Submitted: 19 December, 2024 Accepted: 14 April, 2025 Published: 30 July, 2025 DOI:10.22514/jomh.2025.098

ORIGINAL RESEARCH

JOMH Journal of Men's Health

A study on diagnostic efficacy of dynamic contrast-enhanced magnetic resonance imaging combined with diffusion-weighted imaging in patients with prostate cancer

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Abstract

Background: This study aims to evaluate the diagnostic efficacy of dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI), diffusion-weighted imaging (DWI), and their combination in prostate cancer patients. **Methods**: 134 patients with prostatic diseases (61 cases with benign prostatic hyperplasia and 73 cases with prostate cancer) admitted to our hospital from February 2022 to February 2024 were retrospectively analyzed. DCE-MRI and DWI were performed. A comparison was made between both groups based on needle biopsy results, DWI index, DCE-MRI index, detection results and diagnostic efficacy. Receiver operating characteristic (ROC) curves were plotted to examine diagnostic performance differences between different diagnostic methods. **Results**: In the prostate cancer group, DWI high signal ratio, volume transfer constant (K^{trans}) and rate constant (Kep) were significantly higher, while in the DWI group slightly high signal intensity, low mixed signal ratio and extravascular extracellular volume fraction (Ve) were lower ($p < 0.05$). DCE-MRI and DWI combined had the largest area under the curve (AUC) on the ROC curve ($p < 0.05$). **Conclusions**: A combination of DCE-MRI and DWI for prostate cancer results yielded significantly higher diagnostic accuracy than either modality alone. Clinically, this combined approach can guide prostate cancer diagnosis and treatment with significant clinical value.

Keywords

DCE-MRI; DWI; Combined examination; Prostate cancer; Diagnosis

1. Introduction

Prostate cancer is one of the most common malignancies in men and is particularly insidious at its early stage [1]. Symptoms such as dysuria, hematuria, pain and even distant metastasis may occur if the disease is overlooked, posing a grave threat to the patient's life [2]. Clinical practice continues to face significant challenges in diagnosing prostate cancer. There are several traditional diagnostic methods for prostate cancer, including digital rectal examination (DRE) [3] and prostate-specific antigen (PSA) testing, which are simple and feasible with certain sensitivity [4], but they lack specificity and cannot accurately determine the presence, extent or nature of tumors. Furthermore, these methods are prone to false positives and false negatives. While the needle biopsy is regarded as the "gold standard" for prostate cancer diagnosis [5], it involves risks such as bleeding, infection and misdiagnosis. With the advancement of medical imaging technologies, dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) and diffusion-weighted imaging (DWI) have become increasingly important in diagnosing prostate cancer [6]. DCE-MRI reflects blood perfusion and vascular permeability by observing the dynamic distribution of contrast agents within tissues [7, 8], demonstrating abnormal vascular structure in prostate cancer tissues causes delayed contrast agent clearance and active angiogenesis [9, 10]. DWI detects the restricted diffusion of water molecules in prostate cancer tissues, providing valuable information about the cellular microstructure [11]. These techniques help in the early diagnosis of prostate cancer by identifying high signal intensity and other distinguishing features [12]. However, DCE-MRI or DWI alone may suffer from limitations, such as atypical signal changes, susceptibility to false positives or false negatives [13] and difficulty differentiating complex lesions.

Imaging diagnostic methods for prostate cancer face several challenges in clinical applications, including:

(1) Insufficient sensitivity and specificity: While DRE and PSA testing are useful for preliminary screening, their sensitivity and specificity remain limited. DRE's subjectivity and PSA level fluctuations can lead to false positives and negatives,

affecting clinical diagnostic accuracy. (2) False positives and false negatives: False positives and false negatives result from traditional imaging methods, leading to unnecessary follow-up exams or missed diagnoses. False positives can cause unnecessary anxiety and invasive tests, while false negatives can delay treatment. (3) Complexity of tissue structures and lesions: In prostate cancer, the tissue structure is complex, and the lesions can exhibit a wide variety of imaging characteristics. A single imaging method cannot fully assess the nature and extent of the lesions, particularly when the tumor boundary is unclear. (4) Limitations of contrast-enhanced imaging: DCE-MRI relies on dynamic contrast agent distribution, which can be influenced by patient factors, such as hemodynamic changes, renal function and contrast agent excretion in individuals. Moreover, interpreting DCE-MRI images requires expertise, and contrast agents may cause allergic reactions or other complications. (5) Limitations of DWI: DWI provides information on cellular microstructure, but its ability to distinguish cancer from benign lesions may be compromised by inflammation or other non-cancerous conditions. DWI is also sensitive to imaging parameters, such as *b*-values, which impact image quality and interpretation.

Traditional methods for diagnosing prostate cancer, such as DRE and PSA testing, have significant limitations that can impair early diagnosis and accuracy. Limitations of traditional diagnostic methods include:

(1) DRE: High subjectivity: Depending on the physician's palpation skill and experience, DRE accuracy may vary, making it highly subjective. Limited detection range: Through palpation, DRE primarily evaluates the posterior surface of the prostate, missing tumors at the front or edges that may be present. False positives and false negatives: DRE may result in false positives (abnormal findings that do not indicate cancer) and false negatives (failure to detect existing cancer), which can lead to clinical decision errors. (2) PSA testing: Insufficient specificity: Elevated PSA levels may be associated with various benign prostate conditions, such as benign prostatic hyperplasia and prostatitis, leading high false positives rates. Influence of age and other factors: PSA levels can vary among patients with similar pathological conditions depending on their age, ethnicity and other health conditions, complicating interpretation. Inability to assess tumor aggressiveness: PSA testing does not provide information about the pathological characteristics, aggressiveness or grade.

