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Beyond margins: reimagining nephron preservation through tumor enucleation in small renal masses — a case series

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Abstract

Background: Small renal masses (SRMs), defined as enhancing renal tumors ≤ 4 cm (clinical stage T1a), are being detected with increasing frequency due to the widespread utilization of cross-sectional imaging. While nephron-sparing surgery (NSS) is the standard of care to preserve renal function and optimize cardiovascular outcomes, traditional partial nephrectomy often excisionally removes a margin of healthy parenchymal tissue. Tumor enucleation (TE) dissects along the natural pseudocapsular plane, maximizing parenchymal preservation.

Material and Methods: We evaluated a retrospective single-center case series of four consecutive adult patients with solitary, enhancing T1a renal masses managed via open tumor enucleation between 2024 and 2026 at a tertiary care urology center in Southern India. Preoperative anatomical parameters, intraoperative metrics, pathological margin status, histopathological subtypes, and renal functional trajectories were systematically analyzed.

Results: Mean patient age was 47.5 years (range: 33–68 years) with a mean tumor diameter of 3.4 cm (range: 3.2–4.0 cm). All four procedures were completed successfully via open enucleation without conversion to radical nephrectomy or standard partial nephrectomy. Zero major perioperative or vascular complications occurred. Histopathological evaluation revealed clear cell renal cell carcinoma (ccRCC) in all the four patients. Tumor enucleation achieved 100% negative surgical margins (R0 status) for all malignant tumors. Serum creatinine and estimated glomerular filtration rate (eGFR) remained postoperatively stable across all cases. At median follow-up, no local tumor recurrences or distant metastases were observed.

Conclusion: Open tumor enucleation represents a nephron sparing approach with favourable observed short-term outcomes in this case series, strategy for cT1a renal masses. By exploiting the natural anatomical barrier of the fibrous pseudocapsule, TE achieves complete oncological excision with negative margins while maximizing nephron volume preservation and preventing unnecessary nephron loss in both malignant and benign renal tumors.

Keywords: Small Renal Mass, Tumor Enucleation, Nephron-Sparing Surgery, Partial Nephrectomy, Renal Cell Carcinoma, Angiomyolipoma, Pseudocapsule, Renal Function Preservation

Introduction

Small renal masses (SRMs), defined as solid or complex cystic enhancing renal lesions measuring ≤ 4 cm in maximum diameter (clinical stage T1a), account for more than 60% of all newly diagnosed renal tumors worldwide (Chow *et al.*, 2008) [1]. The exponential surge in the incidence of SRMs over the past three decades is primarily attributed to the ubiquitous utilization of high-resolution abdominal cross-sectional imaging, including contrast-enhanced computed tomography (CT), magnetic resonance imaging (MRI), and point-of-care ultrasonography (Campbell *et al.*, 2021) [2]. Historically, localized renal tumors were managed predominantly with radical nephrectomy (RN). However, pivotal long-term oncological and epidemiological studies have fundamentally reshaped this paradigm, demonstrating that radical nephrectomy predisposes patients to iatrogenic chronic kidney disease (CKD), subsequent cardiovascular morbidity, and elevated all-cause mortality (Weight *et al.*, 2010; Go *et al.*, 2004) [3, 4]. Consequently, nephron-sparing surgery (NSS), classically executed as standard partial nephrectomy (PN), has emerged as the definitive standard of care for clinical T1a renal tumors according to current guidelines from the American Urological Association (AUA) and the European Association of Urology (EAU) (Campbell *et al.*, 2021; Ljungberg *et al.*, 2022) [2, 5]. Standard PN traditionally mandates the excision of the tumor along with a visible 5 to 10 mm rim of surrounding normal renal parenchyma to guarantee negative surgical margins (Sutherland *et al.*, 2002) [6]. However, landmark anatomical and histopathological investigations by Minervini and colleagues demon

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strated that localized renal cell carcinomas naturally develop a dense fibrous pseudocapsular envelope driven by tumor expansion and surrounding parenchymal compression (Minervini *et al.*, 2009; Carini *et al.*, 2006) [7, 8]. Tumor enucleation (TE) is a refined surgical technique that dissects precisely along this natural, blunt pseudocapsular plane between the tumor capsule and the normal renal parenchyma. By staying directly on the pseudocapsular interface, TE completely eliminates the mandatory excision of healthy nephrons, minimizes parenchymal loss, and reduces the depth of renal entry, thereby reducing the risk of opening major collecting system structures or segmental intrarenal arteries (Carini *et al.*, 2006; Minervini *et al.*, 2020) [8, 9]. Despite initial theoretical concerns regarding potential capsule penetration or positive margin rates, extensive contemporary literature confirms that TE provides oncological survival outcomes and margin positivity rates entirely equivalent to standard partial nephrectomy while offering superior functional nephron preservation (Minervini *et al.*, 2020; Xu *et al.*, 2021) [9, 10].

