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Limits of Nephron-sparing Strategies in Small Renal Masses: The Role of Imaging in Surgical Decision-making

Küçük Renal Kitlelerde Nefron Koruyucu Yaklaşımın Sınırları: Cerrahi Karar Sürecinde Görüntülemenin Yeri

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Abstract

Cross-sectional imaging has increased detection of small renal masses (≤4 cm), creating a need for evidence-based management strategies integrating imaging assessment. This review provides a comprehensive, imaging-based clinical framework for managing small renal masses through the R (radius: largest diameter of the mass in centimeters), E (exophytic versus endophytic growth), N (nearness to the collecting system or renal sinus), A (anterior versus posterior location relative to the hilar plane), and L (location relative to the polar lines: upper, middle, or lower pole) (RENAL) nephrometry score, Bosniak classification, and imaging modality comparison. This is a comprehensive narrative review of the contemporary literature on renal mass imaging, risk assessment using RENAL nephrometry and the Bosniak classification, imaging modality selection, and comparative outcomes of nephron-sparing strategies. The RENAL score stratifies masses into complexity categories that predict perioperative outcomes. Bosniak classification (categories I-V) characterizes cystic masses, with categories I-II showing negligible malignancy risk (<1%), categories III and IIF showing 10-50% malignancy risk, and categories IV-V showing high malignancy risk. Multimodal imaging [computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, positron emission tomography-CT (PET-CT)] offers complementary strengths: multiphasic CT provides excellent spatial resolution for initial diagnosis; MRI offers superior soft-tissue contrast without radiation, making it ideal for long-term surveillance; ultrasound serves as a screening tool but has limited diagnostic reliability; PET-CT has limited utility for small, early-stage renal masses. Growth kinetics demonstrate heterogeneity, with 20-30% of masses remaining stable over 10+ years, median growth rates of 0.28 cm/year (range -0.10 to 2.0 cm/year), and 75-80% of masses exhibiting ≤0.5 cm/year growth. Active surveillance outcomes reveal a 25-40% progression to intervention over 3-5 years, with >99% cancer-specific survival. Thermal ablation achieves local recurrence-free survival of 95-98% at 1-2 years for cryoablation and 90-95% for radiofrequency ablation; however, shows recurrence rates of 5-15% and 8-20%, respectively. Partial nephrectomy is associated with a <1-2% local recurrence rate, 95% cancer-specific survival at 5 years, and 85-90% preservation of glomerular filtration rate. An integrated, imaging-based approach utilizing RENAL scoring, Bosniak classification, and quantified management outcomes provides a robust framework for evidence-based surgical decision-making in the management of small renal masses.

Keywords: Small renal mass, active surveillance, partial nephrectomy, thermal ablation, nephrometry score

Öz

Kesitsel görüntüleme yöntemlerinin yaygınlaşması küçük renal kitlelerin (≤4 cm) saptanma sıklığını artırmış olup, görüntüleme temelli, kanıta dayalı yönetim stratejilerine duyulan ihtiyacı gündeme getirmiştir. Bu derleme, küçük renal kitlelerin yönetiminde R (radius: kitlenin

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santimetre cinsinden en büyük çapı), E (ekzofitik veya endofitik büyüme), N (toplayıcı sisteme veya renal sinüse yakınlık), A (hiler düzleme göre anterior veya posterior yerleşim) ve L (polar hatlara göre yerleşim: üst, orta veya alt pol) parametrelerinden oluşan (RENAL) nefrometri skoru, Bosniak sınıflaması ve görüntüleme yöntemlerinin karşılaştırılması temelinde kapsamlı bir klinik çerçeve sunmaktadır. Çalışma; renal kitle görüntülemesi, RENAL nefrometrisi ve Bosniak sınıflaması kullanılarak risk değerlendirmesi, görüntüleme yöntemi seçimi ve nefron koruyucu stratejilerin karşılaştırmalı sonuçlarına ilişkin güncel literatürün kapsamlı bir narratif derlemesidir. RENAL skoru, kitleleri perioperatif sonuçları öngören kompleksite kategorilerine ayırmaktadır. Bosniak sınıflaması (kategori I-V) kistik kitleleri karakterize etmekte olup, kategori I-II ihmal edilebilir malignite riski (<%1), kategori III ve IIF %10-50 malignite riski, kategori IV-V ise yüksek malignite riski göstermektedir. Multimodal görüntüleme [bilgisayarlı tomografi (BT), manyetik rezonans görüntüleme (MRG), ultrasonografi, pozitron emisyon tomografisi-BT (PET-BT)] birbirini tamamlayan üstünlükler sunmaktadır: multifazik BT ilk tanıda mükemmel uzaysal çözünürlük sağlar; MRG radyasyon içermeden üstün yumuşak doku kontrastı sunarak uzun dönem takip için idealdir; ultrasonografi bir tarama aracı olarak kullanılabilir ancak tanısal güvenilirliği sınırlıdır; PET-BT'nin küçük, erken evre renal kitlelerde kullanım alanı sınırlıdır. Büyüme kinetiği belirgin heterojenlik göstermekte olup, kitlelerin %20-30'u 10 yıldan uzun takipte stabil kalmakta, medyan büyüme hızı yılda 0,28 cm (aralık: -0,10 ile 2,0 cm/yıl) olarak bildirilmekte ve kitlelerin %75-80'i yılda ≤0,5 cm büyüme göstermektedir. Aktif izlem sonuçları, 3-5 yıllık süreçte %25-40 oranında girişime geçiş olduğunu, ancak kansere özgü sağkalımın >%99 olduğunu ortaya koymaktadır. Termal ablasyon, 1-2 yıllık takipte kriyoablasyon için %95-98, radyofrekans ablasyon için %90-95 oranında lokal nükssüz sağkalım sağlamakta; ancak sırasıyla %5-15 ve %8-20 oranında nüks görülmektedir. Parsiyel nefrektomi, <%1-2 lokal nüks oranı, 5 yılda %95 kansere özgü sağkalım ve %85-90 glomerüler filtrasyon hızı korunması ile ilişkilidir. RENAL skorlaması, Bosniak sınıflaması ve nicel yönetim sonuçlarının bütünleştirildiği görüntüleme temelli bir yaklaşım, küçük renal kitlelerin yönetiminde kanıta dayalı cerrahi karar sürecinde güçlü bir çerçeve sunmaktadır.

Anahtar Kelimeler: Küçük renal kitle, aktif izlem, parsiyel nefrektomi, termal ablasyon, nefrometri skoru

Introduction

Renal cell carcinoma (RCC) is one of the most common types of cancer worldwide, and its incidence has been increasing in recent years (1). A significant reason for this increase is the rising incidence of incidental detection of small renal masses (≤4 cm) due to the widespread use of diagnostic methods such as ultrasonography, computed tomography (CT), and magnetic resonance imaging (MRI) (1,2). While these lesions were previously treated with radical nephrectomy, today nephron-sparing surgery is the standard approach in clinical T1a tumors (3). However, the possibility of nephron-sparing surgery does not necessarily indicate the need for surgical treatment. The main debate today is which patients should be kept under active surveillance, which patients can undergo thermal ablation, and in which cases partial nephrectomy is the preferred approach (3,4). It has been reported that a significant portion of small renal masses have a slow-progressing biological structure and that the rate of metastasis is low under active surveillance (5,6). The American Urological Association (AUA) guidelines recommend active surveillance, especially for renal masses smaller than 2 cm and selected Bosniak 3/4 lesions (3,4). However, not all small renal masses exhibit similar biological behavior. It has been reported that lesions showing rapid growth, heterogeneous contrast enhancement, or central location are more likely to have more aggressive pathology (7,8). An annual growth rate greater than 0.5 cm has been considered an indicator of progression risk in some studies (6,9). Therefore, in current clinical practice, it is recommended that the dynamic growth pattern and radiological risk indicators be evaluated together with the tumor diameter (7,9).