Advanced Imaging Technologies have several advantages which include:

(1) DCE-MRI: High-resolution imaging: DCE-MRI provides high-resolution images of the prostate and surrounding tissues, clearly delineating tumor shape and location. Hemodynamic assessment: Blood perfusion and vascular permeability in active prostate cancer can be assessed by DCE-MRI based on the dynamic distribution of the contrast agent. Early tumor detection: DCE-MRI enhances the contrast between tumor and normal tissue, aiding in tumor early detection. (2) DWI: Cellular microstructure assessment: In DWI, water molecules diffuse restrictedly through tissues, which provides information about cell density and tissue microstructure. Prostate cancer cells exhibit restricted diffusion, resulting in high signal intensity. Quantitative analysis: Using apparent diffusion coefficient (ADC) values, DWI can improve diagnostic accuracy by distinguishing benign from malignant lesions. Reduction of false positives and false negatives: Detecting lesions with DWI can reduce false positive and false negative rates, thereby providing more reliable diagnostic results.

Advantages of combined application: The combination of DCE-MRI and DWI allows for the full utilization of both techniques' strengths, complementing each other. Combining DCE-MRI hemodynamic data with DWI cellular microstructure data enhances the comprehensiveness and precision of prostate cancer diagnosis. The combination of DCE-MRI and DWI provides better diagnostic results than either technique separately, thereby providing more reliable information for early diagnosis, staging and treatment planning.

Despite the widespread clinical use of traditional diagnostic methods, they have undeniable limitations. New imaging technologies, particularly DCE-MRI and DWI, offer new ways to diagnose prostate cancer early and accurately, improving treatment and prognosis assessment. This study aims to compare the diagnostic efficacy of DCE-MRI and DWI alone, and their combination in prostate cancer patients.

2. Materials and methods

2.1 Clinical data

We retrospectively analyzed the clinical data of 134 patients with prostatic diseases admitted to our hospital between February 2022 and February 2024. Patients' age ranged from 47 to 77 years, with a mean (62.25 $\pm$ 6.34) years, and Body Mass Index (BMI) 16~26 kg/m^2, with a mean (21.12 $\pm$ 2.18) kg/m^2. Based on the results of pathological examinations, they were divided into benign prostatic hyperplasia group (n = 61) and prostate cancer group (n = 73).

2.2 Inclusion and exclusion criteria

2.2.1 Inclusion criteria

Pateints were included if they had; ① according to the Practical Guidelines for Prostate Cancer [14], presence of typical symptoms such as dysuria, hematuria, *etc.*, performed prostate biopsy, and diagnosis of prostate cancer confirmed by needle biopsy; ② performed DCE-MRI and DWI; ③ complete clinical data; ④ rectal examination or cystoscopy not conducted 7 days before the examination; and ⑤ no previous treatment received by the patient.

2.2.2 Exclusion criteria

Pateints were excluded if they ① had other malignant tumors; ② had immune system diseases; ③ suffered from mental disorders; ④ suffered from important organ dysfunction; and ⑤ were receiving radiotherapy or chemotherapy recently.

2.3 Methods

As a retrospective study, examination methods were already documented in existing case records. All patients were given DCE-MRI and DWI examinations by the same group of physicians.

2.3.1 DCE-MRI examination

Patients were scanned using a GE SIGNA Voyager 1.5T MR Imager (Milwaukee, WI, USA).

(1) Preparation before inspection

Medical history was obtained, metal objects were removed from the patient's body. The patient was asked to drink 500 to 1000 mL of water 1 to 2 hours before the examination to moderately fill the bladder. Furthermore, we did an excellent job of explaining the proceedure to the patient to relieve tension. We then started the MRI machine to self-test the system, prepared contrast agent, checkd and calibrated the high-pressure syringe tubing and injection speed.

(2) Examination of the patients

Patients were kept supine during the examination, and the body coil was used to hold their bodies so that motion artifacts were minimized. Localization scans were performed using a fast gradient recalled echo sequence (Repetition Time (TR): 8 to 15 ms; Echo Time (TE): 3 to 6 ms; flip angle: 10 to 15°; Field of View (FOV): 16 to 24 cm; slice thickness 5 to 10 mm), T1-weighted Imaging (T1W1) scans (TR: 300 to 800 ms; TE: 10 to 30 ms; FOV: 16 to 24 cm; slice thickness 3 to 5 mm) and T2-weighted Imaging (T2W1) scans (TR: 3000 to 6000 ms; TE: 80 to 120 ms; FOV: 16 to 24 cm; slice thickness 3 to 5 mm) were performed using spin echo. The contrast agent was rapidly injected into the cubital vein by a high-pressure syringe at an injection rate of 2~3 mL/s. Dynamic contrast-enhanced scanning was performed using a three-dimensional spoiled gradient echo sequence (TR: 3~810 ms; TE: 1~3 ms; FOV: 16~24 cm; slice thickness 3~5 mm). Observing the signal intensity of prostate tissue was done continuously over 30×60 phases.

(3) Check post-processing. Senior doctors analyzed and intervened on the collected images. Kep, K^{trans} and Ve were calculated.

2.3.2 DWI examination

Patients were scanned using a GE Discovery MR750w magnetic resonance imager (Waukesha, WI, USA).

(1) Preparation before inspection

Medical history was obtained, metal objects were removed from the patient's body, and the patient was asked to drink 500 to 1000 mL of water 1 to 2 hours before the examination to moderately fill the bladder. We relieved patient's tension by explaining the proceedure clearly. We then started the MRI machine to self-test the system, selected the appropriate phased array coil and correctly placed it around the patient's lower abdomen to obtain good signal reception.

