Research Square

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Long-Term Assessment of Kidney Function After Nephron-Sparing Surgery Using 99mTc-DMSA Scintigraphy: Is There a Marker for Predicting Split Renal Function?

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Research Article

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Abstract

Objectives

To evaluate split renal function (SRF) using technetium-99m-dimercaptosuccinic acid (^{99m}Tc-DMSA) scintigraphy after nephron-sparing surgery (NSS), and to identify clinical factors affecting SRF decline.

Methods

A retrospective analysis was conducted on open (n = 28) and laparoscopic (n = 18) NSS patients between 2018 and 2023 with at least 1 year of follow-up. Based on postoperative ^{99m}Tc-DMSA, patients were divided into Group-1 (SRF ≤ 45%) and Group-2 (SRF > 45%). Patient's demographics, tumor characteristics, and clinical parameters were compared.

Results

A total of 46-patient (26 males/20 females) with median 55 (25–71) years old were included. Group-1 had larger tumors (40 (12–106) vs. 26 (10–65) mm; p = 0.038), higher PADUA-score (7 (6–9) vs. 6 (6–8); p = 0.028), and longer operation time (180 (90–240) vs. 120 (60–240) min; p = 0.003). NSS without vascular clamping was more common in Group-2 (80.8% vs. 35%, p = 0.002). A significant GFR decline was noted in Group-1 (13.1 (8.1–27.1) vs. 6.1 (-6.2–9.3) ml/min/1.73 m²; p = 0.004). SRF was negatively correlated with tumor size (r=-0.458, p = 0.01), warm ischemia time (r=-0.355, p = 0.015), operation time (r=-0.458, p = 0.001), and hospital stay (r=-0.466, p = 0.001). A tumor size of 29 mm was identified as the optimal cut-off in the ROC-analysis to predict a decrease of SRF below 45% on ^{99m}Tc-DMSA (AUC (CI:95%) = 0.68 (0.52–0.85); p = 0.038).

Conclusions

Long-term SRF decline after NSS appears to be associated with larger tumors and warm ischemia time. Particularly, our results suggest that tumor size ≥ 29 mm may be used as a potential predictor of SRF reduction below 45% on ^{99m}Tc-DMSA.

Introduction

According to 2022 GLOBOCAN data, renal cell carcinoma (RCC) accounts for approximately 2.2% of all cancers [1]. The incidence of RCC increases with age, peaking between 60 and 70 years [2]. Given the elevated risk of comorbid conditions in elderly patients—such as hypertension and diabetes mellitus—that may compromise renal function, nephron-sparing surgery (NSS) is important modality for preserving renal capacity and minimizing the risk of renal failure. The EORTC 30904 randomized trial demonstrated that NSS significantly reduces the incidence of moderate renal dysfunction (eGFR < 60 mL/min/1.73 m²) [3]. The goal of NSS is complete resection of renal tumor with the largest preserved volume of normally parenchyma. However, there is limited knowledge about parenchymal damage during NSS surgery and the function of the remaining renal parenchyma.

Quantitative single-photon emission computed tomography (SPECT) using technetium-99m-dimercaptosuccinic acid (^{99}Tc-DMSA) is a non-invasive, reliable, and reproducible imaging modality for assessing individual renal function [4]. ^{99}Tc-DMSA scintigraphy not only provides high-resolution anatomical images of the kidneys but also allows for the quantitative evaluation of split renal function (SRF), which correlates with the renal plasma flow of each kidney [5]. Due to these characteristics, ^{99}Tc-DMSA, which has been widely used for years to evaluate SRF in various pediatric and adult conditions, has also been utilized to assess parenchymal function in a few NSS studies [6–8].

The aim of this study was to assess SRF using static renal scintigraphy with ^{99}Tc-DMSA in postoperative period in patients who underwent NSS for renal tumors, and to investigate potential clinical factors associated with a decline in SRF on ^{99}Tc-DMSA scintigraphy.