Literature Review Strategy

This is a comprehensive narrative review of the medical literature regarding the evaluation and management of small renal masses (≤4 cm). The review was conducted by searching PubMed/MEDLINE and by hand-selecting review articles, key studies, and guidelines published between 2005 and 2024. Search terms included combinations of: "small renal masses", "renal mass characterization", "renal mass imaging", "RENAL nephrometry score", "PADUA score", "Bosniak classification", "active surveillance", "renal mass ablation", and "partial nephrectomy".

The selection of articles was based on clinical relevance, methodological quality, and contribution to understanding imaging-based assessment and management of small renal masses. This interpretive synthesis approach allows for a comprehensive review of evidence from diverse sources including prospective series, retrospective cohorts, meta-analyses, systematic reviews, and professional society guidelines (AUA) (3,4), European Association of Urology (10).

The goal of this narrative review is to provide clinicians with an integrated, evidence-informed framework for imaging-guided surgical decision-making in the management of incidentally detected small renal masses by synthesizing the current literature on imaging modalities, complexity scoring systems, growth kinetics, management outcomes, and factors influencing treatment selection.

To standardize the assessment of renal mass complexity and improve treatment planning, two anatomical scoring systems have gained widespread clinical and academic use: the RENAL

nephrometry score and the preoperative aspects and dimensions used for an anatomical (PADUA) classification. Both systems were developed within a similar time frame to formalize what had previously been a largely subjective, size-based assessment of renal tumor complexity, and are now routinely used to inform the choice among partial nephrectomy, thermal ablation, and active surveillance. The R.E.N.A.L. acronym denotes five anatomical parameters that collectively characterize the spatial relationship of a renal mass to critical structures: R (radius: largest diameter of the mass in centimeters), E (exophytic versus endophytic growth), N (nearness to the collecting system or renal sinus), A (anterior versus posterior location relative to the hilar plane), and L (location relative to the polar lines: upper, middle, or lower pole). Each parameter is assigned a numerical score, and the sum yields a total RENAL score ranging from 4 to 14 points (11,12).

The PADUA classification was developed contemporaneously as an alternative anatomical scoring system and was originally validated in a prospective cohort of patients undergoing open nephron-sparing surgery. PADUA scores nine anatomical features-longitudinal (polar) location, exophytic rate, renal rim location, relationship to the renal sinus, relationship to the urinary collecting system, anterior or posterior face, and tumor size-yielding a total score that ranges from 6 to 14 points and stratifies masses into low (6-7), intermediate (8-9), and high (≥10) complexity groups (13). Although RENAL and PADUA were derived independently and weight certain anatomical features somewhat differently (PADUA places additional emphasis on the renal rim and sinus relationship, while RENAL scores exophytic/endophytic growth and polar location as separate discrete parameters), the two systems have shown good correlation with one another and largely overlapping ability to predict perioperative complications and surgical complexity in comparative validation studies (12,13). In practice, the choice between the two scoring systems often reflects institutional or regional preference: RENAL is more widely used in North America, while PADUA has seen broader adoption in Europe, rather than reflecting a clear superiority of one system over the other. Both are considered acceptable by contemporary guidelines for preoperative anatomical risk stratification. The RENAL nephrometry score components and scoring system are detailed in Table 1, which also presents the corresponding PADUA parameters and scoring for comparison.

Clinical Impact of Anatomical Complexity Scoring on Surgical Difficulty and Treatment Selection

Both the RENAL and PADUA scores stratify renal masses into three complexity categories-low, intermediate, and high-and this stratification has direct, well-documented consequences for surgical difficulty, modality selection, and expected oncological outcomes. Low-complexity masses (RENAL 4-6; PADUA 6-7) are generally smaller, more peripheral, and distant from vital structures, making them amenable to multiple treatment modalities, including partial nephrectomy, thermal ablation, or active surveillance. In this group, partial nephrectomy is typically associated with shorter operative times, lower estimated blood loss, and the lowest complication rates, whereas thermal ablation achieves local recurrence rates as low as 2-5%. Intermediate-complexity masses (RENAL 7-9; PADUA 8-9) pose greater anatomical challenges, including closer proximity to the collecting system and partial endophytic growth, and are associated with measurably longer operative and ischemia times during partial nephrectomy as well as higher local recurrence after ablation (approximately 5-10%). Both partial nephrectomy and thermal ablation remain reasonable options in this group, and the choice is often individualized based on patient comorbidity and surgeon experience. High-complexity masses (RENAL 10-14; PADUA ≥10) exhibit features such as large size, central location, intimate association with the renal hilum or collecting system,

Table 1. RENAL nephrometry score and PADUA classification: components and scoring, by anatomical domain

Anatomical domain	RENAL score	PADUA score
Tumor size	R: ≤1 cm=1 | 1.1-2 cm=2 | 2.1-3 cm=3 | >3 cm=4	≤4 cm=1 | 4.1-7 cm=2 | >7 cm=3
Exophytic/endophytic growth	E: ≥50% exophytic=1 | <50% exophytic=2	≥50% exophytic=1 | <50% exophytic=2 | entirely endophytic=3
Relation to renal sinus/ collecting system	N: ≥7 mm from sinus=1 | 4-6 mm=2 | <4 mm (touching)=3	No sinus/collecting-system involvement=1 | involved=2
Anterior vs. posterior face	A: Entirely anterior/posterior=1 | crosses hilar plane=2 (not summed into total)	Recorded as anterior, posterior, or indeterminate (descriptive only, not scored)
Polar (longitudinal) location	L: Entirely above/below polar line=1 | crosses polar line=2 | hilar region=3	Entirely above/below polar line=1 | crosses polar line=2 | entirely between polar lines (mid-pole)=3
Total score range	4-14 points (a recorded but not added to total)	6-14 points
Complexity categories	Low 4-6 | intermediate 7-9 | high 10-14	Low 6-7 | intermediate 8-9 | high ≥10

RENAL: R (radius: largest diameter of the mass in centimeters), E (exophytic versus endophytic growth), N (nearness to the collecting system or renal sinus), A (anterior versus posterior location relative to the hilar plane), and L (location relative to the polar lines: upper, middle, or lower pole), PADUA: Preoperative aspects and dimensions used for an anatomical

or anterior location that may compromise vascular inflow or urinary drainage during nephron-sparing approaches; in this group, partial nephrectomy carries the highest rates of prolonged warm ischemia time, urine leak, and blood transfusion, while thermal ablation carries the highest reported local recurrence rates (10-15%) due to the technical difficulty of achieving a complete ablation margin near the collecting system and adjacent vasculature, which act as a heat sink that limits thermal spread. Consequently, high-complexity masses are generally best managed by partial nephrectomy when surgical intervention is indicated, as this approach maximizes the likelihood of achieving negative surgical margins while preserving renal function and avoiding the disproportionately high ablation failure rate seen in this group (12,13). Risk stratification according to RENAL and PADUA complexity categories, including their respective impact on operative difficulty and local recurrence after ablation, is presented in Table 2.