(2) Examination of the patients

Supine positioning was used, and a fixture was used to ensure physical stability. Localization scans were performed using a fast gradient recalled echo sequence (TR: 8 to 15 ms; TE: 3 to 6 ms; flip angle: 10 to 15°; FOV: 20 to 30 cm; slice thickness: 5 to 10 mm), DWI scans were performed using a single-shot echo-planar imaging sequence (TR: 2000 to 10,000 ms; TE: 50 to 100 ms; FOV: 16 to 24 cm; slice thickness: 3 to 5 mm; diffusion sensitivity coefficient b was set at 800 to 1500 s/mm^2 and 0, respectively), and acquisition directions were three orthogonal directions to comprehensively assess the diffusion characteristics of prostate tissue in different directions.

(3) Check post-processing

Senior doctors analyzed and intervened on the collected images. High signal intensity, slightly high signal intensity, low mixed signal intensity and other statistics were analyzed.

Specific MRI sequences and parameters were selected based on the following reasons: Use of DCE-MRI: DCE-MRI provides dynamic information about tumor blood supply, which is critical in prostate cancer diagnosis due to its association with angiogenesis. K^{trans} and Kep reflect prostate tissue hemodynamic characteristics, aiding in differentiation of benign and malignant lesions.

Use of DWI: DWI assesses the diffusion of water molecules in tissue, which is particularly restricted in prostate cancer, resulting in high signal intensity. The chosen b-value range (800–1500 s/mm^2) enhances the contrast between tumors and normal tissues.

Parameter standardization: Standardizing TR, TE and slice thickness ensures image consistency and comparability, improving diagnostic accuracy.

Image quality optimization: The selected sequences and parameters maximize the signal-to-noise ratio and reduce motion artifacts, ensuring clear imaging of the prostate and its pathological features.

Together, these strategies improve diagnostic efficacy and provide robust imaging evidence for clinical practice.

To minimize variability among examiners, the following measures were implemented: (1) Unified training: All image analysis physicians underwent standardized training to ensure consistent interpretation and parameter measurements. (2) Standardized protocol: We followed the same examination protocol and parameter settings for both DCE-MRI and DWI scans, using the same MRI scanner, imaging sequences and patient preparation procedures. (3) Dual evaluation: Two assessors independently evaluated K^{trans}, Kep and Ve, and the results were compared and discussed to ensure consistency. (4) Use of quantitative analysis tools: Computer-aided tools were employed to measure signal intensity and other parameters, reducing subjective interpretation. (5) Regular calibration of equipment: The MRI equipment was calibrated and maintained regularly to ensure consistent image quality. (6) Clear diagnostic standards: All examiners evaluated images based on the same imaging diagnostic standards.

2.4 Outcome measures

Results of DCE-MRI, DWI and their combination were compared. An accurate diagnosis was confirmed by pathological examination.

(1) DWI index. The signal manifestation of high signal intensity, slightly high signal intensity and low mixed signal intensity in the images of the two groups together with apparent diffusion coefficient (ADC) changes were observed and compared.

(2) DCE-MRI parameters. Ve, Kep and K^{trans} were observed and compared between the two groups.

(3) Comparison of test results. Diagnostic results of the three methods and pathological results were compared based on their coincidence.

(4) Diagnostic efficacy. Receiver operating characteristic curve (ROC) curves were used to evaluate diagnostic accuracy.

2.5 Imaging analysis software and algorithms

(1) Imaging acquisition and preprocessing equipment and imaging parameters: High-field MRI equipment (*e.g.*, 3.0T) (MRI 3.0T System, GE Healthcare, Waukesha, WI, USA) was used. Detailed scan parameters such as slice thickness, field of view, matrix size and repetition time/echo time (TR/TE) were recorded for both DCE-MRI and DWI imaging. For standardizing images, OsiriX (OsiriX MD, Pixmeo, Geneva, Switzerland) or FSL (FSL 6.0, Functional Magnetic Resonance Imaging of the Brain Centre, University of Oxford, Oxford, UK) software is used for noise removal, artifact elimination and resampling.

(2) DWI analysis: ADC (Apparent Diffusion Coefficient) calculation: ADC values were calculated using DWI images, with software tools like DICOMpy and 3D Slicer, applying either a double-exponential or single-exponential model. High *vs.* low signal differentiation: Signal intensity analysis was performed using threshold segmentation methods (such as the Otsu algorithm) and region-growing algorithms using MATLAB or Python image processing libraries (such as OpenCV) being applied.

(3) DCE-MRI analysis: Parameter calculation: Specialized DCE-MRI analysis software (NordicICE or DCE-MRI Analysis Software) (NordicICE 3.0.0, Nordic Imaging Lab, Oslo, Norway) was used to calculate K^{trans}, Kep and Ve. Typically, these software tools use pharmacokinetic models to analyze the contrast between tumors and normal tissues. Time-Concentration Curve (TAC) analysis: The TAC for tumor regions was extracted to assess the dynamic distribution of the contrast agent.

(4) Combined analysis and diagnostic efficacy evaluation: Statistical analysis: SPSS (SPSS 28.0, IBM, Armonk, NY, USA) or R was used for statistical tests to compare DWI and DCE-MRI indices. ROC curve analysis was performed with MedCalc (MedCalc 20.2, MedCalc Software Ltd. Ostend, West Flanders, Belgium) or GraphPad Prism (GraphPad Prism 9.5, GraphPad Software Inc., San Diego, CA, USA) to evaluate each parameter's sensitivity and specificity. Image fusion: DWI and DCE-MRI images were registered and fused using ITK-SNAP or 3D Slicer to better understand tumor biological characteristics.

