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"Multiparametric MR Imaging In Prostate Lesions"

Dr. Radhi Sonpura
(Professor And Head Of Radio-Diagnosis Department, Gcs Medical College, Hospital And Research Centre, Ahmedabad).

Dr. Asutosh Dave
(Professor And Head Of Radio-Diagnosis Department, Gcs Medical College, Hospital And Research Centre, Ahmedabad).

Dr. Kavisha Goshwami
(3rd Year Resident In Gcs Medical College, Ahmedabad).

Dr. Harsh Prashnani
(3rd Year Resident In Gcs Medical College, Ahmedabad).

Dr. Dhruvin Doshi
(3rd Year Resident In Gcs Medical College, Ahmedabad).

Dr. Krishn Nandaniya
(3rd Year Resident In Gcs Medical College, Ahmedabad).

Abstract
Purpose of review:- Prostate cancer is the most common solid organ cancer type among American men. Screening and imaging aim to detect early-stage disease that is biologically aggressive. The focus of this study is to review multiparametric MRI in the detection and risk stratification of prostate cancer.
Recent findings:- MP-MRI has been shown to be the most accurate noninvasive technique to localize prostate cancer. Recent studies reported that using MRI for guidance during prostate biopsies increases the yield of prostate biopsies. Moreover, multiparametric and particular MRI sequences such as apparent diffusion coefficient values of diffusion-weighted MRI have been found to correlate negatively with tumor Gleason scores.
Summary:- Among the existing imaging modalities, multiplanar magnetic resonance is the best at detecting prostate cancers. Some risk stratification is possible based on size, extent and apparent diffusion coefficient values. However, prostate MRI remains nonspecific and biopsies must be performed to confirm whether an abnormality is benign or malignant and to assign Gleason scores.

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I. Introduction

Prostate cancer remains the most frequently diagnosed malignancy affecting the male genitourinary system and ranks as the third leading cause of cancer-related deaths in men globally. Accurate diagnosis and lesion characterization are essential for effective patient management and treatment planning.

The emergence of multiparametric magnetic resonance imaging (mpMRI) has significantly improved the detection and evaluation of prostate abnormalities. This imaging technique combines three complementary MRI sequences:

- **T2-weighted (T2W) MRI**: Provides high-resolution anatomical details of the prostate, allowing clear visualization of glandular structures and abnormalities.
- **Diffusion-weighted imaging (DWI)**: Evaluates the diffusion of water molecules within tissues, which helps differentiate between malignant and benign lesions based on cellular density.
- **Dynamic contrast-enhanced MRI (DCE-MRI)**: Involves the use of contrast agents to assess tissue vascularity and perfusion patterns, often indicative of cancerous changes.

To ensure uniform acquisition and interpretation of mpMRI scans, the European Society of Urogenital Radiology (ESUR) developed the Prostate Imaging Reporting and Data System (PI-RADS) in 2012. The main objectives of PI-RADS include:

- Minimizing interobserver variability among radiologists.
- Improving communication between radiologists and referring clinicians through standardized reporting.
- Supporting quality control and encouraging research in prostate imaging.
- Enhancing patient outcomes by offering a reliable risk stratification tool.

In 2015, the American College of Radiology (ACR) collaborated with ESUR to release PI-RADS version 2.0, which offered updated guidance for conducting, interpreting, and documenting mpMRI of the prostate. The goals of PI-RADS v2.0 were to:

- Set minimum technical requirements to ensure consistency across imaging facilities.
- Simplify the language and content used in prostate MRI reports.
- Create a structured scoring system to estimate the likelihood of clinically significant prostate cancer.

PI-RADS v2.0 was designed as a dynamic framework, with subsequent updates based on clinical experience and feedback. One such revision, PI-RADS v2.1, was introduced in 2019 to enhance and clarify the system.

The PI-RADS scoring scale ranges from 1 to 5:

- **PI-RADS 1**: Very low likelihood of clinically significant cancer.
- **PI-RADS 2**: Low probability.
- **PI-RADS 3**: Uncertain; presence of clinically significant disease is ambiguous.
- **PI-RADS 4**: High probability.
- **PI-RADS 5**: Very high likelihood of clinically significant prostate cancer.