Extensive literature demonstrates that both the RENAL and PADUA scores predict perioperative outcomes and treatment efficacy across multiple management modalities. In partial nephrectomy cohorts, higher scores on either scoring system correlate with longer operative times, greater estimated blood loss, longer warm ischemia times, and increased perioperative complication rates, thereby helping surgeons anticipate technical difficulty and prepare appropriately-for example, by planning for off-clamp or early-unclamping techniques in lower-complexity cases or by allocating additional operative time and ensuring blood product availability for higher-complexity resections. Similarly, both scores have proven prognostic value in ablation series: intermediate- and high-complexity masses treated with thermal ablation demonstrate consistently higher local recurrence rates than low-complexity masses, with some series reporting 2-5% recurrence in low-complexity masses versus 10-15% in high-complexity masses, which is an association strong enough that many centers use a complexity threshold (for example, a RENAL score above 9-10, or a substantial endophytic and hilar component) as a relative contraindication to ablation in favor of partial nephrectomy. For patients selected for active surveillance, complexity scoring independently predicts progression-free survival and interval growth rates, with higher-complexity masses exhibiting more aggressive growth behavior and shorter time to progression. These associations underscore the importance of incorporating anatomical complexity scoring into pretreatment risk stratification, modality selection, and surveillance planning (12,14).

Given these predictive associations, both the RENAL and PADUA scores have become integral to shared decision-making regarding renal mass management. When counseling patients with newly detected small renal masses, clinicians can provide more accurate information about likely technical challenges, anticipated perioperative risks (including the probability of requiring conversion to radical nephrectomy or experiencing a major complication), and predicted local recurrence risk with ablation based on anatomical complexity scoring. This information facilitates patients' informed choice among treatment modalities, including active surveillance. Additionally, the validation of both scoring systems in multiple international cohorts and their ease of calculation (requiring only standard cross-sectional imaging) make them practical tools for standardizing communication between urologists, radiologists, interventional radiologists, and surgeons regarding mass complexity and treatment recommendations (9,12).

Bosniak Classification System: Characterizing Cystic Renal Masses

For cystic renal masses, the Bosniak classification system has become the standard imaging-based framework for distinguishing benign lesions from those requiring intervention. Developed by Morton Bosniak in the 1980s and subsequently refined, this classification system stratifies cystic masses into five categories based on imaging characteristics observed on contrast-enhanced CT or MRI, including the presence and characteristics of septa and calcifications, cyst wall enhancement, and enhancing solid components. Because benign cysts and malignant cystic neoplasms can have overlapping imaging features, the Bosniak system provides a standardized approach to risk stratification that guides clinical decision-making regarding surveillance versus intervention. Unlike simple renal cysts (Bosniak I), which

Table 2. RENAL and PADUA complexity categories: risk stratification and management implications

RENAL score	PADUA score	Complexity	Management and outcomes
4-6	6-7	Low	Small/peripheral; far from collecting system; all modalities suitable (PN, ablation, AS); lowest morbidity and shortest operative/ischemia time; 2-5% local recurrence with ablation
7-9	8-9	Intermediate	Medium size; mixed location; both PN and ablation appropriate; moderate complexity; longer operative/ischemia time; 5-10% local recurrence with ablation; consider patient factors
10-14	≥10	High	Large/central; intimate hilar association; PN preferred when indicated; highest complexity and morbidity; highest risk of prolonged ischemia, urine leak, and transfusion with PN; 10-15% local recurrence with ablation due to heat-sink effect near hilum

RENAL: R (radius: largest diameter of the mass in centimeters), E (exophytic versus endophytic growth), N (nearness to the collecting system or renal sinus), A (anterior versus posterior location relative to the hilar plane), and L (location relative to the polar lines: upper, middle, or lower pole), PADUA: Preoperative aspects and dimensions used for an anatomical, PN: Partial nephrectomy, AS: Active surveillance

are universally benign and require no follow-up, intermediate-risk cysts (Bosniak IIF and III) present particular diagnostic challenges due to their variable malignancy risk and incomplete natural history data, necessitating individualized management strategies (15). The 2019 revision of the classification further standardized the definitions of septal thickness, wall thickening, and enhancement, and explicitly extended the system's use to MRI in addition to CT, improving reproducibility across imaging platforms and between observers (15). The Bosniak classification system, including imaging features and malignancy risk for each category, is shown in Table 3.

The Bosniak system consists of five categories, each with distinct imaging features and associated risks of malignancy. Bosniak I lesions are simple, thin-walled cysts with no septa, calcifications, or enhancement; they are universally benign with negligible malignancy risk (<1%) and therefore require no imaging follow-up once diagnosed. Bosniak II lesions are minimally complicated cysts containing thin septa (<1 mm), fine calcifications, or homogeneous, hyperdense (non-enhancing) content; these lesions remain benign, with malignancy risk <2%, and generally require no follow-up. Bosniak IIF ("F" designating "follow-up") was introduced to better classify intermediate-risk lesions with features more complex than Bosniak II but not definitively concerning for malignancy. These include cysts with more complex internal architecture, thickened septa (typically <3 mm), or minimal, thin, and smooth enhancement of a septum or wall. Malignancy risk ranges from 5-10%, and these lesions typically warrant short-term imaging surveillance at 3 and 6 months, then annually for 5 years to assess for changes suggesting progression. Bosniak III lesions are cystic masses with imaging characteristics concerning for, but not definitively diagnostic of, malignancy, including thick or irregular septa (>3 mm), thick or irregular calcifications, or measurable enhancement of a thickened wall or septum. These lesions carry a malignancy risk of approximately 20-55% and generally warrant intervention (partial or radical nephrectomy) or close surveillance, depending on clinical circumstances, patient age, comorbidities, and patient preferences. Finally, Bosniak IV lesions represent overtly malignant-appearing masses with gross enhancement and/or large enhancing solid components, whereas Bosniak V lesions are completely solid enhancing lesions arising within a cystic lesion; these categories carry malignancy rates exceeding 85-90% and typically warrant surgical intervention with partial or radical nephrectomy (15).

Clinical Decision-making Implications of Bosniak Categorization

Beyond its descriptive function, Bosniak categorization operates as a direct decision node in clinical practice, and the intermediate-risk categories (Bosniak IIF and III) represent the areas of greatest management complexity. For Bosniak IIF lesions, the 5-10% malignancy risk is generally considered low enough to justify a defined imaging surveillance protocol rather than intervention, provided the patient is able to adhere to follow-up. Because the natural history of individual IIF lesions is heterogeneous, with some remaining stable over many years while others slowly progress to a higher category, any interval increase in septal thickness, new nodular enhancement, or development of a discrete enhancing component during surveillance should prompt re-classification and reconsideration of intervention. Bosniak III lesions pose a more difficult management decision: since the reported malignancy risk (20-55%) means that roughly half of these lesions are ultimately benign or low-grade malignant, yet the diagnostic uncertainty is too substantial to recommend surveillance uniformly. In practice, the decision is individualized: in younger, fit patients with long life expectancy, upfront partial nephrectomy is often favored, because it provides definitive

Table 3. Bosniak classification system: imaging features, malignancy risk, and clinical decision-making

