International Journal of Multiphysics
Volume 18, No. 3, 2024
ISSN: 1750-9548

Multi-parametric MRI in Renal Cell Carcinoma

Khalid Mohamed Abdel Samad[1], Ahmed Sabry Ragheb[2], Mohamed Mahmoud Seleem[1], Mohamed Hossam Mohamed Ali[1], Mohamed Abdelaleem Soliman[1]

1 Urology Department, Faculty of Medicine, Zagazig University, Egypt

2 Radiology Department, Faculty of Medicine, Zagazig University, Egypt

***Corresponding author:** Mohamed Hossam Mohamed Ali

Email: drmohamedhossam111@gmail.com,

Abstract:

Multiparametric magnetic resonance imaging (mpMRI) has emerged as a powerful noninvasive imaging modality that integrates anatomical and functional sequences for comprehensive tissue evaluation. In renal cell carcinoma (RCC), accurate characterization, staging, and treatment planning remain essential for optimizing clinical outcomes. mpMRI combines T1- and T2-weighted imaging with functional techniques such as diffusion-weighted imaging (DWI) and dynamic contrast-enhanced (DCE) imaging, allowing assessment of tumor cellularity, vascularity, and microenvironment. This review aims to highlight the diagnostic role, clinical applications, and advantages of mpMRI in the evaluation and management of RCC.

Keywords: Multiparametric MRI, Renal cell carcinoma, Diffusion-weighted imaging, Dynamic contrast-enhanced MRI, Renal masses, Imaging diagnosis

Introduction:

Multiparametric MRI (mpMRI) is an advanced imaging technique that combines anatomical and functional MRI sequences to assess tissue morphology, vascularity, and cellularity in a single comprehensive study. It has become the standard noninvasive imaging modality for the evaluation of prostate cancer and is increasingly utilized in renal imaging, mpMRI typically integrates T2-weighted imaging (T2WI) for detailed anatomic visualization, diffusion-weighted imaging (DWI) for assessment of cellular density and diffusion restriction, and dynamic contrast-enhanced (DCE) imaging for evaluation of vascular perfusion and permeability. Optional sequences such as MR spectroscopy and apparent diffusion coefficient (ADC) mapping provide additional quantitative insights into tumor metabolism and aggressiveness **(Trivedi et al., 2021)**.

Technical Principles and Sequences

Each mpMRI component contributes unique diagnostic information. T2WI offers high-resolution anatomic detail in axial, sagittal, and coronal planes, delineating zonal anatomy and potential extracapsular extension. DWI evaluates the Brownian motion of water molecules, with restricted diffusion indicating high cellularity typical of malignancy; quantitative ADC maps enhance reproducibility. **(Panebianco et al., 2018)**

Multiparametric MRI Phases in Evaluation of Renal Masses :

Following intravenous administration of gadolinium-based contrast, imaging is obtained in several phases including the arterial (corticomedullary or nephrogenic) and excretory phases, These multiphasic acquisitions improve lesion detection and help differentiate benign from malignant renal tumors **(Silverman SG et al., 2008).**

The arterial phase, acquired approximately 20–40 seconds after contrast injection, demonstrates marked enhancement of the renal cortex relative to the medulla and is particularly useful for assessing tumor vascularity; hypervascular tumors such as Clear cell renal cell carcinoma typically show strong early enhancement, whereas hypovascular tumors such as Papillary renal cell carcinoma enhance less intensely **(Pedrosa I et al., 2008).**

The nephrogenic phase, obtained approximately 80–120 seconds after contrast administration, shows homogeneous enhancement of the renal parenchyma improves detection and characterization of renal masses **(Silverman SG et al., 2008).**

The excretory phase, usually acquired 3–5 minutes after contrast injection, demonstrates contrast excretion into the collecting system and is useful for evaluating involvement of the renal pelvis or calyces and for detecting lesions arising from the urothelium such as Upper tract urothelial carcinoma, which may appear as filling defects within the opacified collecting system **(Kawashima A et al., 2004).**

Role of mpMRI in RCC

Multiparametric magnetic resonance imaging (mpMRI) integrates anatomical and functional sequences—commonly T1- and T2-weighted imaging, diffusion-weighted imaging (DWI), and dynamic contrast-enhanced (DCE) sequences—to provide a comprehensive evaluation of renal masses and perinephric structures. In the context of renal cell carcinoma (RCC), mpMRI is primarily utilized for lesion characterization, local staging, treatment planning, and post-therapeutic surveillance, particularly when conventional modalities such as CT or ultrasound are inconclusive. Both the European Association of Urology (EAU, 2024) and the National Comprehensive Cancer Network (NCCN, 2025) endorse MRI, including multiparametric protocols, as the preferred imaging modality in cases of contraindicated iodinated contrast, impaired renal function, or indeterminate findings on CT **(Demirel and Davis, 2018)**.

Diagnostic Characterization of Renal Masses

The differentiation of benign from malignant renal lesions represents a key clinical application of mpMRI. Functional sequences enhance diagnostic specificity by evaluating tissue cellularity, vascularity, and fat content. Diffusion-weighted imaging and apparent diffusion coefficient (ADC) mapping typically reveal lower ADC values in malignant RCCs, reflecting restricted diffusion due to increased cellular density. Dynamic contrast-enhanced imaging demonstrates heterogeneous enhancement with rapid arterial uptake and washout, while chemical-shift sequences aid in distinguishing lipid-poor angiomyolipoma from RCC. **(Currie and Stewart, 2023)**.

