection 35 d after cryoablation treated with IV antibiotics. CT showed a small abscess not suited for drainage. Readmitted for IV antibiotics twice 2–3 mo after cryoablation. The abscess increased, and the patient was treated with drainage 4 mo after cryoablation.
Infection and hematuria	2/D	Fever, gross hematuria, and urinary tract infection 38 d after cryoablation. Treated with IV antibiotics for 5 d. The patient had a double-J stent before cryoablation, removed 2 mo after cryoablation.
Abscess	3a/D	Readmitted 84 d after cryoablation with fever and infection. Former treated for infection with IV antibiotics 3 d after cryoablation. CT showed an abscess. Treated with drainage and PO antibiotics. CT after 6 mo found regression, and patient fully recovered.
Abscess	3a/D	Abscess in the cryoablation cavity found at a routine CT follow-up 89 d after cryoablation. Because of severe dementia, symptoms were difficult to detect; however, the patients' caretakers described periods with malaise and severe fatigue 1–3 mo after cryoablation. Abscess was treated with drainage and IV antibiotics under 1 wk of hospitalization.
Abscess	3b/D	Sixty-four days after cryoablation readmitted with urosepsis. CT showed hydronephrosis, severe hydroureter, and an abscess. Treated with drainage, double-J stent under GA, and IV antibiotics. The patient was known to have BPH and underwent intermittent catheterization because of chronic urine retention. Double-J stent removed 2 mo later in connection with TUR-P. Renography 6 mo after cryoablation showed that the kidney had fully recovered to baseline.
Abscess	3b/D	The patient had a double-J stent before treatment, inserted on the day of cryoablation under IV antibiotic coverage. The double-J stent was removed 27 d after cryoablation. Treated with PO antibiotic 5 d after cryoablation because of positive urine culture before cryoablation. CT follow-up 3 mo after cryoablation showed hydronephrosis and uroplania. Had symptoms consisting of pain located around the kidney but no clinical signs of infection. Treated with a double-J stent for 3 mo. The patient fully recovered 6 mo after cryoablation.
Displacement of a prophylactic double-J stent	3b/D	Had a double-J stent prophylactic before cryoablation. Could not be removed because of displacement 8 wk after cryoablation. Removed under GA. In addition, developed urine retention just after cryoablation. Did not achieve sufficient emptying of the bladder after double-J stent insertion. Severe comorbidity with diabetes, apoplexia cerebri, and known LUTS before cryoablation. Was discharged with a urethral catheter, which became a permanent solution.

continued

Table E2. Description of Postoperative Complications after Partial Nephrectomy and Cryoablation, within 30 and 90 Days *(continued)*

Postoperative complications 30–90 d	Grade†/‡	Comments
Pain	3b/D	Severe pain and unconsciousness. Interpreted as pain provoked because of a double-J stent. The double-J stent was removed 5 wk after cryoablation under GA because of pain and lack of patient cooperation with removal in LA. Readmitted and treated with IV pain relief. The patient had known mental illness.
Abscess	3b/D	Had a double-J stent prophylactic to cryoablation because the tumor location was close to the ureter. This was removed 14 d after cryoablation. Six weeks after cryoablation, the patient was admitted with fever, pain, and reduced appetite. CT showed a 12-cm × 10-cm × 7-cm abscess. Treated with drainage, IV antibiotics, and a new double-J stent because of hydronephrosis.

Note–Postoperative complications were graded according to the Clavien-Dindo classification (16) and, additionally, with the Society of Interventional Radiology classification for cryoablation (18).

AC = active surveillance; ATA = antithrombotic agent; BPH = benign prostatic hyperplasia; CT = computed tomography; GA = general anesthesia; IV = intravenous; LA = local anesthesia; LUTS = lower urinary tract symptoms; PO = peroral; POD = postoperative day; TUR-P = transurethral resection of the prostate; US = ultrasound.

*Case shown in **Figure 2**.

†Graded according to the Clavien-Dindo classification (16).

‡Graded according to the Society of Interventional Radiology classification (18).