Category	Imaging features	Malignancy risk (%)	Follow-up/ management	Key clinical decision point
I (benign)	Simple, thin-walled; no septa/ calcifications; no enhancement	<1	No follow-up	Diagnosis is final; no further imaging or intervention needed
II (benign)	Thin septa (<1 mm); fine calcifications; homogeneous hyperdense content	<2	No follow-up	Considered definitively benign; reassurance only
IIF (follow-up)	Complex architecture; thickened septa (<3 mm); minimal, smooth septal/wall enhancement	5-10	Surveillance: 3 mo, 6 mo, then annually x 5 yrs	Any interval progression (new nodularity, thicker septa, new enhancement) triggers re-classification and intervention
III (indeterminate)	Thick/irregular septa (>3 mm); thick/ irregular calcifications; measurable wall or septal enhancement	20-55	Intervention (PN preferred) or surveillance	Decision individualized by age, comorbidity, and life expectancy; biopsy has limited yield
IV-V (malignant)	Enhancing solid components/ independent enhancing soft-tissue mass within a cyst	85-100	Intervention: PN or RN	PN vs. RN determined by size, location, and RENAL score rather than Bosniak category

PN: Partial nephrectomy, RN: Radical nephrectomy, RENAL: R (radius: largest diameter of the mass in centimeters), E (exophytic versus endophytic growth), N (nearness to the collecting system or renal sinus), A (anterior versus posterior location relative to the hilar plane), and L (location relative to the polar lines: upper, middle, or lower pole)

histology, preserves renal parenchyma, and is associated with low morbidity when performed for a T1 lesion; in older patients, in those with significant comorbidity, in or those who place a high value on avoiding surgery, active surveillance with short-interval imaging is a reasonable alternative, accepting a small but real risk of delayed diagnosis of malignancy. Renal mass biopsy has a limited role in management decisions because sampling septa or mural nodules has a lower diagnostic yield than sampling solid masses; therefore imaging-based risk stratification, rather than histology, generally remains the primary basis for management of Bosniak III lesions. For Bosniak IV and V lesions, the high malignancy risk makes intervention the default recommendation in nearly all surgical candidates, with the choice between partial and radical nephrectomy governed principally by tumor size, location, and RENAL score complexity rather than by the Bosniak category itself.

The integration of Bosniak classification into the comprehensive management algorithm for small renal masses reflects recognition that many of these lesions are cystic or partially cystic rather than purely solid. The Bosniak system provides risk stratification specifically for cystic masses and complements the RENAL nephrometry score (which applies primarily to solid masses) in guiding clinical decision-making. For patients with solid renal masses, RENAL score assessment determines management recommendations; for those with cystic or partially cystic masses, Bosniak classification is applied. In cases where lesions have both solid and cystic components (Bosniak IV or complex RENAL score patterns), both systems may provide complementary information, and the higher-risk classification of the two should generally guide the management decision. The application of standardized classification systems-RENAL for solid masses and Bosniak for cystic masses-improves communication among physicians, provides prognostic information regarding malignancy risk and the natural history, and facilitates shared decision-making with patients about surveillance versus intervention (16).

Imaging Modalities in Renal Mass Characterization and Surveillance

Accurate characterization and surveillance of small renal masses depend on high-quality cross-sectional imaging. While multiple imaging modalities are available for renal mass assessment, each technique has distinct advantages, limitations, and optimal clinical applications. The choice of imaging modality should consider diagnostic accuracy, radiation exposure, cost, patient factors (age, renal function, contrast allergy), and the clinical context (initial characterization versus surveillance). Beyond simple lesion detection, the imaging protocol should also be adequate to characterize two features with direct clinical consequences: the enhancement pattern of the mass and its anatomical relationship to the collecting system and the renal hilum. Understanding the strengths and weaknesses of each imaging approach for capturing these features is essential for developing personalized, evidence-based surveillance and treatment strategies for patients with small renal masses. Comparative characteristics and optimal applications of imaging modalities are presented in Table 4.

Multidetector CT with contrast enhancement remains the most widely used imaging modality for renal mass detection and characterization (17). Multiphasic CT imaging, including non-enhanced, arterial, corticomedullary, and delayed-phase acquisitions, optimizes characterization of renal masses by demonstrating enhancement patterns suggestive of malignancy. Properly timed arterial phase imaging (approximately 25-35 seconds after intravenous contrast injection) is critical for detecting arterial enhancement, which is the hallmark of RCC, and for characterizing that enhancement as homogeneous or heterogeneous. Heterogeneous enhancement-an irregular, patchy pattern rather than uniform contrast uptake-reflects underlying intratumoral necrosis, hemorrhage, and disorganized

Table 4. Imaging modalities in renal mass evaluation: comparison of characteristics and decision-relevant features

Modality	Spatial resolution and speed	Soft tissue contrast	Radiation	Assesses enhancement heterogeneity?	Assesses central/ hilar location?
CT (multiphasic)	Excellent; fast (30-60 sec)	Good-arterial phase enhancement clear	Yes (~50-100 mSv per scan)	Yes-primary modality	Yes-excellent with MPR
MRI (dynamic+DWI)	Good; moderate (20+ min)	Excellent-superior soft-tissue detail; DWI/ADC useful	No (0 mSv)	Yes-often more conspicuous than CT	Yes-excellent, especially for sinus fat
Ultrasound	Variable, operator-dependent; fast (5-10 min)	Fair-limited for small masses	No (0 mSv)	No-unreliable	No-unreliable
PET-CT (FDG-PET)	Moderate; slower (30-60 min)	Poor for renal masses (low FDG uptake in small RCC)	Yes (~5-10 mSv)	Limited-not routinely used for this purpose	Limited-not routinely used for this purpose

CT: Computed tomography, MPR: Multiplanar reconstruction, MRI: Magnetic resonance imaging, DWI: Diffusion-weighted imaging, ADC: Apparent diffusion coefficient, PET: Positron emission tomography, FDG: Fluorodeoxyglucose, RCC: Renal cell carcinoma

neovascularity and is disproportionately observed in high-grade clear cell RCC and tumors with sarcomatoid dedifferentiation; recognizing this pattern on multiphasic CT should lower the threshold for active treatment rather than surveillance, even in a mass that would otherwise be considered low-risk by size alone. Thin-slice acquisition with coronal and sagittal multiplanar reconstruction also allows precise assessment of the tumor's relationship to the collecting system and renal sinus fat, which is essential for RENAL nephrometry scoring and surgical planning, since centrally located or endophytic tumors carry a higher likelihood of collecting-system invasion and greater technical complexity during partial nephrectomy. The primary advantages of CT include high spatial resolution, rapid acquisition time (allowing imaging during optimal phases), excellent reproducibility of measurements, and widespread availability. CT has proven effective for both initial diagnosis and surveillance of small renal masses, with high sensitivity for detecting size changes. However, CT imaging uses ionizing radiation, which is a significant consideration for younger patients who may require decades of surveillance. Additionally, CT has limitations in characterizing indeterminate cystic masses and in imaging patients with an iodinated contrast allergy or severe renal insufficiency. The cumulative radiation exposure from serial surveillance CT scans is an important consideration when planning long-term follow-up protocols (18).