Local Staging and Surgical Planning

mpMRI demonstrates superior accuracy in delineating the local extent of RCC, including assessment of perinephric fat invasion, renal vein and inferior vena cava (IVC) thrombus, and collecting system involvement . MRI venography sequences, particularly contrast-enhanced T1-weighted imaging, provide critical information for determining the surgical approach, including the need for thrombectomy. These capabilities make mpMRI indispensable for preoperative staging and multidisciplinary surgical planning in complex RCC cases **(Pei et al., 2023)**.

mpMRI indications in RCC :

Multiparametric MRI (mpMRI) is increasingly used in renal cell carcinoma (RCC) for its ability to provide detailed anatomical and functional information. One of its primary indications is the characterization of renal masses, particularly for differentiating benign lesions, such as oncocytomas or fat-poor angiomyolipomas, from malignant tumors. **(de Silva et al., 2022)**.

Another key application is local staging and surgical planning, where mpMRI accurately assesses tumor size, extent, and involvement of perinephric fat, the renal vein, inferior vena cava (IVC), and collecting system. This information is crucial for determining the feasibility of nephron-sparing surgery and tailoring operative approaches. mpMRI is also used for treatment response assessment; it can differentiate residual or recurrent tumor from post-surgical or post-ablation fibrosis, and functional sequences, such as diffusion-weighted imaging and dynamic contrast-enhanced MRI, can detect early microvascular or cellular changes in response to systemic therapies like VEGF-TKIs or immune checkpoint inhibitors **(de Silva et al., 2022)**.

In addition, mpMRI allows noninvasive evaluation of renal function, including perfusion and filtration, which is particularly important in patients with solitary kidneys or chronic kidney disease. Finally, mpMRI is

indicated when CT is limited or contraindicated, such as in patients with iodinated contrast allergy, impaired renal function (eGFR <30 mL/min/1.73 m²), or when prior ultrasound or CT studies provide insufficient lesion characterization. Collectively, these capabilities make mpMRI a versatile and essential tool in the modern management of RCC **(Makvandi et al., 2022)**.

Advantages of mpMRI

Multiparametric MRI (mpMRI) offers several clinical advantages in the management of renal cell carcinoma (RCC). Its high-resolution anatomical imaging allows precise visualization of zonal anatomy, tumor location, and local extension, which is essential for accurate staging and surgical planning. The incorporation of functional sequences, such as diffusion-weighted imaging (DWI) and dynamic contrast-enhanced (DCE) MRI, enables detection of early tissue changes, restricted diffusion, and tumor vascularity, providing insights into tumor aggressiveness and biology. mpMRI is non-invasive and does not use ionizing radiation, making it suitable for repeated follow-up and longitudinal monitoring. It also facilitates targeted biopsy guidance through MRI–ultrasound fusion or in-bore techniques, improving the detection of clinically significant tumors while reducing unnecessary biopsies. Additionally, mpMRI serves as a valuable active surveillance tool, allowing clinicians to monitor tumor progression with minimal invasiveness. Its role in treatment planning is well established, guiding nerve-sparing surgery, focal therapies, and radiotherapy. Finally, mpMRI's high negative predictive value enables reliable exclusion of clinically significant tumors, thereby reducing the risk of overtreatment and supporting informed clinical decision-making **(Posada Calderon et al., 2023)**.

References:

1. Currie, C. & Stewart, S. 2023. The relationship of apparent diffusion coefficient values of renal cell carcinoma before and after cryotherapy ablation. Radiography, 29, 473-478.
2. de Silva, S., Lockhart, K. R., Aslan, P., Nash, P., Hutton, A., Malouf, D., et al. 2022. Differentiation of renal masses with multi-parametric MRI: the de Silva St George classification scheme. BMC Urol, 22, 141.
3. Demirel, H. C. & Davis, J. W. 2018. Multiparametric magnetic resonance imaging: Overview of the technique, clinical applications in prostate biopsy and future directions. Turk J Urol, 44, 93-102.
4. Kawashima, A., Vrtiska, T. J., LeRoy, A. J., Hartman, R. P., McCollough, C. H., & King Jr, B. F. (2004). CT urography. Radiographics, 24(suppl_1), S35-S54.
5. Makvandi, K., Hockings, P. D., Jensen, G., Unnerstall, T., Leonhardt, H., Jarl, L. V., et al. 2022. Multiparametric magnetic resonance imaging allows non-invasive functional and structural evaluation of diabetic kidney disease. Clin Kidney J, 15, 1387-1402.
6. Panebianco, V., Giganti, F., Kitzing, Y. X., Cornud, F., Campa, R., De Rubeis, G., et al. 2018. An update of pitfalls in prostate mpMRI: a practical approach through the lens of PI-RADS v. 2 guidelines. Insights into Imaging, 9, 87-101.
7. Pedrosa, I., Chou, M. T., Ngo, L., H. Baroni, R., Genega, E. M., Galaburda, L., ... & Rofsky, N. M. (2008). MR classification of renal masses with pathologic correlation. European radiology, 18(2), 365-375.
8. Pei, X., Lu, M., Liu, Z., Liu, B., Deng, Y., Yuan, H., et al. 2023. The value of enhanced multiparameteric MRI diagnostic model for preoperatively predicting surgical methods of inferior vena cava in patients with renal tumors and inferior vena cava tumor thrombus. BMC Med Imaging, 23, 86.
9. Posada Calderon, L., Eismann, L., Reese, S. W., Reznik, E. & Hakimi, A. A. 2023. Advances in Imaging-Based Biomarkers in Renal Cell Carcinoma: A Critical Analysis of the Current Literature. Cancers [Online], 15.
10. Silverman, S. G., Israel, G. M., Herts, B. R., & Richie, J. P. (2008). Management of the incidental renal mass. Radiology, 249(1), 16-31.
11. Trivedi, J., Sutherland, T. & Page, M. 2021. Incidental findings in and around the prostate on prostate MRI: a pictorial review. Insights into Imaging, 12, 37.