Using mpMRI in combination with the PI-RADS system has greatly improved the differentiation of benign and malignant lesions, enhanced diagnostic precision, informed biopsy decisions, and contributed to more tailored treatment planning.

II. Materials And Methods

A prospective observational study was carried out in the Radiodiagnosis Department at GCS Hospital, Ahmedabad, over a 12-month period from January to December 2024. Ethical approval was obtained from the hospital's Institutional Ethics Committee, and all patients provided written informed consent prior to participation.

The study included 60 male patients aged 50 years or older who exhibited clinical suspicion of prostate abnormalities. Eligibility was based on elevated serum prostate-specific antigen (PSA) levels, abnormal digital rectal examination (DRE) findings, or suspicious features observed on transrectal ultrasonography (TRUS). Patients were excluded if they had contraindications to MRI (e.g., metallic implants or pacemakers), a history of prostate surgery, or a previously confirmed malignancy.

Each participant underwent a full clinical evaluation including medical history, DRE, and PSA testing. TRUS was conducted to assess the size, echotexture, and any focal abnormalities in the prostate. This was followed by multiparametric MRI of the prostate.

All mpMRI scans were performed using a 1.5 Tesla Signa Explorer MRI system (GE Healthcare). The imaging protocol followed PI-RADS v2.1 standards and included T1-weighted, T2-weighted, DWI, ADC maps, and DCE sequences. Lesions identified through mpMRI were scored based on the PI-RADS classification system. Those with PI-RADS scores of 3 or higher were referred for TRUS-guided biopsy to confirm diagnosis via histopathology. Biopsy results were then compared with imaging findings to determine the diagnostic accuracy of mpMRI for detecting clinically significant prostate cancer.

Clinical, imaging, laboratory, and histopathological data were compiled and analyzed to evaluate the diagnostic utility of mpMRI in characterizing prostate lesions.

Inclusion And Exclusion Criteria

Inclusion Criteria:

- Male patients with suspected prostatic nodules or glandular enlargement.

Exclusion Criteria:

- Patients with implanted electronic or metallic devices such as:
  - Cardiac pacemakers
  - Insulin pumps
  - Cochlear implants
  - Neurostimulators

- Individuals with metallic foreign bodies in the eye or intracranial clips.
- Patients with impaired kidney function.

MRI Protocol and Imaging Parameters All MRI scans were performed using a 1.5T Signa Explorer MRI machine with a body coil. Patients were scanned in the supine position, and the protocol included:

- **T1WI and T2WI**: Conducted in axial and coronal planes with a field of view (FOV) of 350 mm, slice thickness of 3 mm, and inter-slice gap of 0.3 mm.
- **DCE-MRI**: Gadolinium-based contrast (Gad-DTPA) was administered at a dose of 0.2 mmol/kg (max 15 mmol), injected at a rate of 3 mL/s. Early-phase images were acquired at 2 minutes post-injection, with delayed-phase images at 5 minutes, to assess enhancement kinetics.
- **DWI with ADC Mapping**: Acquired using b-values of 0, 500, and 1000 s/mm² (TR: 1570 ms; TE: 75 ms; FOV: 160 mm; slice thickness: 3 mm). Regions of interest (ROIs) were drawn over lesions to calculate ADC values.

Lesions were interpreted using PI-RADS v2.1 criteria. The dominant imaging sequence used to assign the PI-RADS score depended on lesion location—DWI for peripheral zone (PZ) and T2WI for transition zone (TZ). DCE imaging was scored as 0 (no early enhancement) or 1 (focal early enhancement). For PI-RADS 3 lesions with positive DCE findings, the final score was upgraded to 4.

Lesion Assessment:-

All imaging was reviewed in a single session by a team of radiologists. Patients underwent TRUS-guided biopsy targeting the MRI-identified suspicious lesions within 2 weeks of scanning. The prostate was divided into 18 regions: 12 within the PZ and 6 within the TZ, and each was scored from 1 to 5 based on imaging findings. The final PI-RADS score was based on dominant imaging criteria specific to lesion location.