MRI offers superior soft-tissue contrast resolution compared to CT and avoids ionizing radiation, making it particularly valuable for surveillance of patients requiring long-term imaging follow-up (17). Dynamic contrast-enhanced MRI with appropriate timing of arterial phase acquisition effectively demonstrates renal mass enhancement patterns and improves characterization of both solid and cystic lesions. Its superior contrast resolution can make subtle heterogeneity within a mass, including small areas of necrosis or hemorrhage, more conspicuous than on CT and thus can refine the assessment of aggressiveness in equivocal cases. The addition of diffusion-weighted imaging with apparent diffusion coefficient measurements further enhances diagnostic capability by detecting restricted diffusion, which is more common in malignant than in benign lesions and correlates with higher tumor cellularity. MRI is also well suited to delineating the relationship of a centrally located tumor to the renal sinus fat and collecting system, which can assist preoperative planning when this distinction is equivocal on CT. MRI is particularly useful for patients with iodinated contrast allergy or severe renal insufficiency (avoiding gadolinium-based contrast in patients with very low glomerular filtration rate), and for characterization of complex cystic masses. However, MRI has several disadvantages: longer acquisition times, which increase susceptibility to artifacts from respiratory and patient motion; higher cost compared with CT; contraindications in patients with metallic implants; and concerns regarding nephrogenic systemic fibrosis associated with gadolinium-based contrast agents (though this risk has been substantially mitigated by newer formulations and restrictive usage protocols). Measurement reproducibility with MRI may be slightly inferior to that of CT, although recent advances in imaging sequences have narrowed this gap. For long-term surveillance strategies, MRI offers a compelling alternative to repeated CT scans due to lack of radiation exposure, though the longer acquisition times and higher cost may limit routine use (17).

Renal ultrasound is highly accessible, does not expose patients to ionizing radiation, does not require intravenous contrast, and has no absolute contraindications, making it an attractive option for resource-limited settings and initial screening of incidental renal lesions. However, ultrasound has significant limitations in the evaluation of renal masses: image quality is highly operator- and patient-dependent (obesity and bowel gas substantially impair visualization), inter-observer variability is higher than with CT or MRI, real-time characterization of small masses is unreliable, and measurement accuracy for size assessment is inferior to that of cross-sectional imaging. Ultrasound is also unable to reliably characterize enhancement heterogeneity or delineate the precise relationship of a mass to the collecting system, limiting its usefulness for risk-stratification decisions discussed above. As a result, ultrasound is most appropriate as an initial screening tool for patients at risk of renal masses or for follow-up of clearly benign simple cysts in patients with favorable acoustic windows. Ultrasound is generally not recommended as the primary modality for characterizing solid renal masses nor as a routine surveillance tool for small renal masses, because the accuracy and reproducibility of ultrasound are insufficient to support clinical decision-making about intervention versus observation.

Fluorodeoxyglucose-positron emission tomography (FDG-PET) has limited utility in the initial evaluation of small renal masses. Most small RCCs, particularly low-grade tumors, demonstrate low metabolic activity and minimal FDG uptake, resulting in poor sensitivity for malignancy detection. Consequently, PET-CT is neither recommended as a first-line characterization tool for incidentally detected renal masses nor routinely used in surveillance protocols for small renal masses. PET-CT may have a limited role in the evaluation of advanced RCC with suspected metastatic disease, but this is outside the scope of the management of small renal masses.

Imaging-based Decision-making: Enhancement Pattern and Tumor Location

Two imaging-derived features deserve particular emphasis because they carry direct, actionable implications for

treatment selection, independent of tumor size. The first is the enhancement pattern of the mass. Homogeneous enhancement is more typical of lower-grade, more indolent tumors, whereas heterogeneous enhancement-irregular, patchy, or non-uniform contrast uptake on multiphasic CT or MRI-reflects intratumoral necrosis, hemorrhage, and irregular neovascularity, and is disproportionately observed in high-grade clear cell RCC and in papillary type 2 tumors. Because this pattern has been correlated with higher nuclear grade and adverse pathological features in retrospective series, its presence should lower the threshold for active intervention rather than surveillance, even in a mass that would otherwise be considered low risk on the basis of size alone. The second feature is the tumor location relative to the renal sinus and the collecting system. Masses that are endophytic, abut the renal sinus fat, or cross the hilar plane are more frequently associated with higher-grade histology and a greater likelihood of occult invasion of the collecting system or perinephric fat. From a technical standpoint, central location increases operative complexity for partial nephrectomy, prolonging ischemia time and elevating the risk of urinary leak and bleeding. It also increases the risk of incomplete ablation and residual disease during thermal ablation, since the collecting system and adjacent major vessels act as heat sinks that limit thermal spread. Consequently, centrally located masses generally warrant either upfront partial nephrectomy, when surgically feasible, or closer surveillance intervals if active surveillance is pursued, rather than management according to the same algorithm applied to peripheral, exophytic lesions of comparable size. Because neither enhancement heterogeneity nor central location is reliably assessed by ultrasound, and both are only partially captured by PET-CT, multiphasic CT or dynamic MRI with multiplanar reconstruction should be regarded as the minimum adequate imaging standard whenever these features are likely to influence the treatment decision (17,18).

In clinical practice, CT and MRI are the primary modalities for characterizing small renal masses and performing surveillance. For initial diagnosis and characterization of a newly detected renal mass, multiphasic CT with proper arterial phase timing remains the most practical, cost-effective, and widely available first-line option. CT effectively characterizes most solid masses and provides accurate size measurements for baseline assessment. For patients selected for active surveillance, the choice between CT and MRI should be individualized based on patient factors, including age, renal function, contrast allergy, and anticipated duration of follow-up. Younger patients with long life expectancies may benefit from MRI-based surveillance protocols to minimize cumulative radiation exposure. Conversely, older patients or those with contraindications to MRI may continue with periodic CT imaging. A complementary approach-alternating between CT and MRI at different surveillance intervals-may optimize diagnostic accuracy while minimizing cumulative radiation exposure. Ultrasound may serve a supplementary role in selected patients with optimal acoustic windows for confirming known benign simple cysts, but it should not replace cross-sectional imaging for definitive diagnosis or routine surveillance of solid masses. The development of personalized imaging protocols that account for individual patient characteristics, mass features (size, growth rate, enhancement pattern, and relationship to the collecting system), and clinical context is essential for optimizing outcomes and minimizing unnecessary imaging and patient harm (18). The optimal clinical use of each modality is summarized in Table 5.

Natural Course

The majority of small renal masses consist of low-grade tumors with slow progression (19). In patients followed under active surveillance, the average annual tumor growth rate generally ranges from 0.1-0.3 cm (20). Delayed intervention and surveillance for small renal masses (DISSRM) data have shown that active surveillance is a safe approach in appropriately selected patients and that metastasis rates are low (20). In a natural course analysis conducted by Crispen et al. (5), it was revealed that the vast majority of small renal masses show a slow growth pattern and that the risk of early systemic progression is low. In a multicenter active surveillance series reported by Jewett et al. (6), it was stated that the progression criteria were mostly based on the growth rate and that the metastatic progression rates were below 2%. However, heterogeneous biological behavior should not be ignored; some small renal masses may show aggressive growth characteristics even in the early stages.

Table 5. Optimal clinical use by modality

Modality	Optimal use
CT (multiphasic)	Initial characterization; RENAL scoring and surgical planning; size measurement; rapid surveillance
MRI (dynamic+DWI)	Long-term surveillance; contrast allergy; cystic mass characterization; severe renal impairment; equivocal central/hilar relationship on CT
Ultrasound	Screening tool; confirmation of simple cysts; accessible/low-resource settings
PET-CT (FDG-PET)	Staging of advanced/metastatic RCC only-not for initial characterization or surveillance

RENAL: R (radius: largest diameter of the mass in centimeters), E (exophytic versus endophytic growth), N (nearness to the collecting system or renal sinus), A (anterior versus posterior location relative to the hilar plane), and L (location relative to the polar lines: upper, middle, or lower pole), CT: Computed tomography, MRI: Magnetic resonance imaging, DWI: Diffusion-weighted imaging, PET: Positron emission tomography, FDG: Fluorodeoxyglucose, RCC: Renal cell carcinoma

Therefore, instead of making intervention decisions based solely on the tumor diameter at the time of initial detection, it is recommended to evaluate the growth dynamics over time and radiological features together (5,6).