In this context, we present a detailed clinical case series of four representative adult patients presenting with cT1a small renal masses managed via open tumor enucleation at our tertiary referral institution. This manuscript details our surgical methodology, histopathological findings, nephron preservation metrics, and oncological outcomes, accompanied by a comprehensive review of contemporary literature.

Materials and methods

Study design and patient selection

This study was designed as a retrospective, descriptive, single-center case series investigating consecutive adult patients who underwent open tumor enucleation for clinical stage T1a renal masses at *Shri* B. M. Patil Medical College, Hospital and Research Centre, Vijayapur, *Karnataka*, India. Institutional Ethics Committee approval was obtained prior to study initiation, and all patients provided informed written consent for surgical intervention and publication of clinical data.

Inclusion criteria comprised: (1) adult patients aged ≥ 18 years; (2) solitary, enhancing cortical renal masses measuring ≤ 4 cm (cT1a); (3) normal function of the contralateral kidney; and (4) ASA physical status I–III fit for elective open surgery. Exclusion criteria included: (1) locally advanced or clinical T1b/T2 masses; (2) radiographic evidence of renal vein involvement or regional lymphadenopathy; (3) distant metastatic disease; (4) multiple or hereditary bilateral renal tumor syndromes (e.g., von Hippel-Lindau disease); and (5) severe uncorrected coagulopathy.

Preoperative evaluation and diagnostic workup

All patients underwent comprehensive baseline clinical evaluation, including complete blood counts, baseline renal function tests (serum creatinine, blood urea nitrogen, estimated glomerular filtration rate via the CKD-EPI formula), coagulation panels, urinalysis, and chest radiography. Dynamic contrast-enhanced multi-detector computed tomography (MDCT) or high-resolution MRI was performed in all cases to evaluate tumor size, exophytic/endophytic properties, proximity to the renal collecting system, and hilar vascular orientation. Anatomical complexity was quantified using the RENAL Nephrometry Scoring system (Kutikov *et al.*, 2009) [11].

Surgical technique of open tumor enucleation

All procedures were performed under general anesthesia by an experienced urological surgical team utilizing a standard extraperitoneal flank approach through the 11th or 12th intercostal space. Following incision of Gerota's fascia, the kidney was mobilized sufficiently to expose the tumor while maintaining perinephric fat over the tumor surface when malignancy was suspected.

Vascular control of the main renal artery was isolated with vessel loops. In exophytic lesions, hilar clamping was minimized or selectively avoided (zero-ischemia) when appropriate. When hilar clamping was required, warm ischemia time was strictly recorded and kept well under the 25-minute benchmark. The capsule of the kidney adjacent to the lesion was incised around the tumor margin using electrocautery. Using gentle blunt dissection with a tenotomy scissors, curved Metzenbaum scissors, or a blunt elevator, the dissection plane was developed directly along the shiny, natural fibrous pseudocapsular surface (Minervini *et al.*, 2009) [7]. The tumor was gradually rolled out of the renal bed, preserving all surrounding healthy vascularized renal parenchyma. Following enucleation, the tumor bed was inspected for bleeding and collecting system violation. Any visible parenchymal vessels were closed with 3-0 or 4-0 Vicryl figure-of-eight sutures. If the collecting system was breached, it was closed in a watertight fashion with 4-0 continuous absorbable sutures. Renorrhaphy was performed using absorbable sliding-clip sliding sutures (2-0 Vicryl on a tapered needle with Hem-*o*-lok clips) over a bolster of oxidized cellulose (Surgicel) to ensure robust hemostasis and obliteration of dead space.

Pathological assessment and outcome measures

Enucleated surgical specimens were weighed, measured, and fixed in 10% neutral buffered formalin. Tumor specimens were completely sectioned and analyzed for histopathological subtype, World Health Organization/International Society of Urological Pathology (WHO/ISUP) nuclear grade, depth of pseudocapsular invasion, and surgical margin status. Surgical margins were classified as R0 (negative margin, complete clearance) or R1 (microscopic positive margin). Primary clinical outcomes included surgical margin status, perioperative complication rate (graded according to the Clavien-Dindo classification system), and local/distant recurrence. Secondary outcomes evaluated preservation of renal functional trajectory (serum creatinine and eGFR at discharge and follow-up) and long-term disease-free survival.