(5) Overall Workflow:

Image acquisition: MRI equipment was used to obtain DWI and DCE-MRI images.

Image preprocessing: Images were denoised, standardized and resampled.

Feature extraction: Parameters like ADC, K^{trans}, Kep and Ve were computed.

Data analytics: Statistical software was used for intergroup comparisons and ROC curve plotting.

Results summary: Results were integrated, conclusions were drawn and pathology results were compared.

2.6 Statistics

Data were analyzed and differences between groups were assessed by students *t*-test, for continuous variables, and chi-square (χ^2) test, for categorical variables, both using SPSS 27.0 software. A p-value < 0.05 indicated significant differences. ROC (receiver operating characteristic curve) curves were plotted utilizing SPSS to further compare diagnostic methods differences.

3. Results

3.1 DWI index comparison

Patients in the prostate cancer group had a significantly higher proportion of high signal intensity, but with a significantly lower proportion of slightly high signal intensity and low mixed signal intensity ($p < 0.05$, Table 1) compared to the benign prostatic lesion group.

3.2 Comparison of DCE-MRI index

Patients in the prostate cancer group had significantly higher K^{trans} and Kep, but with significantly lower Ve ($p < 0.05$, Table 2) than the benign prostatic lesion group.

3.3 Results of ROC curve analysis

The combined diagnosis of the two yielded the largest area under the ROC curve (AUC), showing a statistically significant difference ($p < 0.05$), and thus indicating superior diagnostic performance (Table 3, Fig. 1).

3.4 Results of overall model quality

The overall model quality results showed that the single index and combined index were >0.5, suggesting that all three diagnostic methods were useful in detecting renal cell carcinoma. Accordingly, the combined index has the highest predictive value (Fig. 2).

4. Discussion

Atypical early symptoms, prostate anatomy complexity, limitations in detection methods and tissue heterogeneity all pose challenges to early prostate cancer diagnosis [15]. Traditional DRE is a simple, convenient and cost-effective method of evaluating prostate size and texture. However, its sensitivity and specificity are low, and it can miss tumors located deeper within the prostate or those of smaller size. Further, DRE accuracy greatly depends on the examiner's experience. PSA tests, while widely used, have limited specificity. PSA levels can be elevated by conditions like prostatitis and benign prostatic hyperplasia, resulting in false positives, and consquently unnecessary anxiety and excessive testing. To improve diagnostic efficacy, DCE-MRI and DWI have been increasingly applied. DCE-MRI identifies hemodynamic changes that help differentiate prostate cancer from benign lesions [16], while DWI detects microstructural changes that help identify early lesions [17]. However, both methods have limitations such as low resolution, unclear visualization of lesion details and susceptibility to interference when used in isolation. Therefore,

TABLE 1. DWI index comparison (n, %).

Group	Case	High signal	Slightly high signal	Low-mixed signal
Prostate cancer group	73	59, 80.82	14, 19.18	0, 0.00
Benign prostatic lesion group	61	0, 0.00	48, 78.69	13, 21.31
t value	—	88.085	–47.339	–17.229
p value	—	<0.001	<0.001	<0.001

TABLE 2. DCE-MRI index ($\bar{x} \pm sd$).

Group	Case	Ve	Kep (min)	K^{trans} (min)
Prostate cancer group	73	0.38 ± 0.05	0.94 ± 0.09	0.54 ± 0.03
Benign prostatic lesion group	61	0.58 ± 0.17	0.72 ± 0.20	0.47 ± 0.07
t value	—	−9.296	8.181	7.424
p value	—	<0.001	<0.001	<0.001

Ve: extravascular extracellular volume fraction; Kep: rate constant; K^{trans}: volume transfer constant.

TABLE 3. Results of ROC curve analysis.

Index	AUC	Standard Error	*p* value	95% Confidence interval	
				Lower Limit	Upper Limit
DWI	0.762	0.037	<0.001	0.689	0.835
DCE-MRI	0.902	0.028	<0.001	0.847	0.957
Combined	0.938	0.022	<0.001	0.895	0.980

AUC: area under the curve; DWI: diffusion-weighted imaging; DCE-MRI: dynamic contrast-enhanced magnetic resonance imaging.