Material and Methods

The study was approved by the Institutional Ethics Committee. A retrospective analysis was performed on patients who underwent NSS at our institution between 2018 and 2023, with a minimum follow-up period of one year. The results of ^{99}Tc-DMSA scintigraphy performed after the first postoperative year were evaluated in patients who had no preoperative pathology other than the tumor in the affected kidney and a completely normal contralateral kidney, as confirmed by contrast-enhanced computed tomography (CT). Of the 98 patients initially

reviewed, 52 were excluded due to incomplete data, chronic kidney disease (stage ≥ 2), solitary kidney, nephrolithiasis, congenital renal anomalies, or a history of renal or ureteral surgery.

Patient characteristics-including age, sex, comorbidities, Charlson Comorbidity Index, American Society of Anesthesiologists (ASA) score, smoking status, and body mass index (BMI)-were recorded. Tumor characteristics were assessed using tumor size, laterality, and nephrometry scores (RENAL and PADUA). Perioperative and clinical parameters, including type of surgery, operation time (OT), warm ischemia time (WIT), estimated blood loss (EBL), length of hospital stay, and preoperative and postoperative estimated glomerular filtration rate (eGFR), were also analyzed.

Split renal function has been reported to be nearly equal in healthy individuals (50.1% vs. 49.9%; p = 0.629), whereas it is reduced in kidneys with cysts ≥ 4 cm compared to the contralateral side (48.3% vs. 51.7%; p = 0.001) [9]. Therefore, we only included patients with morphologically normal kidneys -except for the presence of a tumor- on preoperative contrast-enhanced abdominal CT, and who were expected to have an approximately equal split renal function (~ 50%) and in the first year of NSS, we defined a cut-off value of 45% for split renal function on ^{99m}Tc-DMSA scintigraphy. Based on ^{99m}Tc-DMSA scintigraphy results, patients were divided into two groups according to the split renal function (SRF) of the operated kidney: Group 1 included those with an SRF ≤ 45%, and Group 2 included those with an SRF > 45%. Patient demographics, tumor characteristics, and operative and clinical parameters were compared between the two groups.

Surgical Technique

Laparoscopic NSS was performed using a transperitoneal approach, whereas open NSS was conducted via a retroperitoneal approach. All procedures were performed by experienced surgeons in NSS. In both LPN and OPN cases, the collecting system was closed when necessary, and renorrhaphy was completed with the placement of absorbable hemostatic material (Surgicel®, Ethicon, USA) within the renal parenchyma.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 25. The distribution of variables was assessed both visually (via histograms and probability plots) and analytically (using the Kolmogorov-Smirnov and Shapiro-Wilk tests). Non-normally distributed variables were presented as medians with ranges (minimum–maximum), while categorical variables were expressed as percentages and cross-tabulations. The Mann-Whitney U test was used to compare non-normally distributed variables between two independent groups. Differences in categorical variables between independent groups were assessed using the Chi-square test or Fisher's exact test (when Chi-Square assumptions were not met). The Wilcoxon test was employed to compare paired non-normally distributed variables (i.e., preoperative vs. postoperative values). The Spearman correlation test was used to evaluate associations between non-normally distributed numerical and ordinal variables. The predictive value of various parameters for identifying a decline in DMSA values was assessed using Receiver Operating Characteristic (ROC) curve analysis. A p-value of less than 0.05 was considered statistically significant.

Results

A total of 46 patients (26-male/20-female) with a median age of 55 (25–71) years were included in the study. The median BMI of the patients was 29 (22–45) kg/m^2. Nine patients had diabetes mellitus, 20 had hypertension, and 30 were smoker. The ASA scores were 1 in 22 patients, 2 in 23 and 3 in 1. Of the patients, 20 (43.5%) underwent NSS for a right renal mass, and 18 (39.1%) underwent laparoscopic NSS. Pathology revealed clear cell RCC in 25 (54%) patients, chromophobe RCC in 6 (13%) patients, papillary RCC in 6 (13%) patients and benign (cyst, angiomyolipoma etc.) in the remaining 9 (19.5%) patients. There were 20 (43.5%) patients in Group 1 (SRF on ^{99m}Tc-DMSA ≤ 45%) and 26 (56.5%) patients in Group 2 (SRF on ^{99m}Tc-DMSA > 45%). Comparison of patient characteristics, tumor characteristics, operative and clinical parameters between group 1 and group 2 are shown in Table 1 and Table 2. There was no difference between group 1 and group 2 in terms of age, gender, BMI, surgical side, surgical technique, comorbidities, smoking status, preoperative eGFR values and peri-operative EBL (p > 0.05).