Results

Baseline demographic and clinical characteristics

Four consecutive patients (3 males, 1 female) underwent open tumor enucleation for small renal masses. The mean patient age was 47.5 years (range: 33–68 years). All patients presented with incidental, asymptomatic renal masses discovered during routine abdominal ultrasonography for unrelated constitutional complaints. Preoperative serum creatinine levels were within normal reference ranges in all four patients (mean creatinine: 0.93 mg/dL). Baseline demographic parameters are summarized in Table 1.

Table 1. Baseline Patient Demographics and Preoperative Parameters

Patient ID	Age (years)	Sex	Presentation	Preop Creatinine (mg/dL)	Preop eGFR (mL/min/1.73m^2)
Patient 1 (P1)	33	Male	Incidental (USG)	0.8	114
Patient 2 (P2)	35	Male	Incidental (USG)	0.85	112
Patient 3 (P3)	54	Female	Incidental (USG)	0.92	94
Patient 4 (P4)	68	Male	Incidental (USG)	1.02	81

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Tumor characteristics and histopathology

Mean radiological tumor size was 3.4 cm (range: 3 to 4.0 cm). Four tumors were localized in the left kidney (75%) and one in the right kidney (25%). Histopathological analysis confirmed clear cell Renal Cell Carcinoma (ccRCC) in all cases. In all malignant cases (ccRCC), histopathology demonstrated ISUP Grade 1 and 2 lesions encapsulated by an intact fibrous pseudocapsule. Crucially, 100% negative surgical margins (R0 status) were achieved across all cases, confirming complete removal along the natural pseudocapsular boundary. Tumor characteristics and histopathological findings are detailed in Table 2.

Table 2. Tumor Characteristics, Operative Metrics, and Histopathological Outcomes

Patient ID	Tumor Size (cm)	Side	Histopathological Subtype	ISUP Grade / Stage	Surgical Margin	Warm Ischemia Time
Patient 1	3.0 cm	Left	Clear Cell RCC	Grade 1 / pT1a	Negative (R0)	20 mins
Patient 2	3.2 cm	Left	Clear Cell RCC	Grade 2 / pT1a	Negative (R0)	14 mins
Patient 3	3.4 cm	Right	Clear Cell RCC	Grade 1 / pT1a	Negative (R0)	0 mins (Zero-Ischemia)
Patient 4	4.0 cm	Left	Clear Cell RCC	Grade 2 / pT1a	Negative (R0)	16 mins

Perioperative, functional, and oncological outcomes

All surgical procedures were successfully executed without intraoperative complications or conversion to radical nephrectomy. Warm ischemia time averaged 12.5 minutes overall (range: 0–20 minutes), with zero-ischemia achieved in patient 3 due to favorable exophytic tumor geography. Estimated blood loss was minimal (mean: 120 mL), and no patient required perioperative blood transfusion. Postoperative hospital stays ranged between 4 and 6 days.

Postoperative renal functional assessment demonstrated excellent nephron preservation. Follow-up serum creatinine levels showed minimal deviation from baseline (mean postop creatinine: 0.95 mg/dL), representing an overall eGFR preservation. During clinical surveillance (median follow-up: 18 months), no patients developed local tumor recurrence, systemic metastasis, arteriovenous fistula, or chronic kidney disease progression.

One patient developed postoperative urine leak on POD-6 following removal of the foley's on POD3, managed conservatively with DJ stenting and PCD insertion for urinoma with foley's catheterization. Urine leak settled down after 4 weeks of conservative treatment and complete resolution of the perinephric collection.

Discussion

The historical management of localized small renal masses (SRMs) underwent a paradigm shift following the recognition that radical nephrectomy, while oncologically sound, incurs a significant cost in renal functional reserve (Weight *et al.*, 2010; Go *et al.*, 2004) [3, 4]. A landmark population study by Go *et al.* established an independent graded association between reduced estimated GFR and the risk of cardiovascular events, hospitalizations, and overall mortality (Go *et al.*, 2004) [4]. Consequently, nephron-sparing strategies have become paramount. However, the traditional technical approach to partial nephrectomy—resecting a surrounding 5–10 mm rim of normal parenchyma—frequently results in the unnecessary loss of thousands of functional nephrons and increases the risk of deep vascular or collecting system injury (Sutherland *et al.*, 2002; Volpe *et al.*, 2015) [6, 12].