Histopathological Examination:-

Biopsy specimens were preserved in 4% buffered formaldehyde for 48 hours and processed using standard clinical pathology procedures. A pathologist—blinded to imaging results—analyzed hematoxylin-eosin and saffron-stained slides, marked cancerous areas, determined lesion location, and assigned a Gleason score. High-grade prostate cancer was defined as having a primary Gleason pattern score of 4 or above.

In a histopathological analysis of 60 patients, the distribution of diagnoses is as follows:

Histopathology	Number of Lesions	Percentage (%)
Adenocarcinoma	42	70.0
Benign Prostatic Hyperplasia	12	20.0
Focal Adenoma	4	6.7
Prostatitis	2	3.3

This distribution indicates that adenocarcinoma is the most prevalent diagnosis, accounting for 70% of cases. Benign Prostatic Hyperplasia (BPH) was identified in 20% of patients, while focal adenoma and prostatitis were less common, representing 6.7% and 3.3% of cases, respectively.

These findings align with previous studies. For instance, a hospital-based study in India reported that all 34 prostatic malignancies were adenocarcinomas, with no other histological types observed. Another study evaluating prostate biopsy results found that 17.8% of cases were malignant, with the most common Gleason score being 3+3.

These comparisons suggest that while the prevalence of specific prostate conditions can vary across different populations, adenocarcinoma remains the predominant malignancy detected in prostate biopsies.

In analysing the Gleason scores from TRUS biopsies of 42 malignant prostate lesions, the distribution is as follows:

Gleason Score	Number of Lesions	Percentage (%)
6	14	33.3
7	13	31.0
8	9	21.4
9	4	9.5
10	2	4.8
Total	**42**	**100.0**

Tumor Grade Distribution:

The data show that approximately one-third (33.3%) of the cases were classified as low-grade tumors with a Gleason score of 6. Tumors of intermediate grade, corresponding to a Gleason score of 7, were identified

in 31.0% of the patients. High-grade malignancies (Gleason scores 8 to 10) comprised 35.7% of the cases, with 21.4% having a score of 8, 9.5% a score of 9, and 4.8% a score of 10.

Statistical Analysis:

Continuous variables were summarized using mean and standard deviation, while categorical variables were described using frequency distributions. The difference in ADC values between benign and malignant lesions was analyzed using the Mann–Whitney U test. A p-value less than 0.05 was considered statistically significant. Diagnostic performance was evaluated through sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Receiver Operating Characteristic (ROC) curve analysis was also conducted to assess diagnostic accuracy.

1-Specificity

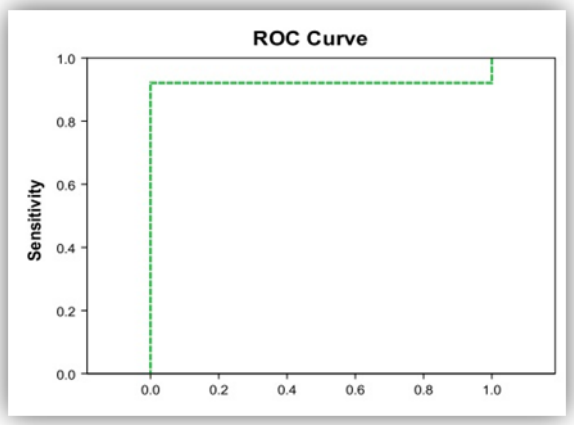

Fig. 1 ROC curve for the sensitivity and specificity of Mp-MRI with PI-RAD2.0 scoring system.

Assessment of the Accuracy of Multi-Parametric MRI

Table 3: DWI with ADC Value in 41 PZ Lesions and T2WI in 19 TZ Lesions with DCE-MRI Findings and PI-RADS 2.0 Scoring System

PI-RADS Score	DWI PZ Findings	No & Percentages	T2 TZ Findings	No & Percentages
1	No abnormality	05 (12.20%)	No abnormality	06 (31.60%)
2	Indistinct area on ADC map	04 (09.80%)	Well-defined hypo-intense/heterogeneous	05 (26.30%)
3	Moderate diffusion restriction	07 (17.10%)	Heterogeneous with obscured margin	03 (15.80%)
4	Marked diffusion restriction	17 (41.50%)	Non-circumscribed hypo-heterogeneous	01 (05.30%)
5	>1.5 cm with marked restricted diffusion or invasive behavior	08 (19.50%)	>1.5 cm non-circumscribed or invasive behavior	04 (21.10%)