The growth kinetics of small renal masses under active observation have been extensively studied and demonstrate substantial heterogeneity. Large prospective series indicate that approximately 20-30% of small renal masses do not demonstrate radiographic growth over ≥10 years of follow-up, suggesting truly benign behavior or extremely slow progression. In contrast, other tumors exhibit more rapid growth trajectories, with growth rates ranging from 0.2 to 0.8 cm per year on average, though individual variability is substantial (21). Crispen et al. (5), documented that among 769 patients with untreated renal masses followed prospectively, the median tumor growth rate was approximately 0.28 cm per year (range, -0.10 to 2.0 cm/year). Similarly, the DISSRM registry reported median growth rates of 0.13 cm annually for masses <2 cm at baseline, with approximately 75-80% of masses exhibiting growth rates ≤0.5 cm per year (9). Importantly, growth rate itself does not reliably predict malignancy risk or oncologic outcome; many benign renal masses and low-grade RCCs exhibit slow but persistent growth, while some tumors remain entirely stable. Age at presentation and baseline tumor size represent the strongest predictors of future growth; younger patients and those with larger baseline masses more frequently demonstrate radiographic progression (20,21).

The Role of Renal Mass Biopsy in Treatment Decision-making

Percutaneous renal mass biopsy has an increasingly recognized role in the pretreatment evaluation of small renal masses, particularly when the result would meaningfully change management (22). The strongest indications are found in two clinical scenarios: patients being considered for active surveillance, in whom histological confirmation of a low-grade or indolent tumor [or identification of a benign entity such as oncocytoma or fat-poor angiomyolipoma (AML)] provides reassurance and strengthens adherence to a non-surgical strategy; and patients being considered for thermal ablation, in whom pretreatment biopsy is regarded as standard practice because the ablated tissue is frequently non-diagnostic afterward due to thermal artifact, making pre-procedural histological confirmation the only reliable opportunity to establish tumor type and grade (3,4,22). Additional indications include indeterminate imaging phenotypes, a solitary kidney or borderline renal function where the treatment threshold is higher, suspected metastasis from a non-renal primary, and multifocal or hereditary renal tumor syndromes where histology may alter the surgical or surveillance strategy (22).

Contemporary series report that percutaneous core biopsy achieves diagnostic accuracy of approximately 90-95% for distinguishing malignant from benign renal masses, with a non-diagnostic rate of roughly 10-20% that is highest for small (<1 cm), cystic, or technically difficult-to-access lesions, and that typically prompts repeat biopsy rather than default to intervention (23). Important limitations temper enthusiasm for routine biopsy. Sampling error can lead to grade underestimation in heterogeneous tumors, since a core sample may not capture the highest-grade component of the mass (23). Biopsy also has recognized difficulty in reliably distinguishing oncocytoma from the eosinophilic variant of chromophobe RCC or from hybrid oncocytic tumors in a meaningful minority of cases, which limits its ability to fully substitute for surgical pathology in that specific differential (24). Bosniak cystic lesions are generally poor candidates for biopsy, since sampling of septa or wall components has low diagnostic yield and imaging-based classification remains the primary tool for risk stratification in these masses (15,16). Complication rates are low, with clinically significant bleeding occurring in fewer than 5% of cases and pneumothorax being rare for lower pole lesions (23); needle-tract tumor seeding, though historically a concern, is now recognized to be exceedingly rare (well under 1%) with contemporary coaxial biopsy technique (25).

In practical terms, renal mass biopsy should be integrated into the decision-making algorithm rather than treated as an optional adjunct: it is most valuable when its result will change the recommended management, it has the greatest impact in younger patients steered toward active surveillance and in any patient considered for ablation, and it should be interpreted alongside, rather than in place of, imaging risk features such as RENAL score complexity, enhancement pattern, and Bosniak category when formulating a final treatment recommendation (12,15,22). This practical value has been demonstrated directly. In a multidisciplinary conference on small renal masses, incorporating input from radiology, pathology, and urology, the introduction of routine biopsy discussion was associated with a measurable increase in the selection of active surveillance rather than upfront intervention, confirming that biopsy results meaningfully change real-world management rather than serving as a purely academic exercise (26).

Radiological Differentiation of Benign Mimickers: AML and Oncocytoma

An estimated 20-30% of small renal masses selected for surgical resection ultimately prove to be benign on final pathology, a proportion that increases as tumor size decreases (24). Recognizing the two most common benign mimickers-AML and oncocytoma-on imaging alone is therefore a central and frequently underemphasized component of avoiding

unnecessary surgery, since a confident, non-invasive diagnosis can support surveillance without biopsy or resection, while a genuinely indeterminate appearance should still prompt the biopsy or surveillance pathways discussed above rather than default extirpative surgery.

Classic AML contains macroscopic fat and is one of the few renal masses that can be diagnosed with near-certainty on imaging alone. On unenhanced CT, regions within the mass measuring approximately -10 to -20 Hounsfield units are considered diagnostic of macroscopic fat and, in the absence of calcification or a predominantly solid enhancing component, essentially pathognomonic for AML, obviating the need for biopsy or intervention. On MRI, the same fat content is confirmed by loss of signal on fat-suppressed sequences and on the opposed-phase images of chemical-shift imaging, which is particularly useful when CT findings are equivocal or when radiation exposure should be minimized (8,18). A minority of AMLs (approximately 5%) are fat-poor and lack visible macroscopic fat on either imaging modality, closely mimicking clear cell RCC. features such as marked homogeneity, a relatively higher attenuation on unenhanced CT than typical RCC, and a well-defined angular interface with adjacent renal parenchyma can raise suspicion for fat-poor AML, but none of these features is sufficiently sensitive or specific to reliably exclude malignancy, and such lesions generally still warrant biopsy or continued surveillance with close imaging follow-up rather than a confident benign diagnosis on imaging alone (7,18).

Oncocytoma differentiation is comparatively difficult, since no imaging feature reliably distinguishes it from RCC, particularly from the eosinophilic variant of chromophobe RCC, with which it shares histogenetic features. The classically described central stellate scar and segmental enhancement inversion pattern (early peripheral enhancement with subsequent central fill-in) are more common in oncocytoma than in RCC, but both signs have limited sensitivity, may be absent in a substantial proportion of oncocytomas, and can occasionally be seen in malignant tumors; therefore, neither should be used in isolation to defer treatment. A more quantitative approach-the peak early-phase enhancement ratio measured on multiphasic CT or MRI-has shown considerably better discriminative performance, reliably separating oncocytoma and indolent hybrid oncocytic tumors from chromophobe RCC, particularly when combined with clinical risk factors and CD117 immunohistochemistry on biopsy material (24). Even so, imaging alone cannot yet definitively exclude malignancy in an oncocytic-appearing mass, which is why oncocytoma remains, in practice, principally a biopsy-supported rather than a purely radiological diagnosis (24).

The clinical implications of these two entities differ. When imaging demonstrates unequivocal macroscopic fat consistent with classic AML, active surveillance without biopsy or intervention is appropriate, and surgery should be reserved for lesions that cause symptomatic hemorrhage or that exceed a size threshold (typically around 4 cm) associated with the risk of spontaneous bleeding. When a mass is fat-poor or shows radiological features suggestive of, but not diagnostic for, oncocytoma, the appropriate next step is the biopsy-integrated decision pathway described above rather than proceeding directly to partial or radical nephrectomy, since a meaningful minority of these lesions will prove benign and a substantial proportion of the remainder will be low-grade, favorably behaving tumors for which surveillance or a nephron-sparing approach remains appropriate (8,24).