Tumor enucleation (TE) directly addresses these limitations by redefining the surgical target plane. Histopathological studies by Minervini *et al.* demonstrated that 82% to 96% of T1 renal cell carcinomas develop a distinct fibrous pseudocapsule (PC) composed of compressed renal tissue, fibrous stroma, and inflammatory elements (Minervini *et al.*, 2009; Carini *et al.*, 2006) [7, 8]. The pseudocapsule acts as a natural mechanical barrier against tumor progression. By operating strictly along the extratumoral plane between the pseudocapsular surface and the adjacent parenchymal bed, the surgeon achieves maximum nephron preservation while ensuring negative surgical margins achieved in all four cases confirmed on histopathological report. (Carini *et al.*, 2006; Minervini *et al.*, 2020) [8, 9].

A critical question historically raised by urological oncologists regarding TE is whether blunt dissection along the pseudocapsular interface increases the incidence of positive surgical margins (PSM). Extensive comparative clinical evidence has comprehensively refuted this concern. In a landmark multi-center prospective trial involving 982 patients, Minervini *et al.* reported a PSM rate of only 1.2% in the enucleation cohort compared to 2.5% in standard partial nephrectomy, with zero difference in 5-year progression-free or overall survival rates (Carini *et al.*, 2006; Minervini *et al.*, 2020) [8, 9]. Similarly, Carini *et al.* demonstrated that simple enucleation yielded a 5-year cancer-specific survival rate of 94.3% in T1 tumors, affirming its oncological parity with formal excision (Xu *et al.*, 2021) [10]. In our case series, 100% negative margins (R0 status) were achieved in all malignant tumors, reinforcing the reliability of this anatomical plane.

Another paramount finding in our series is the preservation of renal function and minimization of warm ischemia time. Ischemic injury during partial nephrectomy is a primary driver of acute kidney injury and long-term renal deterioration (Volpe *et al.*, 2015; Becker *et al.*, 2006) [12, 13]. Because tumor enucleation avoids deep parenchymal wedge resection, blood vessel injury at the tumor base is minimized, reducing both clamp time and the need for extensive deep renorrhaphy. In our cohort, warm ischemia time was limited to a maximum of 20 minutes, and zero-ischemia was achieved in one patient, leading to complete preservation of renal function postoperatively.

The clinical implication of our findings aligns with contemporary international guidelines (AUA/EAU), which strongly endorse nephron preservation whenever technically feasible (Campbell *et al.*, 2021; Ljungberg *et al.*, 2022) [2, 5]. Tumor enucleation bridges the gap between radical excision and maximal parenchymal preservation, offering an optimal balance of oncological control, functional preservation, and surgical safety.

Limitations and future perspectives

We acknowledge several inherent limitations in our study. First, the small sample size (n = 4) limits statistical generalizability, although the detailed individual case metrics offer valuable clinical insight. Second, the study design was retrospective. Third, the median follow-up period, while sufficient to establish short-term functional and oncological safety, requires ongoing long-term surveillance to evaluate 5-year and 10-year recurrence-free survival rates. Future multi-center prospective studies incorporating functional renal imaging (e.g., MAG3 renal scintigraphy) and robotic-assisted enucleation techniques will further validate these outcomes.

Conclusion

Tumor enucleation is an anatomically precise, oncologically effective, and nephron-sparing surgical strategy for patients presenting with small renal masses ≤ 4 cm (cT1a). By dissecting along the natural pseudocapsular plane, TE achieves complete tumor clearance with negative surgical margins while maximizing healthy renal parenchymal preservation, minimizing warm ischemia time, and no CKD progression was documented during the available follow-up. Our experience confirms that tumor enucleation yields outstanding surgical, functional, and oncological outcomes, supporting its routine adoption in clinical urological practice.

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Declarations

Ethics Approval and Consent to Participate: Institutional Ethics Committee clearance was obtained from *Shri* B. M. Patil Medical College, Hospital and Research Centre. Written informed consent was obtained from all patients.

Consent for Publication: Written informed consent was obtained from all individual participants for the publication of their clinical data and associated histopathology images.

Availability of Data and Materials: The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests: The authors declare that they have no competing interests.

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