Table 1
Analysis of Categorical Variables According to DMSA Scintigraphy

Variables		Group 1 (DMSA ≤ 45%) n (%)	Group 2 (DMSA > 45%) n (%)	P*
Gender	**Male**	11 (55)	15 (57.7)	0.855
	Female	9 (45)	11 (42.3)	
Side	**Right**	8 (40)	12 (46.2)	0.676
	Left	12 (60)	14 (53.8)	
Surgical type	**Laparoscopic**	7 (35)	11 (42.3)	0.615
	Open	13 (65)	15 (57.7)	
Hypertension	**No**	9 (45)	17 (65.4)	0.167
	Yes	11 (55)	9 (34.6)	
Diabetes Mellitus	**No**	16 (80)	21 (80.8)	0.948
	Yes	4 (20)	5 (19.2)	
Smoking	**No**	11 (55)	19 (73.1)	0.202
	Yes	9 (45)	7 (16.9)	
Ischemia, n (%)	**No clamp**	7 (35)	21 (80.8)	**0.002**
	Yes	13 (65)	5 (19.2)	

*Chi-Square *test was performed and p < 0.05 was considered statistically significant.*

DMSA:99m Tc-Dimercaptosuccinic acid

Table 2
Analysis of Numerical Variables According to DMSA Scintigraphy

Variables	All Patients (n = 46)	Group 1 (n = 20) (DMSA ≤ 45%)	Group 2 (n = 26) (DMSA > 45%)	P*
Age, year	55 (25–71)	56 (25–71)	55 (38–66)	0.894
BMI, kg/m^2	29 (22–45)	29 (22–45)	29 (23–37)	0.731
Tumor size (CT), mm	32 (10–110)	32 (12–110)	25 (10–62)	**0.041**
Tumor size (Pathology), mm	34 (10–106)	40 (12–106)	26 (10–65)	**0.038**
RENAL score	5 (4–8)	5 (4–8)	4 (4–6)	0.06
PADUA score	7 (6–9)	7 (6–9)	6 (6–8)	**0.028**
Operation time, min	156 (60–240)	180 (90–240)	120 (60–240)	**0.003**
Warm ischemia time, min	11 (0–42)	21 (0–39)	0 (0–42)	**0.005**
Estimated blood loss, ml	558 (50-2500)	250 (50-1700)	300 (50-2500)	0.672
SRF (%)	45.5 (10.1–61)	41.2 (10.1–45)	47.9 (45.2–61)	**0.000**
Preopative Creatinine, ml/dl	0.82 (0.4–1.25)	0.74 (0.55–1.25)	0.82 (0.4–1.16)	0.166
Preoperative eGFR, ml/min/1.73 m^2	96 (61–180)	98 (61–134)	88 (68–180)	0.150
Postoperative Creatinine, ml/dl	0.9 (0.52–1.59)	0.88 (0.52–1.59)	0.83 (0.53–1.36)	0.298
Postoperative eGFR, ml/min/1.73 m^2	88 (44–152)	81 (44–140)	89 (57–152)	0.465
Δ-eGFR, ml/min/1.73 m^2	8.13 (0.56–14.3)	13.1 (8.1–27.1)	6.1 (-6.2-9.3)	**0.004**
Hospitalization, day	5 (2–16)	5 (2–10)	4 (2–16)	**0.012**
Mann-Whitney U test was performed and p < 0.05 was considered statistically significant.				
DMSA: Technetium-99m-dimercaptosuccinic acid, SRF: Split Renal Function, Δ-eGFR: Postoperative–Preoperative estimated glomerular filtration rate				