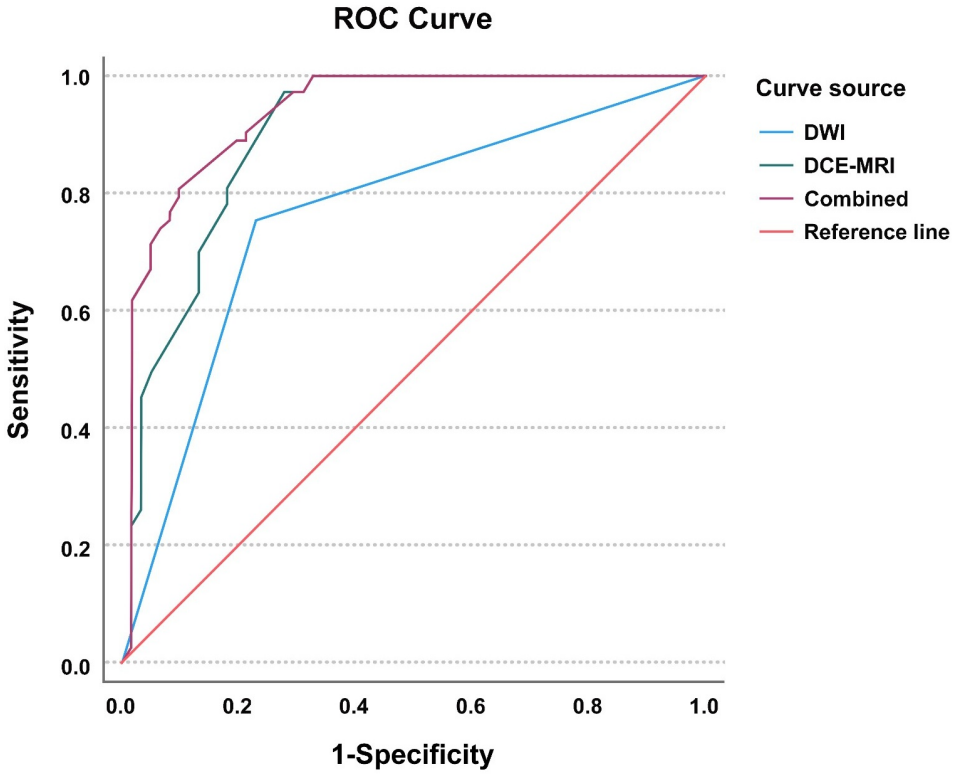

FIGURE 1. ROC curve. ROC: Receiver operating characteristic; DWI: diffusion-weighted imaging; DCE-MRI: dynamic contrast-enhanced magnetic resonance imaging.

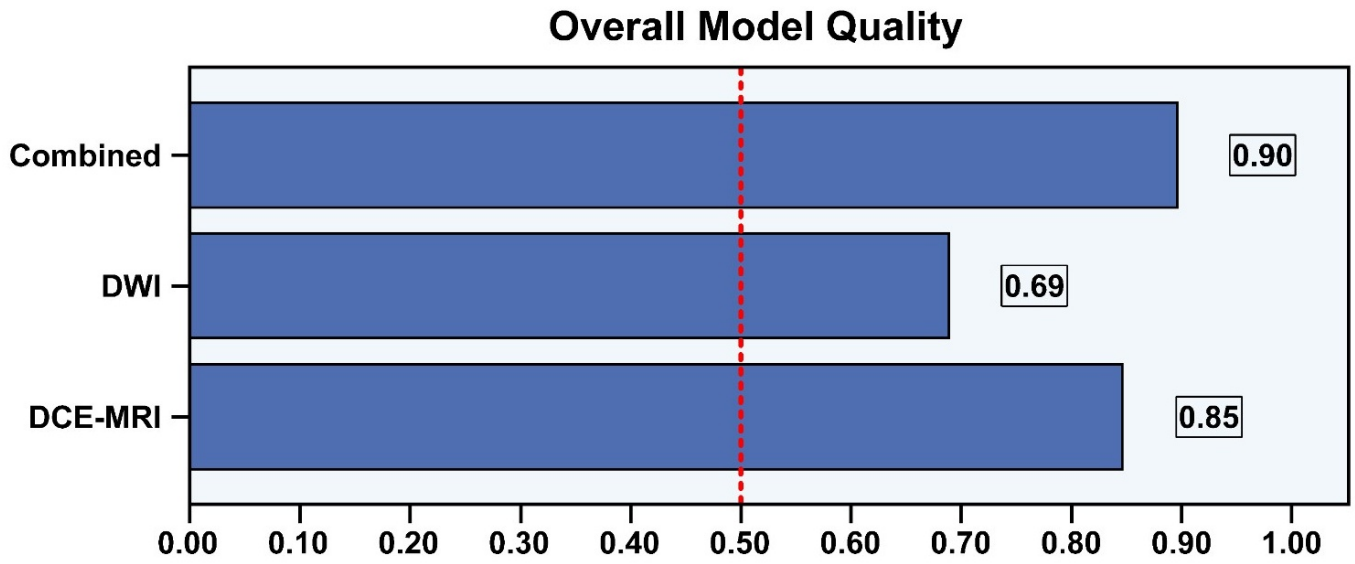

FIGURE 2. Overall model quality. DWI: diffusion-weighted imaging; DCE-MRI: dynamic contrast-enhanced magnetic resonance imaging.

it is often necessary to combine both techniques to improve diagnostic accuracy.

In this study, the proportion of DWI with high signal intensity, K^{trans} and Kep was higher, while the proportion of DWI with slightly high signal intensity, low mixed signal intensity and Ve were significantly lower in the prostate cancer group ($p < 0.05$). DWI and DCE-MRI are both capable of differentiating prostate cancer. This is because DWI reflects tissue microstructural differences through signal intensity changes. In prostate cancer, cell proliferation leads to increased cell density, smaller extracellular space, a higher nucleocytoplasmic ratio, and greater restriction of water molecular diffusion. Benign prostatic lesions, on the other hand, have a more regular cell arrangement, less restricted diffusion [18], and milder changes in extracellular space, contributing to differences in signal intensity. These variations help distinguish prostate cancer from benign lesions. By contrast, DCE-MRI shows tissue structural differences by assessing vascular function and blood flow [19]. Tumor angiogenic factors cause increased vascular endothelial cell space and permeability in prostate cancer tissues, leading to greater leakage of contrast agents from intravascular to extravascular space [20]. This results in a higher K^{trans}. Kep value is also increased by increased vascular permeability and faster exchange of substances between the extravascular and intravascular spaces [21]. Proliferating cancer cells compress the surrounding extravascular—extracellular space, leading to decreased Ve.