ADC p < 0.001

Diagnosis	No. of Cases (PZ Lesions)	No. of Cases (TZ Lesions)
Benign	09 (19.50%)	15 (78.90%)
Malignant	32 (80.50%)	04 (21.10%)

DCE-MRI Findings:

DCE-MRI Result	PZ Lesions	TZ Lesions
Positive	30 PZ (73.20 %)	09 TZ (47.40%)
Negative	11 PZ(26.80%)	10 TZ (52.60%)

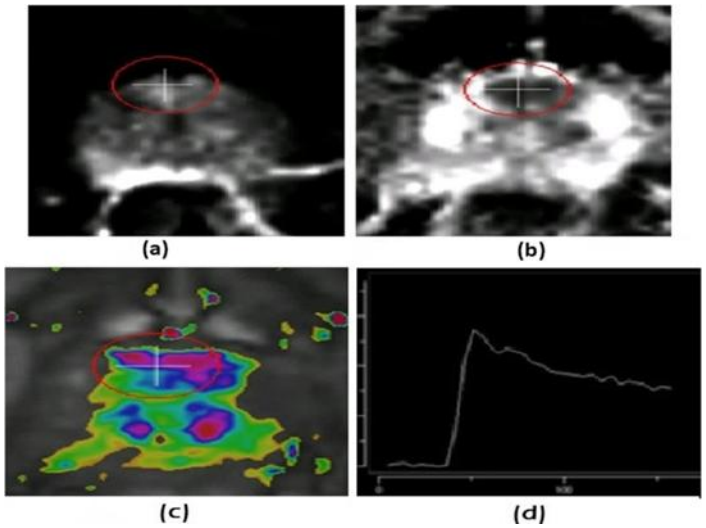

Fig. 2: 58yrs old patient, with felt P/R hard suspicious prostate nodule, (a and b) DWI and ADC map revealed nodular lesion at the anterior aspect of PZ with significant diffusion restitution, ADC value measuring ''0.8763", (c and d) DCE-MRI revealed moderate enhancement with type III enhancement curve).PI-RADS 2.0, score = 4. All MP-MRI findings are collectively diagnostic of Malignant lesion. Histo-pathology: Adeno-Ca. (Gleason score 8).

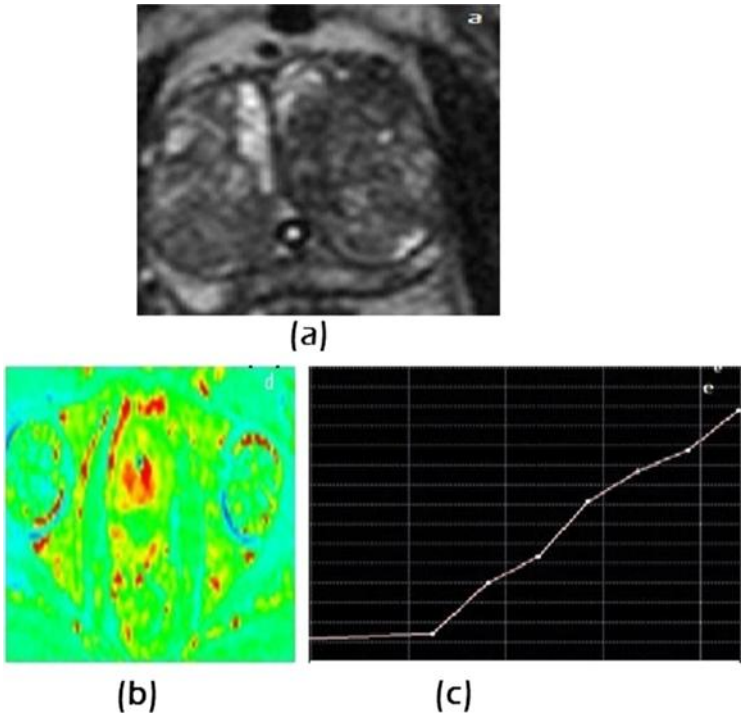

Fig. 3 68 yrs old patient, c/o : enlarged prostate with suspicious nodular gland felt by P/R (a) T2WI, showed heterogeneous texture with no definite well defined focal lesion, (b and c) DCE-MRI revealed gradual enhancement with persistent rising type I enhancement curve. All MP-MRI findings are diagnostic of Benign prostatic lesion: PI-RADS 2.0 score = 1, Histopathology: Benign prostate hypertrophy, no malignancy.