Pathological tumor size was median 34 mm (10–106) and WIT was median 11 mins (0–42). RENAL and PADUA nephrometry scores were median 5 (4–8) and 7 (6–9), respectively. Median eGFR decreased from 96 (61–180) to 88 (44–152) ml/min/1.73 m^2 in all patients (p = 0.004). However, when preoperative and postoperative eGFR values were analyzed separately, a statistically significant decrease in eGFR was found in group 1 (98 (61–134) vs 81 (44–140) ml/min/1.73 m^2, p = 0.003), while no statistically significant difference was observed in group 2 (88 (68–180) vs 89 (57–152) ml/min/1.73 m^2, p = 0.276). In addition, group 1 patients had statistically higher tumor size (40 (12–106) vs 26 (10–65) mm, p = 0.038), PADUA score (7 (6–9) vs 6 (6–8), p = 0.028) and longer OT (180 (90–240) vs 120 (60–240) min, p = 0.003). The rate of NSS without renal artery clamping (80.8% vs. 35%, p = 0.002) was higher in group 2, while higher WIT (21 (0–39) vs 0 (0–42) min, p = 0.005) was found in the Group 1. The eGFR decline after NSS was significantly higher (13.1 (8.1–27.1) vs 6.1 (-6.2-9.3) ml/min/1.73 m^2, p = 0.004) in decreased DMSA uptake (≤ 45%) group.

The correlation analysis of clinical parameters is presented in Table 3. The SRF ratio on ^{99m}Tc-DMSA scintigraphy was negatively correlated with pathological tumor size (r=-0.458, p = 0.01), WIT (r=-0.355, p = 0.015), OT (r=-0.458, p = 0.001), and length of hospitalization (r=-0.466, p = 0.001). No significant correlation was found between SRF ratio and RENAL score (r=-0.211, p = 0.159), PADUA score (r=-0.213, p = 0.154), or EBL (r=-0.092, p = 0.541). Figure 1 shows the ROC curve analysis for the effect of tumor size on kidney function. 29 mm tumor size (sensitivity:75%, specificity:61.5%, AUC (CI: 95%) = 0.68 (0.52–0.85), p = 0.038) were calculated as optimized cut-off points for predicting loss of function (< 45% of SRF on ^{99m}Tc-DMSA) on postoperative ^{99m}Tc-DMSA scintigraphy.

Table 3
Correlation Analysis of the Clinical Parameters

DMSA	DMSA	Age	BMI	Tumor size	RENAL_ score	PADUA_ score	Operation time	Ischemia time	EBL	Hospitalization
	1	**− .07**	**− .171**	**− .458****	**− .211**	**− .213**	**− .458****	**− .355***	**− .092**	**− .466****
Age	− .007	1	− .7	− .142	− .03	− .014	.02	− .073	− .052	− .131
BMI	− .171	− .07	1	**− .316***	− .071	− .024	.158	.111	**.387****	**.505****
Tumor size	**− .458****	.142	**.316***	1	.116	.195	.07	− .019	.250	**.495****
RENAL_score	− .211	− .03	.071	.116	1	**.857****	.016	.033	− .198	− .107
PADUA_score	− .213	− .014	− .071	.195	**.857****	1	− .01	.016	− .1	0.01
Operation time	**− .458****	.02	.158	.07	.016	− .01	1	**.553****	.201	**.436****
Ischemia time	**− .355***	− .073	.111	− .019	.033	.016	**.553****	1	− .095	**.439****
EBL	− .092	− .052	**.387****	.250	− .198	− .1	.201	− .095	1	**.365***
Hospitalization	**− .466****	− .131	**.505****	**.495****	− .107	0.01	**.436****	**.439****	**.365***	1

Spearmen correlation analysis was performed (*p < 0.05, **p < 0,01).