Based on ROC curve analysis, the combined use of DWI and DCE-MRI provides the best diagnostic efficacy and predictive value. Specifically, DWI focuses on structural changes at cellular level, while DCE-MRI assesses vascular function and blood perfusion. By combining the two, false positives from benign prostatic lesions (as seen with DWI alone) and blood perfusion changes due to local inflammation (as seen with DCE-MRI alone) are reduced. The combined approach minimizes false positives and false negatives caused by benign prostatic hyperplasia and tissues with limited diffusion restrictions. By analyzing multiple parameters, this combined approach provides a more comprehensive assessment of prostate tissues, improving diagnostic efficacy.

For prostate cancer diagnosis, combining DCE-MRI and DWI offers the following advantages: (1) Improved diagnostic accuracy: The combination of tissue blood perfusion data from DCE-MRI with diffusion properties from DWI [22] enhances diagnostic information richness. Mutual verification improves overall diagnostic accuracy. (2) Early and small lesion detection: DWI is more sensitive to early tumor detection [23] and can detect lesions before significant structural changes have occurred. When combined with the high resolution of DCE-MRI, which provides blood perfusion information, it enhances the detection of small lesions, thus aiding early detection. (3) Enhanced differential diagnosis: The specific findings on DCE-MRI and DWI (high signal intensity, high K^{trans}, *etc.*) distinguish prostate cancer from granulomatous prostatitis or prostatitis, thereby reducing misdiagnosis risk and improving differentiating benign and malignant lesions [24]. (4) Monitoring treatment response: The combined approach allows for real-time monitoring of tumor shrinkage, blood perfusion changes, and water molecule diffusion recovery during treatment. By adjusting treatment plans based on ongoing results, effective management is assured.

DCE-MRI and DWI together have demonstrated significant differences in prostate cancer diagnostic effectiveness. These differences may be related to the tumor microenvironment, biological characteristics and physiological basis of these imaging techniques. Here are some details about the potential biological mechanisms behind these differences:

(1) Biological characteristics of tumor cells: Compared to benign prostate hyperplasia cells, prostate cancer cells exhibit a higher proliferation rate and metabolic activity. Prostate cancer tissues often show strong angiogenesis, which increases the K^{trans} value due to increased proliferation and metabolism. Enhanced uptake of contrast agents by tumor tissues, indicating changes in tumor vascular structure and function. Due to

prostate cancer tissues' high metabolic activity, Kep (elimination rate constant) may be elevated, suggesting a faster clearance rate of contrast agents. Changes in the extracellular matrix and cell proliferation in prostate cancer tissues result in a decrease in Ve. This may be associated with remodeling of the tumor microenvironment, which includes changes in extracellular matrix and stromal components.

(2) Changes in the tumor microenvironment: The tumor microenvironment in prostate cancer differs from that in benign prostate hyperplasia, and this may influence imaging results. Tumor-related inflammation: Prostate cancer is often accompanied by chronic inflammation, which affects tissue diffusion properties, affecting DWI signals. Hypoxia: Hypoxic conditions within tumors can affect cell diffusion. Hypoxia alters cellular hydration and membrane functionality, influencing DWI signal characteristics.

(3) Cell membrane characteristics: Physicochemical properties of prostate cancer cell membranes may differ from those of benign prostate hyperplasia cells, which affect DWI signal intensity. Cell membrane integrity: Due to cell death or membrane remodeling, cancer cell membranes can become more permeable, increasing DWI signal intensities. Intracellular and extracellular fluid distribution: Fluid distribution inside and outside prostate cancer cells may be influenced by cellular proliferation, apoptosis and tumor cell metabolism, contributing to significant differences in DWI signals.

(4) Sensitivity of imaging techniques: The differences in DCE-MRI and DWI imaging mechanisms and sensitivities contribute to the observed differences. DCE-MRI provides information on the tumor's microenvironment and angiogenesis status, primarily through blood flow and vascular permeability. DWI reflects water molecules' diffusion properties and indicates tissue cell density and membrane integrity. Thus, DWI has unique advantages for detecting cell proliferation and assessing tumor malignancy.

(5) Clinical implications: Combined diagnostic approach of DCE-MRI and DWI offers a more comprehensive view of the tumor, aiding in early diagnosis and improving prostate cancer detection accuracy. Combining both morphological and biologic characteristics of the tumor provides a more reliable basis for clinical decision-making. For the development of new therapeutic strategies and precision medicine, it is important to understand these biological mechanisms.

Overall, DWI and DCE-MRI examinations in prostate cancer patients show significant differences due to the tumor's biological characteristics, microenvironmental changes, and imaging techniques. To optimize clinical diagnosis and treatment of prostate cancer, further research is needed. A study by Bayoumi Dalia [25] examined 220 patients with non-mass enhancement (NME) breast lesions. To investigate the characteristics of benign and malignant NME lesions, various MRI techniques, including DCE-MRI, DWI, and magnetic resonance spectroscopy (MRS), were used. Multiparametric MRI (Mp-MRI) was found to be more accurate than DCE-MRI and other functional sequences (DWI, MRS), with an accuracy of 91.2%, sensitivity of 89.9%, specificity of 87.8%, positive predictive value of 89.2%, and negative predictive value of 82.2%. The results confirmed that functional MRI techniques such as DWI and MRS provide valuable information for evaluating NME lesions. Their diagnostic accuracy, specificity, and sensitivity are high for differentiating benign from malignant NME breast lesions. The combination of multiparametric MRI and DCE-MRI improves diagnostic accuracy and reduces negative biopsies rate. This supports the results of our study, which showed that DCE-MRI and DWI combined yield higher prostate cancer diagnostic efficiency.