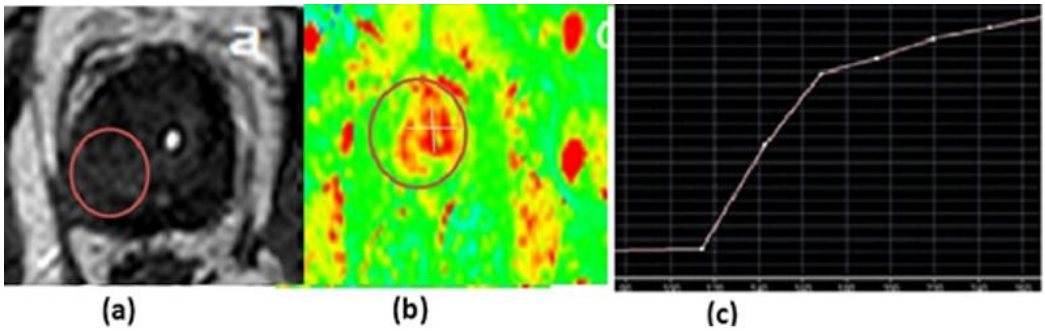

Fig. 4 60 yrs old patient, with hard suspicious Rt. prostatic nodule felt by at P/R examination. (a) T2WI, showed a non-homogenous poorly defined focal area at the Rt. sided TZ lesion (red circle). (b and c) DCE-MRI revealed early enhancement with type II enhancement curve. PI-RADS 2.0, score = 4 All MP-MRI findings are collectively diagnostic of Malignant lesion, Histopathology: Adeno-Ca. (Gleason score 7).

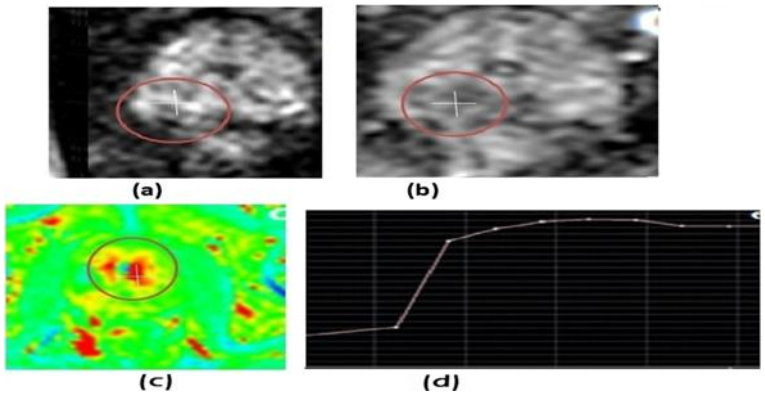

Fig. 5 69 yrs old patient, with hard suspicious Rt. prostatic nodule felt by P/R (a and b) DWI and ADC map revealed moderate diffusion restriction at Rt. side peripheral zone lesion (red circle), ADC value ''0.958.93", (c and d) DCE-MRI revealed mild enhancement with type II enhancement curve. PI-RADS 2.0 score = 3. All MP-MRI findings are collectively diagnostic of mostly Malignant lesion. Histo-pathology: Adeno-Ca. (Gleason score 8).