Δ-eGFR = Postoperative–Preoperative estimated glomerular filtration rate, DMSA: Technetium-99m-dimercaptosuccinic acid, BMI: body mass index, EBL: estimated blood loss

Discussion

NSS is the primary treatment modality for T1a renal tumors and is also recommended for larger, appropriate renal tumors [10]. NSS aims to preserve the renal capacity of patients after surgery by removing the tumor with a safe surgical margin and protecting the maximal renal tissue. Despite better renal function preservation compared to nephrectomy, NSS was associated with an 11.3% postoperative decline in eGFR, from 99.82 to 88.57 mL/min/1.73 m² [11]. Di Maida et al. reported a decrease in eGFR of 17% (5.4%–29.3%) following open NSS and 10.9% (3.9%–17.4%) following laparoscopic NSS [12]. A 12% decrease in eGFR was observed at 6 months postoperatively [preop: 92 (78–97) vs. postop: 73 (67–90)] in patients with a median tumor size of 30 mm (20–36) and a WIT of 14 minutes (12–19) in another study [13]. We observed an 8.5% decrease in eGFR at the first postoperative year in our NSS patients. This decline in eGFR was significantly greater in our Group 1 patients (13.4% vs. 6.9%; p = 0.004).

Preservation of renal volume is an important factor for renal function. After NSS, renal parenchymal volume [14], and SRF decline [15]. Grosher et al. reported an average loss of 17.8% in parenchymal volume and 20.7% in individual kidney function, as measured by ^{99m}Tc-DMSA, at a mean of 3.5 (1–6) months after NSS [7]. However, assessing renal volume and especially SRF is not easy. Considering medical and economic factors, performing nuclear scintigraphic testing before and after NSS is not feasible for patients. Therefore, in our study, we had to compare the post-NSS ^{99m}Tc-DMSA scintigraphy findings of our patients with the results of previous study. Kwon et al. found no significant SRF difference between kidneys in healthy individuals (%50.1 vs. %49.9; P = 0.629) [9]. In patients with renal cysts (median size 7.2 cm), SRF was reduced in cystic kidneys (median loss: 5.8%) than healthy control individuals and was also lower than in the contralateral healthy kidney (%48.3 vs. %51.7; P = 0.001) [9]. Consistent with the literature, most of our patients had T1a (76.1%) or T1b (21.7%) tumors [11, 16]. Since most of our patients had small renal masses, to clearly evaluate the clinical impact of NSS on SRF, patients were grouped based on whether their SRF on DMSA scintigraphy was below or above 45%. Tumor size, PADUA score, OT, WIT, duration of hospitalizastion and percentage of GFR decline were higher in patients with ≤ 45% SFR on DMSA.

Another aspect is evaluating which clinical factors influence individual kidney function after NSS. The SRF on ^{99m}Tc-DMSA scintigraphy showed a moderate negative correlation with pathological tumor size, WIT, OT and duration of hospitalization in our patients. Larger tumors and more complex surgeries may contribute to prolonged OT, WIT, length of hospital stay, and increased EBL. Functional loss after NSS is mainly due to peritumoral injury or ischemia from vascular clamping [8].

Renal lesions typically do not contribute to function and may compress adjacent parenchyma. Postoperative function of the operated kidney is considered to depend on the volume of resected nephrons as well as the severity of warm ischemic damage [17]. Dente et al. reported a 7% decrease in SRF at 6 months on ^{99m}Tc-DMSA in kidneys operated with open clampless NSS [18]. Kondo et al. showed an adverse effect of tumor size on residual renal function (coefficient: -0.496; p = 0.01) [19]. In the present study, SRF on ^{99m}Tc-DMSA

scintigraphy showed a negative correlation (r = -0.458; p = 0.01) with pathological tumor size. ROC analysis identified a tumor size of 29 mm as the optimal cut-off value for predicting loss of function on ^{99m}Tc-DMSA, with an acceptable sensitivity of 75% and a specificity of 61.5%. Smaller tumor resections appear to be associated with reduced functional loss. Therefore, our results may offer a simple clinical tool—tumor size—for predicting SRF of less than 45% following NSS.

The optimal WIT duration for preventing significant renal impairment remains unclear. While evidence is limited, the data suggest that keeping WIT under 25 minutes is beneficial [20]. Cold ischemia allows for safely prolonged ischemia times [20]. But the interruption of renal arterial flow still leads to inevitable parenchymal damage [13]. Thompson et al. found that in open NSS, WIT > 20 minutes and cold ischemia > 35 minutes are associated with a higher incidence of kidney damage.