A study by Xu Qiaoyu [26] assessed the diagnostic value of ADC values and DCE-MRI parameters in differentiating tumor deposits (TD) and metastatic lymph nodes (MLN) in rectal cancer (RC). A pre-treatment MRI was conducted on 30 RC patients (59 lesions). TDs and MLNs differ significantly in in morphological features such as size, shape and margin. Combining DCE-MRI and DWI parameters provided higher diagnostic efficiency (AUC = 0.825), indicating improved diagnostic accuracy when ADC values are integrated with DCE-MRI parameters. Sharma Garima's study [27] evaluated 33 untreated patients with primary bone tumors using DWI and DCE-MRI. DWI and DCE-MRI parameters showed a strong correlation, further supporting the value of combining these techniques. Both techniques were found to be highly effective in cancer diagnosis, with their combined use superior to either method alone.

In modern medical imaging, DCE-MRI and DWI are vital tools for detecting and evaluating tumors. Particularly in the diagnosis of prostate cancer, their combined application has significant clinical value. Clinical Significance of DCE-MRI and DWI Parameter Changes include:

(1) Significance of DWI parameter changes: High signal ratio: A high signal ratio in DWI indicates high cell density and restricted water diffusion in prostate cancer tissues. The signal intensity increases due to tumor cell growth, which narrows the intercellular spaces and limits water diffusion. Mild high signal and low mixed signal ratio: The ratio of mild high signals to low mixed signals may indicate how aggressive and differentiated the tumor is. Undifferentiated tumors often exhibit higher cell density and lower signal intensity, reflecting their malignant biological behavior.

(2) Significance of DCE-MRI parameter changes: K^{trans} (Volume Transfer Constant): K^{trans} measures the rate at which contrast agents transfer from blood vessels to tumor tissues. Higher K^{trans} values suggest increased tumor angiogenesis, often associated with greater tumor activity and invasiveness. Neovascularization, which is crucial to tumor growth and metastasis, can be detected in prostate cancer by elevated K^{trans} values. Kep (Rate Constant) and Ve (Extravascular Extracellular Volume Fraction): Kep measures the rate at which contrast agents return to the bloodstream from tumor tissue. Elevated Kep values are generally correlated with increased tumor blood supply. A decrease in Ve indicates a reduction in the volume of extravascular extracellular fluid in the tumor tissue, which may be related to tumor cell swelling and metabolic activity.

(3) Clinical value of combined DCE-MRI and DWI application: The combined analysis of DCE-MRI and DWI parameters provides a more comprehensive description of tumor characteristics. Based on ROC curve analysis, the combined approach is significantly more effective than either method alone. Several clinical implications follow from this find-

ing. Improved diagnostic accuracy: Combining DCE-MRI and DWI enhances the differentiation between benign and malignant lesions, leading to improved prostate cancer early detection rates. Guided treatment decisions: A thorough assessment of tumor blood supply and cell density can assist in personalized treatment planning, such as selecting the most appropriate surgical or radiotherapy strategy. Monitoring treatment response: Combining DCE-MRI and DWI during treatment allows for timely adjustments to treatment plans based on tumor response.

DCE-MRI and DWI are of significant clinical value in prostate cancer diagnosis. Diagnostic accuracy is improved as well as treatment decisions are informed by detailed analyses of their parameter changes. Therefore, it is recommended that these two imaging techniques be integrated into clinical practice for improved diagnostics and therapeutics.

DCE-MRI and DWI enhance diagnostic accuracy and may also influence treatment plans for prostate cancer diagnosis and treatment. The potential impact of combining DCE-MRI and DWI on treatment strategies includes:

(1) Personalized treatment strategies development: DCE-MRI and DWI offer a comprehensive view of prostate cancer imaging characteristics. Blood supply, cellular density, and diffusion characteristics can be evaluated by physicians to understand the tumor's biological behavior. Treatment plans can be tailored based on this information. For instance, choosing treatment methods: Based on the tumor's aggressiveness and stage, physicians can determine appropriate treatment options, including surgery, radiotherapy, hormone therapy or watchful waiting. Elevated K^{trans} and high DWI signal ratios may indicate a more aggressive tumor, guiding a more intensive treatment plan. Adjusting treatment intensity: Imaging findings can guide the dose and timing of radiotherapy or hormone therapy. Physicians may increase treatment intensity or alter treatment approach if imaging reveals inadequate tumor response.

(2) Monitoring treatment response: The combination of DCE-MRI and DWI offers an effective means of monitoring tumor response to treatment. Regular imaging exams enable physicians to: Assess efficacy: Changes in imaging parameters, such as K^{trans} and the DWI high signal ratio, are indicators of a tumor's response to treatment. A significant improvement in these parameters post-treatment suggests that the therapy may be effective, whereas a lack of improvement could necessitate adjustments to the treatment plan. Early detection of recurrence: DWI is sensitive to diffusion restrictions within tumor cells, while DCE-MRI detects changes in tumor blood supply. By identifying early signs of recurrence, physicians can modify the treatment plan in a timely manner.

(3) Risk assessment and prognosis prediction: Combining DCE-MRI with DWI improves prognosis assessment. For example, Prognostic stratification: Clinicians can identify patients at higher risk by analyzing imaging parameters. It allows for more aggressive treatments to be considered for high-risk patients and more conservative approaches for low-risk patients. Psychological support: A clear imaging assessment and prognosis prediction helps patients better understand their condition, resulting in more active participation in treatment decisions.

(4) Multidisciplinary collaboration and treatment plan optimization: The combined analysis of DCE-MRI and DWI fosters collaboration among multidisciplinary teams, such as urologists, radiologists and oncologists. By sharing imaging results, the team can: Unify treatment goals: Ensure that all healthcare providers have an understanding of the patient's condition, resulting in more consistent treatment plans. Optimize resource allocation: Surgical interventions and radiotherapy can be allocated more efficiently based on imaging results, resulting in better treatment outcomes.