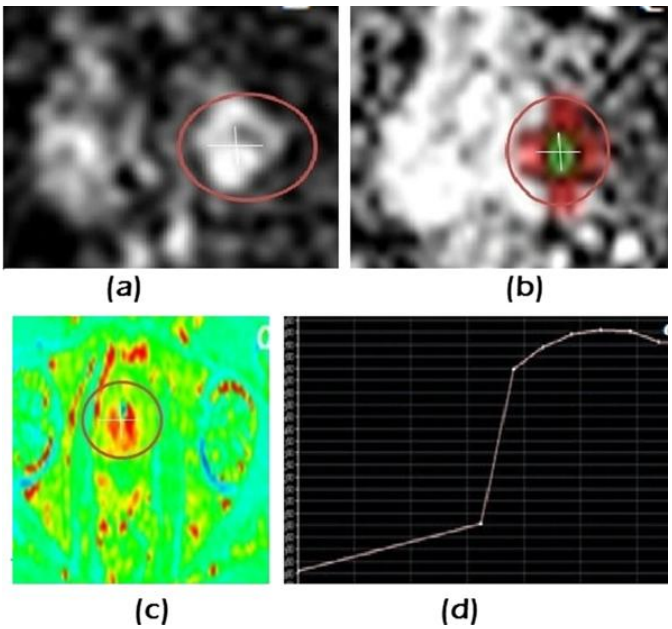

Fig. 6 66 yrs old patient with hard suspicious Lt. prostatic nodule at P/R examination. (a) DWI showed a moderate diffusion restriction of the lesion (red circle), (b) ADC map revealed, ADC value ''0.641", (c and d) DCE-MRI revealed early moderate enhancement (red circle),with type II enhancement curve). The total PI-RADS 2.0 score given to this lesion, was = 4. All Mp-MRI findings are collectively diagnostic of Malignant lesion. Histopathology: Adeno-Ca. (Gleason score 8).

III. Results:

Among the 60 prostatic lesions evaluated in this study, 40 were confirmed as malignant on histopathology, with 32 located in the peripheral zone (PZ) and 8 in the transition zone (TZ), all diagnosed as adenocarcinoma. The remaining 20 lesions were benign—9 in the PZ and 11 in the TZ—with histopathological findings comprising 13 cases of benign prostatic hyperplasia, 4 adenomas, and 3 instances of prostatitis (see Tables 1 and 2).

Mp-MRI Analysis:

I. Diffusion-Weighted Imaging (DWI) and ADC Evaluation (PZ Lesions, n=37): DWI revealed moderate to marked diffusion restriction in 24 lesions—7 scored as PI-RADS 3 and 17 as PI-RADS 4. An additional 8 lesions measuring over 1.5 cm or showing invasive characteristics were assigned a PI-RADS score of 5. The average ADC value for confirmed malignant lesions was $\mathbf{0.89 \pm 0.24 \times 10^{-3}\ mm^2/s}$ (see Figure 1). In contrast, 7 benign lesions showed no significant signal changes on the ADC map. The mean ADC value for benign lesions was $\mathbf{1.34 \pm 0.21 \times 10^{-3}\ mm^2/s}$, which was significantly higher than that of malignant lesions ($\mathbf{p < 0.001}$) (Table 3).

II. Dynamic Contrast-Enhanced MRI (DCE-MRI): Early enhancement followed by rapid washout—a pattern suggestive of malignancy—was observed in 39 lesions. For 6 lesions initially scored as PI-RADS 3 based on DWI alone, the inclusion of positive DCE findings led to score upgrades in 4 of these cases, supporting a malignant diagnosis. Conversely, 21 lesions (including 7 benign and 2 indeterminate cases) showed either no enhancement or a gradually rising enhancement pattern, interpreted as negative (Table 3; Figures 2, 5, and 6).

III. T2-Weighted Imaging (TZ Lesions, n=10): T2WI detected 3 lesions with ill-defined heterogeneous signals (PI-RADS 3), one lesion with non-circumscribed hypo-heterogeneous characteristics (PI-RADS 4), and 4 lesions displaying invasive features or sizes exceeding 1.5 cm (PI-RADS 5). Eleven benign lesions (scores 1–2) showed either normal or well-defined hypo-intense/heterogeneous appearances (6 and 5 lesions respectively) on T2WI (Table 3). DCE-MRI identified focal early enhancement with rapid washout in 9 lesions. For three lesions initially scored as PI-RADS 3 on T2WI, DCE findings elevated two to score 4, aiding in malignancy detection. Ten lesions showed no enhancement or slow progressive enhancement and were categorized as negative (Table 3; Figures 3 and 4).