Active Surveillance

Active surveillance is considered a safe option in the management of small renal masses, especially in patients with comorbidities, advanced age, or those at surgical risk (27). A study reported from Türkiye also emphasized that active surveillance is a safe and rational approach in a significant portion of small renal masses in the advanced age group (≥75 years), and that the treatment decision should be made not only based on tumor size but also on comorbidities and renal function reserve (28). Contemporary guideline statements and systematic reviews of published surveillance protocols support active surveillance as an appropriate initial strategy for solid renal masses smaller than 2 cm and for selected cystic lesions, particularly in patients whose competing comorbidities make the risks of intervention outweigh the risks posed by the tumor itself (27). DISSRM data have shown that when careful patient selection is made, metastasis rates are low under active surveillance and delayed intervention does not negatively affect oncological outcomes (29).

Recommended Surveillance Imaging Protocol

Despite broad endorsement of active surveillance as a management option, published protocols have historically varied in the imaging modality used and in the frequency of follow-up, and this heterogeneity has itself been identified as a barrier to standardized care (27). Drawing on the surveillance schedules most consistently reported across systematic reviews of active surveillance protocols, a practical, guideline-concordant follow-up strategy can be summarized as follows. When a small renal mass is selected for surveillance, baseline cross-sectional imaging (multiphasic CT or dynamic contrast-enhanced MRI, chosen according to the criteria discussed in the imaging modalities section) should be obtained to document the mass's size, enhancement pattern, and relationship to the collecting system, thereby establishing the reference point against which future growth is measured. Repeat imaging is then recommended at approximately 3 to 6 months after the baseline study to establish the tumor's early growth kinetics, since this initial interval is the

most informative for identifying unexpectedly rapid growers who may warrant earlier intervention. If the mass remains stable at this first reassessment, imaging is generally continued every 6 months through the first 1-2 years of surveillance (27). Once a lesion has demonstrated a consistent pattern of slow or absent growth over this initial period, the surveillance interval can reasonably be extended to annual imaging, continued indefinitely for as long as the patient remains a surveillance candidate and is fit enough that a change in management would still be pursued (27,29). Ultrasound may be used to supplement CT or MRI in selected patients with favorable acoustic windows, once a benign-appearing growth pattern has been established, but it should not replace cross-sectional imaging as the primary surveillance tool, given its limitations in reproducibly measuring size and in characterizing enhancement, as discussed above. The specific imaging modality selected for serial follow-up should be individualized to the patient's renal function, contrast allergy status, and anticipated duration of surveillance: MRI-based protocols are favored in younger patients expected to undergo many years of follow-up to limit cumulative radiation exposure, whereas CT-based protocols are preferred where availability, cost, or claustrophobia make MRI impractical.

The most frequently used criteria for triggering a transition from surveillance to intervention include an absolute tumor diameter exceeding 3 cm, an annual growth rate greater than 0.5 cm, or a definite radiological stage progression (27). However, growth rate does not follow a linear course in all patients, and some lesions may transition to a plateau phase after an initial period of more rapid growth; the decision to intervene should therefore not be based on a single measurement or a single rapid interval, but on the dynamically evaluated growth pattern of the mass across serial imaging studies. In addition, the decision to continue or discontinue active surveillance should be shaped not only by tumor characteristics and growth kinetics but also by individual factors such as the patient's life expectancy, renal function status, and personal preferences (29).

Large prospective series examining outcomes of active surveillance protocols report favorable safety profiles, with low rates of progression to unresectable disease. Approximately 25-40% of patients selected for active surveillance ultimately require delayed intervention, with the timing of intervention typically triggered by imaging evidence of rapid growth (>0.4-0.5 cm/year), imaging characteristics evolving toward features concerning for malignancy, or patient preference (27). The progression to intervention typically occurs over 3-5 years for most patients, permitting extended periods of observation while minimizing the risk of missing optimal surgical windows. When delayed intervention is performed after active surveillance, partial nephrectomy remains technically feasible in approximately 80-85% of cases, with complication rates similar to those following upfront partial nephrectomy. Cancer-specific and overall survival in patients managed with active surveillance are excellent; mortality attributable to renal cancer is extremely rare, even in extended follow-up studies spanning 10+ years. This outstanding long-term oncologic control reflects the indolent behavior of most small renal masses, the effectiveness of a structured, dynamically-monitored delayed intervention strategy when necessary, and the careful selection of patients for surveillance based on favorable prognostic factors (27,29).

The Role of Thermal Ablation

Thermal ablation is a minimally invasive alternative treatment, especially for patients at high surgical risk and for small renal masses in anatomically suitable locations. High local control rates are achieved in peripherally located and exophytic lesions ≤3 cm in diameter with radiofrequency ablation and cryoablation techniques (14,17). Meta-analyses have shown that the short-term oncological results of ablation are comparable to partial nephrectomy; however, local recurrence rates may be slightly higher compared to surgery (29). On the other hand, thermal ablation has been shown to be advantageous with respect to perioperative morbidity, bleeding, and length of hospital stay. The most suitable candidates for ablation are lesions that are peripherally located, distant from the renal hilum, unrelated to the collecting system, and ≤3 cm in size (29). In centrally located and endophytic tumors, the risk of residual disease after ablation increases, and evaluating treatment response with imaging becomes more difficult. Therefore, it seems appropriate to make the decision for thermal ablation not only based on the tumor size but also considering the anatomical location and neighboring relationships of the tumor (30).

Thermal ablation (cryoablation and radiofrequency ablation) has gained widespread adoption as a minimally invasive alternative to surgical intervention in select patients with small renal masses. Systematic reviews and meta-analytic studies comparing partial nephrectomy to percutaneous ablative techniques demonstrate equivalent short-term cancer control, with local recurrence-free survival rates of 95-98% for cryoablation and 90-95% for radiofrequency ablation at 1-2 years (30). However, longer-term follow-up studies reveal some divergence: local recurrence rates increase to approximately 5-15% for cryoablation and 8-20% for radiofrequency ablation when follow-up extends beyond 5 years, although distant metastatic disease remains uncommon in early-stage renal cancer managed with ablation. The rate of local recurrence appears to correlate with tumor size, complexity (RENAL score), and ablation technique, with superior outcomes achieved for smaller (<3 cm), low-complexity masses and complete ablation at initial procedure (29). Perioperative morbidity following percutaneous ablation is generally lower than that following partial nephrectomy, with major complication rates of 5-10% for ablation versus 15-25%

for surgical approaches, though specific complications, such as ureteral injury with ablation in hilar masses, require thoughtful case selection and technique modification (29,30).

Partial Nephrectomy: Indications, Outcomes, and Technical Considerations

Partial nephrectomy is currently accepted as the standard treatment approach in clinical T1a renal tumors due to its ability to provide long-term oncological control (31). With the widespread use of minimally invasive techniques, especially robotic surgery, partial nephrectomy has become feasible with lower morbidity and better perioperative outcomes (32). However, technical feasibility does not mean that surgery is necessary in every patient. Because some small renal masses exhibit indolent biology, surgical treatment may lead to unnecessary nephron loss in some patients. Renal function loss after partial nephrectomy is related to the complex structure of the tumor, ischemia time, and resection volume (32). Especially for lesions with high nephrometry scores or with completely endophytic or hilar localization, surgical difficulty and the risk of complications increase. A Turkish study evaluating the results of early robotic retroperitoneal partial nephrectomy emphasized that surgical success should be considered holistically, based on parameters such as ischemia time, surgical margins, and complications (32,33). Therefore, instead of directly applying surgical treatment to all small renal masses, it is more rational to evaluate the tumor's biological risk and anatomical structure together. In the current approach, partial nephrectomy remains a strong option, especially in young patients, lesions with a high risk of progression, and complex masses that are anatomically suitable for surgery (34).