The effect of renal ischemia on functional outcomes after NSS also remains debated. Bakirtas et al. found that ^{99m}Tc-DMSA uptake at 3 months postoperatively was similar to preoperative levels in the NSS kidney (with a tumor size = 37.4 (25–68) mm, a WIT = 53.7 (38–90) minutes and an external renal hypothermia) [21]. Similarly, based on their findings in patients who underwent adequate renal hypothermia during NSS, Kondo et al. concluded that arterial clamping does not have a negative impact on residual renal function [19]. Unlike our late postoperative findings, Gurram et al. also found that although ischemia type and WIT duration influence short-term renal function, they do not correlate with changes in GFR at 12 months [22]. However, Tachibana et al. stated that prolonged ischemia time adversely affects renal function as measured by ^{99m}Tc-DMSA and causes significant renal damage [17].

Hidas et al. found a greater SRF decline with sutures than with tissue sealant (20.36% vs. 11.49%; p = 0.02) in patients with tumors similar in size to ours (35 mm, range 20–60 mm). [8]. However, in the same study, WIT was significantly shorter in the sealant group (19 min vs 29.2 min; p = 0.02) and an SRF reduction of 11.49% was detected in 19 minutes of WIT [8]. Another study reported a 17% (13%–23%) eGFR decrease in open NSS (WIT: 17 (13 – 23) min) and 10.9% (3.9%-17.4%) in laparoscopic NSS (WIT: 15 (12.5 – 22.5) min) [12]. There was a moderate negative correlation between SRF and WIT in our patients.

This study has several limitations. Firstly, it is a retrospective analysis. Additionally, the single-center design and the relatively small sample size may affect the generalizability of our findings. Another limitation is the inability to compare postoperative outcomes with preoperative ^{99m}Tc-DMSA scintigraphy results. However, to minimize this limitation, we included only patients whose kidneys appeared entirely normal on contrast-enhanced CT, apart from the presence of the tumor.

In this study, we assessed the long-term renal function following NSS using 99mTc-DMSA scintigraphy in patients with renal tumors. Our findings suggest that larger tumor size and prolonged warm ischemia time are negatively correlated with split renal function on postoperative ^{99m}Tc-DMSA scintigraphy. Specifically, a tumor size ≥ 29 mm was identified as an optimal cut-off for predicting a reduction in SRF below 45%. This highlights the importance of considering tumor size and warm ischemia time in preoperative planning and patient counseling for NSS. Although NSS remains the preferred treatment to preserve renal function, understanding the factors that contribute to functional decline can help optimize surgical outcomes and improve patient care. Further studies with larger, multi-center cohorts are needed to validate these findings and refine surgical strategies. Nevertheless, our results suggest that a simple clinical parameter—tumor size ≥ 29 mm—may be indicative of renal function loss as assessed by static scintigraphy.

Declarations

Author Contribution

MK : Surgical and Medical Practices, Concept, Design, Data Collecting, Literature Search, Data interpretation, Manuscript drafting and writingGO : Surgical and Medical Practices, Concept, Design, Statistical analysis, Literature Search, Manuscript drafting and writingCO : Data Collecting, Literature Search, Concept, Design, Statistical analysis, Manuscript drafting and writingKAD : Data Collecting, Literature Search, Concept, Design, Manuscript drafting and writingYS : Surgical and Medical Practices, Concept, DesignHKC : Surgical and Medical Practices, Concept, Design, Literature Search, Data interpretation, Manuscript drafting and writing, SupervisionSY : Surgical and Medical Practices, Concept, Design, Literature Search, Data interpretation, Supervision

References

1. Bray F et al (2024) Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 74(3):229–263
2. Capitanio U et al (2019) Epidemiology of Renal Cell Carcinoma. Eur Urol 75(1):74–84