Table E3. Association between Patient, Tumor, and Treatment Characteristics with Postoperative Complications within 30 and 90 Days, Major Complications within 90 Days, and Readmission within 30 Days

Patient, tumor, and treatment characteristics	Cryoablation				Partial nephrectomy			
	Overall postoperative complications within 30 d (n = 14)	Overall postoperative complications within 90 d (n = 10)	Major complications (n = 10)	Readmission within 30 d (n = 11)	Overall postoperative complications within 30 d (n = 20)	Overall postoperative complications within 90 d (n = 0)	Major complications (n = 3)	Readmission within 30 d (n = 12)
Age	0.299	0.310	0.202	0.737	0.308	-	0.328	0.317
Sex	0.059	1.000	0.460	0.723	0.376	-	1.000	0.062
BMI <18.5 18.5–24.9 ≥25 ≥30 ≥35	0.948	0.852	0.852	0.951	0.415	-	0.729	0.323
Smoking Yes No Former	0.855	1.000	1.000	0.827	0.249	-	0.230	0.228
Alcohol use None Female, <7 units; male, <14 units Female, >7 units; male, 14 units	0.583	0.233	0.755	0.425	0.101	-	1.000	0.603
Symptoms of RCC Yes No	0.210	1.000	1.000	0.353	0.467	-	1.000	1.000
Other malignity None Ongoing treatment Follow-up/ surveillance	0.062	0.864	1.000	0.568	1.000	-	1.000	1.000
Other renal disease Yes No	0.474	0.207	1.000	0.237	0.569	-	1.000	1.000
CCI	0.343	0.632	0.216	0.452	0.702	-	**0.026**	0.059
ASA group	0.567	1.000	1.000	1.000	0.234	-	0.473	0.317
Performance score	0.767	0.254	0.190	0.224	0.321	-	0.442	0.052
RENAL score 4–6 (low) 7–9 (medium) 10–12 (high)	**0.004**	0.145	0.392	0.084	0.558	-	1.000	0.893
Clinical tumor stage cT1a cT1b	1.000	0.610	0.610	0.352	0.196	-	0.553	0.122
Tumor size	0.638	0.305	0.359	0.265	0.106		0.530	0.204
Endophytic ≥50% exophytic <50% exophytic 100% endophytic	**0.003**	0.065	0.665	0.061	0.839	-	0.564	0.115
Nearness to collecting system/renal sinus ≥7 mm 4–7 mm ≤4 mm	0.112	0.258	0.064	0.622	0.448	-	0.666	0.522
Multiple tumors	0.595	1.000	1.000	0.595	1.000	-	1.000	1.000
Sedation or GA	1.000	0.568	0.170	0.596	n/a	-	n/a	n/a
Double-J stent	0.448	**0.007**	**0.007**	**0.016**	n/a	-	n/a	n/a

continued

Table E3. Association between Patient, Tumor, and Treatment Characteristics with Postoperative Complications within 30 and 90 Days, Major Complications within 90 Days, and Readmission within 30 Days *(continued)*

Patient, tumor, and treatment characteristics	Cryoablation				Partial nephrectomy			
	Overall postoperative complications within 30 d (n = 14)	Overall postoperative complications within 90 d (n = 10)	Major complications (n = 10)	Readmission within 30 d (n = 11)	Overall postoperative complications within 30 d (n = 20)	Overall postoperative complications within 90 d (n = 0)	Major complications (n = 3)	Readmission within 30 d (n = 12)
Number of probes/ tumor 2–3 4–5 6–7	0.637	0.635	0.635	0.297	n/a	-	n/a	n/a
Hydrodisplacement Yes No	0.762	0.164	0.497	1.000	n/a	-	n/a	n/a
WIT Zero ischemia WIT 1–30 min	n/a	n/a	n/a	n/a	0.749	-	0.483	0.702

Note–Significant values are highlighted in bold. Categorical variables were analyzed using the Fisher exact test or chi-square test. Continuous variables were analyzed using the *t*-test or Wilcoxon rank sum test. The level of statistical significance was set at .05.

ASA = American Society of Anesthesiologists; BMI = body mass index; CCI = Charlson comorbidity index; GA = general anesthesia; n/a = not applicable; RCC = renal cell carcinoma; RENAL score = radius-endophytic-nearness-anterior-location nephrometry score; WIT = warm ischemia time.