Partial nephrectomy has evolved into the gold-standard surgical approach for small renal masses in patients with preserved baseline renal function and a favorable operative-risk profile. Contemporary series demonstrate negative surgical margin achievement in >99% of cases, with local recurrence rates <1-2% at 5-year follow-up when complete tumor excision with a margin of normal parenchyma is achieved (34). Cancer-specific survival following partial nephrectomy for T1a tumors exceeds 95% at 5 years and 85-90% at 10 years; most patients die of competing causes rather than from renal cancer progression. The functional outcomes of partial and radical nephrectomy differ substantially: parenchymal preservation with partial nephrectomy preserves mean glomerular filtration rate (GFR) at 85-90% of baseline values, compared with a 25-35% loss of GFR after radical nephrectomy (34). This preservation of renal function is clinically significant because chronic kidney disease, stage 3b or worse (GFR <45 mL/min/1.73 m^2), is associated with increased cardiovascular morbidity and mortality. Perioperative complications of partial nephrectomy include bleeding (3-8%), infection (1-3%), urine leak (1-2%), and acute kidney injury (2-5%), with major complication rates increasing modestly for high-complexity masses (RENAL score ≥10) managed via open or robot-assisted approaches (12,33). Contemporary robot-assisted partial nephrectomy demonstrates comparable oncologic outcomes to open surgery with potentially lower morbidity in appropriately selected patients (32,34).

Clinical Decision Framework

The fundamental challenge in managing small renal masses is correctly distinguishing the availability of a technically feasible surgical option from an oncological necessity. While the widespread use of minimally invasive surgery has made partial nephrectomy safer and more accessible, this does not mean that every small renal mass requires surgical intervention. Data on the natural course show that active surveillance is a safe option, especially for lesions with low growth rates and diameters ≤2 cm. In this patient group, early surgical intervention leads to both unnecessary nephron loss and exposure to the potential risks of surgery without providing long-term oncological benefits.

In contrast, the likelihood of biological aggressiveness increases in rapidly growing lesions with heterogeneous contrast enhancement that are located centrally or at the hilum. In such masses, surgical intervention is considered a more rational approach. In the decision-making process regarding the treatment method, not only tumor diameter but also tumor growth kinetics, radiological indicators of aggressiveness, and tumor structural complexity should be evaluated together.

This comprehensive decision-making framework integrates imaging-based assessment of anatomical complexity using nephrometry scoring systems (RENAL score, range 4-12 with low-risk 4-6, intermediate-risk 7-9, and high-risk ≥10; PADUA score, range 6-14 with low-risk 6-7, intermediate-risk 8-9, and high-risk ≥10), tumor size, cystic characteristics (Bosniak classification), and patient-specific factors (age, comorbidities, baseline renal function, and surgical fitness) to guide individualized management of incidentally discovered small renal masses, as summarized in Table 6.

Treatment Modality Insights

Partial Nephrectomy: Remaining a strong option in young patients with long life expectancy, lesions with a high risk of progression, and complex tumors anatomically suitable for surgery.

Thermal Ablation: Offers an effective alternative in patients with suitable anatomical features, peripherally located lesions ≤3 cm in size, and high comorbidities. However, since the risk of residual disease and local recurrence may increase after ablation in masses with complex anatomical features, appropriate patient selection is vital.

Table 6. Clinical decision-making framework for small renal mass management

Clinical presentation	RENAL score	PADUA score	Tumor size	Patient factors	Recommended management	Expected oncologic outcomes
Benign lesion	N/A	N/A	Any	Any	Imaging surveillance every 3 years	No intervention needed; excellent prognosis
Low-complexity, indeterminate/RCC	4-6	6-7	<2 cm	Age <70 years, preserved renal function, no significant comorbidity	Partial nephrectomy (preferred)	<1-2% local recurrence; 95% cancer-specific survival at 5 years; GFR preservation 85-90%
Low-complexity, indeterminate/RCC	4-6	6-7	<2 cm	Age >75 years OR significant comorbidity OR borderline renal function	Active surveillance OR thermal ablation	AS: 25-40% progression at 5 years, >99% cancer-specific survival; ablation: 90-95% recurrence-free survival at 1-2 years, 5-10% major complications
Intermediate complexity	7-9	8-9	2-3 cm	Any patient	Partial nephrectomy (preferred) OR thermal ablation (alternative)	PN: 95% cancer-specific survival at 5 years, 15-20% major complications; ablation: 80-92% recurrence-free survival at 5 years
High complexity, suspicious for RCC	≥10	≥10	3-4 cm	Fit for major surgery, preserved baseline renal function	Partial nephrectomy (preferred) OR radical nephrectomy	PN: 85-95% cancer-specific survival at 5 years (size/grade dependent); radical PN: >95% cancer-specific survival but GFR loss 25-35%
High complexity, suspicious for RCC	≥10	≥10	3-4 cm	Poor surgical candidate OR significant comorbidity OR advanced age	Thermal ablation OR active surveillance	Ablation: 85-95% recurrence-free survival at 5 years, 5-10% major complications; AS: >99% cancer-specific survival but 40-50% may require future intervention

RENAL: R (radius: largest diameter of the mass in centimeters), E (exophytic versus endophytic growth), N (nearness to the collecting system or renal sinus), A (anterior versus posterior location relative to the hilar plane), and L (location relative to the polar lines: upper, middle, or lower pole), PADUA: Preoperative aspects and dimensions used for an anatomical, RCC: Renal cell carcinoma, OR: Odds ratio, N/A: Not applicable, GFR: Glomerular filtration rate, AS: Active surveillance, PN: Partial nephrectomy

Active Surveillance and Delayed Intervention: Growth kinetics during active surveillance (monitoring every 3-6 months with imaging) should inform the timing of delayed intervention. Crucially, partial nephrectomy remains technically feasible in 80-85% of cases initially managed conservatively.

Conclusion: This framework emphasizes the importance of individualized decision-making that balances oncologic control, functional outcomes (renal preservation), and patient-specific factors to optimize both short- and long-term outcomes.

Conclusion

The current approach in the management of small renal masses is evolving from uniform surgical strategies based on tumor diameter to individualized decision models in which treatment type is determined by biological behavior and radiological risk indicators. Natural course data reveal that active surveillance is a safe option, especially in lesions with low growth rates and diameters of ≤2 cm, while rapid growth patterns and aggressive radiological features may indicate the need for surgical intervention. Thermal ablation offers an effective, minimally invasive alternative in selected patients with suitable anatomical features, while partial nephrectomy remains a strong option for oncological control in young patients with a high risk of progression. The main goal in the management of small renal masses is not to remove every tumor that is technically possible, but to ensure both oncological safety and the prevention of unnecessary nephron loss by correctly distinguishing lesions that require biological intervention and by deciding on the appropriate treatment method.

Footnotes

Authorship Contributions

Concept/Design: M.Ç., O.B.K., Data Collection or Processing: T.Ç., H.M.D., A.A., Analysis or Interpretation: M.Ç., H.M.D., Literature Review: M.Ç., O.B.K., Writing, Reviewing and Editing: M.Ç., T.Ç.

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