3. Scosyrev E et al (2014) Renal function after nephron-sparing surgery versus radical nephrectomy: results from EORTC randomized trial 30904. Eur Urol 65(2):372–377
4. Groshar D et al (1989) Quantitation of renal uptake of technetium-99m DMSA using SPECT. J Nucl Med 30(2):246–250
5. Kawamura J, Hosokawa S, Yoshida O (1979) Renal function studies using 99mTc-dimercaptosuccinic acid. Clin Nucl Med 4(1):39–46
6. Ergun R et al (2021) Abnormal DMSA renal scan findings and associated factors in older children with vesicoureteral reflux. Int Urol Nephrol 53(10):1963–1968
7. Groshar D et al (1999) Renal function after tumor enucleation: assessment by quantitative SPECT of 99mTc-dimercaptosuccinic acid uptake by the kidneys. J Nucl Med 40(6):968–971
8. Hidas G et al (2007) Functional significance of using tissue adhesive substance in nephron-sparing surgery: assessment by quantitative SPECT of 99m Tc-Dimercaptosuccinic acid scintigraphy. Eur Urol 52(3):785–789
9. Kwon T et al (2016) Simple renal cyst and renal dysfunction: A pilot study using dimercaptosuccinic acid renal Scan. Nephrol (Carlton) 21(8):687–692
10. Ljungberg B (Chair), C.-E. AB, Albiges L, Bedke J, Capitanio U, Dabestani S, Hora M, Klatte T, Kuusk T, Lund L, Marconi L, Pignot G, Powles T, Tran M, Volpe Patient Representative A: Bonn S, R.H. Giles Guidelines Associates: Y. Abu-Ghanem R, Campi S Fernández-Pello Montes, C. Palumbo Guidelines Office: N. Schouten (2024) ISBN 978-94-92671-23-3. 2024: EAU Guidelines Office, Arnhem, The Netherlands. https://uroweb.org/guidelines
11. Cao Y et al (2025) Comparing the long-term prognosis and renal function changes of partial nephrectomy (PN) and radical nephrectomy (RN) in T1 stage renal cell carcinoma patients. Transl Androl Urol 14(3):740–750
12. Di Maida F et al (2025) Perioperative and Mid-Term Oncological and Functional Outcomes After Partial Nephrectomy for Entirely Endophytic Renal Tumors: A Prospective Multicenter Observational Study (The RECORD2 Project). Cancers (Basel), 17(7)
13. Long JA et al (2022) Superselective Ischemia in Robotic Partial Nephrectomy Does Not Provide Better Long-term Renal Function than Renal Artery Clamping in a Randomized Controlled Trial (EMERALD): Should We Take the Risk? Eur Urol Focus 8(3):769–776
14. Woldu SL et al (2015) Comparison of Renal Parenchymal Volume Preservation Between Partial Nephrectomy, Cryoablation, and Radiofrequency Ablation Using 3D Volume Measurements. J Endourol 29(8):948–955
15. Acosta Ruiz V et al (2021) Split renal function after treatment of small renal masses: comparison between radiofrequency ablation and laparoscopic partial nephrectomy. Acta Radiol 62(9):1248–1256
16. Yao Y et al (2020) The Mayo Adhesive Probability Score Predicts Longer Dissection Time During Laparoscopic Partial Nephrectomy. J Endourol 34(5):594–599
17. Tachikake T et al (2009) Decrease of renal function due to warm ischemia after laparoscopic partial nephrectomy: evaluation using 99mTc-DMSA renal scintigraphy. Urol Int 82(2):162–165
18. Dente D et al (2010) Open partial nephrectomy with no clamping of the pedicule: a good surgical option in treatment of renal cancer. Minerva Urol Nefrol 62(4):341–346
19. Kondo T et al (2002) Impact of arterial occlusion during partial nephrectomy on residual renal function: an evaluation with (99m)technetium-dimercaptosuccinic acid scintigraphy. Int J Urol 9(8):435–440
20. Volpe A et al (2015) Renal Ischemia and Function After Partial Nephrectomy: A Collaborative Review of the Literature. Eur Urol 68(1):61–74
21. Bakirtas H et al (2009) Nephron-sparing surgery: the effect of surface cooling and temporary renal artery occlusion on renal function. Urol Int 82(1):24–27
22. Gurram S et al (2025) *Renal Function After Partial Nephrectomy: A Comparative Analysis of Warm, Cold, and No Ischemia Methods.* Urol Pract, : p. 101097upj0000000000000779