This study underscores the substantial advantages of integrating DCE-MRI and DWI in prostate cancer diagnosis. The findings offer valuable insights into clinical practice and may have broad implications for clinical guidelines.

(1) Improve diagnostic accuracy: Combining DCE-MRI with DWI significantly improves diagnostic accuracy compared to using either imaging technique alone, based on the areas under the ROC curve. Clinicians should prioritize the combined use of these modalities for improving diagnostic precision and reducing misdiagnoses.

(2) Optimizing screening processes: DCE-MRI and DWI together are more effective at screening high-risk prostate cancer patients. These findings may influence clinical screening guidelines, recommending the joint use of these imaging techniques to detect and treat prostate cancer early.

(3) Formulating personalized treatment plans: The integration of DCE-MRI and DWI provides more comprehensive tumor characteristics, potentially influencing personalized treatment plans. With more precise imaging assessments, physicians can choose more appropriate treatments, such as selective radiotherapy, surgery or medication.

(4) Updating clinical decision support tools: The study's findings may encourage medical institutions and professional organizations to update clinical decision support tools and guidelines, incorporating recommendations for the combined use of DCE-MRI and DWI. When diagnosing prostate cancer, physicians would be able to make more informed, evidence-based decisions.

(5) Promoting multidisciplinary collaboration: Prostate cancer diagnosis and treatment necessitate collaboration across medical specialties. To ensure patients receive comprehensive care, updated clinical guidelines may foster closer collaboration between urologists, radiologists, and oncologists.

(6) Foundation for future research: This study provides a foundation for further research, encouraging large-scale prospective studies to validate the application of DCE-MRI and DWI on prostate cancer patients at different stages. Such research will contribute to imaging technology advancement and provide data to support forward-looking clinical guidelines development.

While the combined application of DCE-MRI and DWI in prostate cancer diagnosis has demonstrated substantial clinical value, several challenges persist in the realm of quantitative diagnosis, as outlined below:

(1) Standardization and consistency: Variations in imaging equipment and scanning parameters can lead to discrepancies in DCE-MRI and DWI results. In the absence of standardized protocols, it is difficult to compare and validate results across different institutions. For quantitative analysis to be reliable,

uniform imaging standards and parameter settings are essential [28].

(2) Interpretation of quantitative parameters: Clinical significance of DCE-MRI parameters such as K^{trans}, Kep and Ve requires further investigation. While elevated K^{trans} is typically associated with tumor angiogenesis, the biological characteristics of different types of prostate cancer and their impact on imaging features remain incompletely understood. Furthermore, DWI's ADC values can be influenced by various factors, including the diffusion properties of tissue water molecules and the tumor microenvironment [29].

(3) Correlation between imaging and pathology results: This study demonstrates that combining DCE-MRI and DWI improves prostate cancer detection, but establishing a correlation between imaging biomarkers and pathology results remains challenging. A more personalized approach to diagnosing cancer can be enabled by exploring the relationship between imaging characteristics and histological grading, staging and prognosis.

(4) Practicality in clinical application: Diagnostic accuracy is greatly influenced by the experience and judgment of imaging physicians and radiologists. Clinical decision-making can be improved by integrating quantitative analysis results into clinical decision-making.

(5) Potential for dynamic monitoring: Most current studies focus on static image evaluation; however, dynamic changes in prostate cancer (*e.g.*, during treatment) are critical for monitoring disease progression and prognosis. Further research is needed to explore dynamic monitoring and assess the potential applications of DCE-MRI and DWI in evaluating tumor treatment response and recurrence detection.

While DCE-MRI and DWI can be combined for quantitative diagnosis of prostate cancer, challenges such as standardization, interpretability and correlation with clinical pathology remain. As research and technology progress, early diagnosis and treatment of prostate cancer will improve, leading to better clinical management strategies for patients. This study has some limitations. Since the study included a relatively small number of patients, in-depth statistical analysis and generalization of the results are greatly limited. Due to the limited sample size, results may be influenced by chance, thus greatly limiting the reliability of the study findings. As a single-center study, this study is undoubtedly underrepresented in terms of the variability in setting and patient population. To provide a more accurate and reliable basis for diagnosing prostate cancer, larger, multicenter, prospectively designed studies are warranted.

5. Conclusions

In summary, DCE-MRI combined with DWI is significantly more effective than DCE-MRI or DWI alone for prostate cancer diagnosis. This combined approach offers important clinical guidance for the diagnosis and treatment of prostate cancer. For enhanced reliability and applicability, multicenter or prospective studies are recommended.

AVAILABILITY OF DATA AND MATERIALS

The authors declare that all data supporting the findings of this study are available within the paper and any raw data can be obtained from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

LiLY—designed the study and carried them out. LiLY, KYH, HFQ, LingLY—supervised the data collection. LiLY, KYH, HFQ—analyzed the data; prepared the manuscript for publication and reviewed the draft of the manuscript. LiLY, KYH—interpreted the data. All authors have read and approved the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval was obtained from the Ethics Committee of Ningbo Yinzhou Seconed Hospital (Approval no. 2024058). Written informed consent was obtained from legally authorized representatives for anonymized patient information to be published in this article.

ACKNOWLEDGMENT

Not applicable.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Lili Ying, Kaiyan Hu, Haifeng Qiu, Lingling Ying. A study on diagnostic efficacy of dynamic contrast-enhanced magnetic resonance imaging combined with diffusion-weighted imaging in patients with prostate cancer. Journal of Men's Health. 2025; 21(7): 69-78. doi: 10.22514/jomh.2025.098.