Overall PI-RADS Scoring (PI-RADS v2.0): Across all 60 suspicious lesions, final PI-RADS scoring classified 30 lesions as malignant (scores 4–5), 20 as benign (scores 1–2), and 10 as indeterminate (score 3). Histopathology confirmed 8 of the 10 indeterminate lesions to be malignant and 2 as benign. The diagnostic performance of mpMRI using the PI-RADS v2.0 scoring system demonstrated a **sensitivity of 93.12%**, **specificity of 94.32%**, and **overall diagnostic accuracy of 93.07%** in detecting malignant prostatic lesions (Table 4).

Table 4. Sensitivity, specificity and accuracy of Mp-MRI with PI-RADS 2.0 in diagnosis of prostatic focal lesions.

Sensitivity	**93.12 %**
Specificity	94.32 %
Positive Predictive value	97.80 %
Accuracy	93.07 %

IV. Discussion:

Magnetic Resonance Imaging (MRI) of the prostate has become an essential tool in the clinical management of prostate cancer, offering detailed anatomical and functional assessment. The introduction of the PI-RADS (Prostate Imaging Reporting and Data System) has further enhanced the consistency and clinical utility of prostate MRI by providing a standardized framework for interpretation [11].

In this study, histopathological analysis served as the reference standard, confirming 38 cases of prostate adenocarcinoma and 17 benign lesions. Multiparametric MRI (mpMRI) was employed as the primary imaging modality to evaluate these lesions. These findings are in alignment with previous work by Schlemmer et al. and Franiel, who also identified mpMRI as the preferred method for prostate cancer detection [12,13].

The study utilized PI-RADS version 2 to differentiate between malignant and benign prostate lesions. Diffusion-weighted imaging (DWI) was the primary diagnostic sequence for lesions in the peripheral zone (PZ), while T2-weighted imaging (T2WI) played a similar role for lesions in the transition zone (TZ). This approach is supported by Leonardo et al., who introduced the concept of zone-specific dominant sequences in PI-RADS criteria, and by Barentsz et al., who emphasized that DWI and T2WI should guide lesion scoring in the PZ and TZ, respectively [14,15].

Among the 41 PZ lesions evaluated, DWI assigned 7 lesions a score of 3, 17 lesions a score of 4, and 8 lesions a score of 5. The mean apparent diffusion coefficient (ADC) value for malignant lesions was **$0.89 \pm 0.24 \times 10^{-3}$ mm²/s**. In contrast, no diffusion restriction was observed in 9 benign lesions, which had significantly higher mean ADC values of **$1.34 \pm 0.21 \times 10^{-3}$ mm²/s** ($p < 0.001$).

The overall PI-RADS v2 scoring across all 60 evaluated lesions identified 30 malignant lesions with scores of 4 or 5, 20 benign lesions with scores of 1 or 2, and 10 indeterminate lesions (score 3). Histopathology confirmed that 8 of the indeterminate lesions were malignant and 2 were benign.

These findings are consistent with prior studies validating the PI-RADS classification system as a reliable tool for interpreting mpMRI and predicting the likelihood of clinically significant prostate cancer [25,26]. Currently, mpMRI is considered the most precise and sensitive imaging modality for prostate cancer localization and evaluation [27].

This study's statistical analysis showed that mpMRI, using the PI-RADS v2 framework, achieved a **sensitivity of 93.12%**, **specificity of 94.32%**, and **overall accuracy of 93.07%**. These outcomes are in agreement with results reported by Daniel, who demonstrated good diagnostic performance using summed PI-RADS scores (sensitivity 90%, specificity 62%) [28]. Alistair et al. reported a sensitivity of 97% and specificity of 60% for detecting significant prostate cancer using PI-RADS scores of 1 or 2 [29]. Similarly, Portalez et al. documented a sensitivity of 73.5%, specificity of 81.5%, and accuracy of 95.2% [26].

V. Conclusions:

The use of PI-RADS version 2 scoring in conjunction with multiparametric MRI—incorporating diffusion-weighted imaging with ADC quantification, T2-weighted imaging, and dynamic contrast-enhanced MRI—proved to be a reliable, non-invasive, and highly accurate method for evaluating focal prostatic lesions. This imaging strategy effectively differentiates between malignant and benign conditions, supporting its role as a key diagnostic tool in prostate cancer assessment.

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