Figures

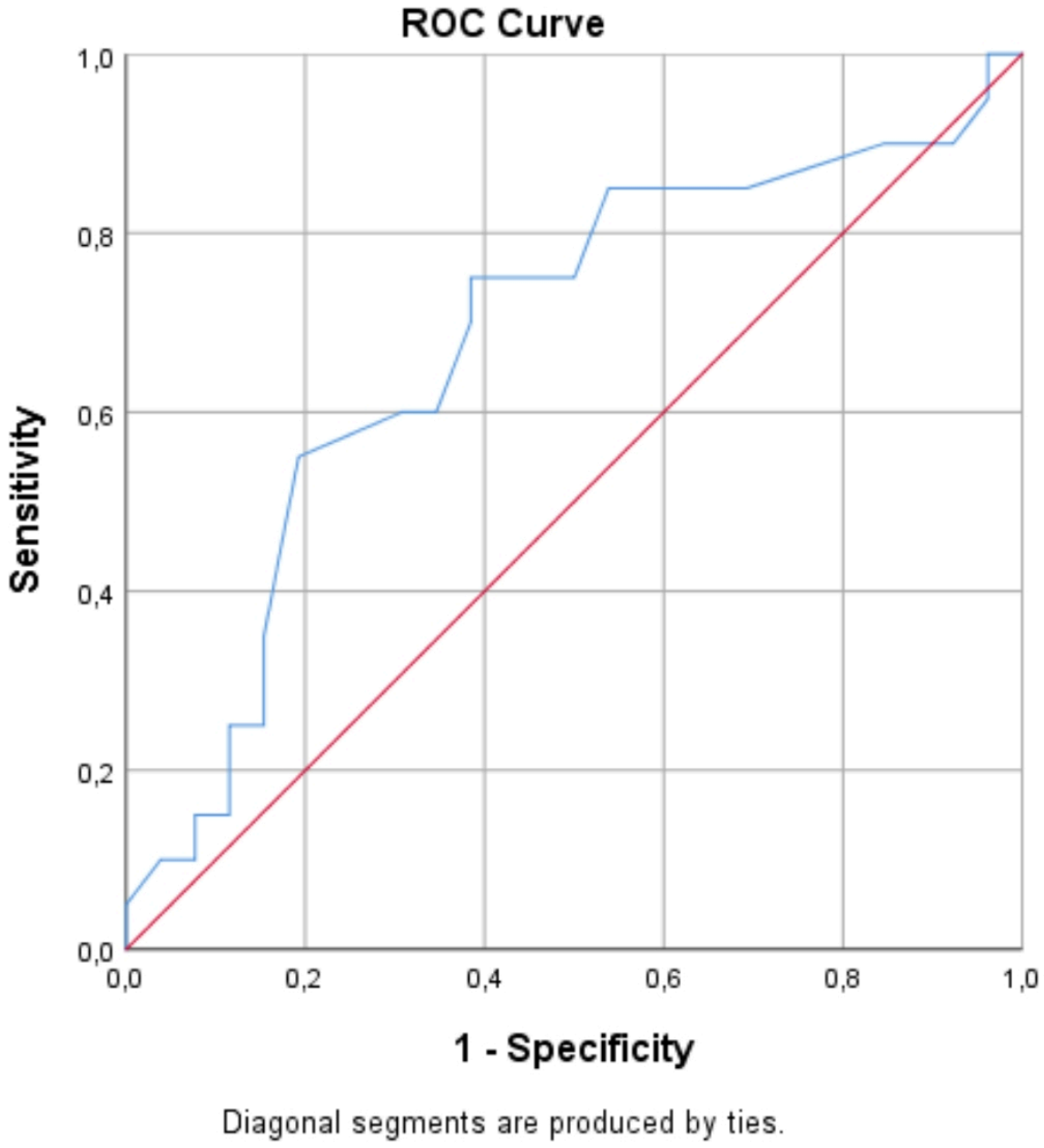


Figure 1

ROC Curve Analysis for the Tumor Size on Renal Function