

# Predictive Value of Quantitative T2-Weighted MRI Morphometric Parameters for Clinically Significant Prostate Cancer in PI-RADS v2.1 $\geq 4$ Lesions

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## Research Article

**Keywords:** Prostate cancer, PI-RADS v2.1, Volume, MRI

**Posted Date:** October 23rd, 2026

**DOI:** <https://doi.org/10.21203/rs.3.rs-11034966/v1>

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**Additional Declarations:** No competing interests reported.

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# Abstract

## Objective

To evaluate the diagnostic accuracy of quantitative T2-weighted MRI morphometric parameters for detecting clinically significant prostate cancer (csPCa) in prostate lesions with PI-RADS v2.1 category  $\geq 4$ .

## Methods

This retrospective study included 153 patients who underwent multiparametric MRI according to the PI-RADS v2.1 protocol followed by prostate biopsy. A total of 165 prostate lesions with PI-RADS v2.1 scores  $\geq 4$  were analyzed. Based on histopathological results, lesions were classified as csPCa or benign prostatic hyperplasia (BPH). Quantitative morphometric parameters, including maximum diameter, mean diameter, cross-sectional area, and volume, were measured on tri-planar T2-weighted images. Differences between csPCa and BPH lesions, as well as zone-specific characteristics in the peripheral zone (PZ) and transition zone (TZ), were assessed. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the diagnostic performance of each parameter and to determine optimal cutoff values.

## Results

Among the 165 lesions, 108 were csPCa (69 in the PZ and 39 in the TZ) and 57 were BPH (20 in the PZ and 37 in the TZ). csPCa lesions demonstrated significantly larger maximum diameter, mean diameter, area, and volume compared with BPH lesions in both the PZ and TZ (all  $p < 0.05$ ). ROC analysis showed that lesion volume achieved the highest diagnostic performance among all morphometric parameters, with area under the curve (AUC) values of 0.819 in the PZ and 0.811 in the TZ. The optimal volume thresholds for differentiating csPCa from BPH were 1.23 cm<sup>3</sup> in the PZ and 1.07 cm<sup>3</sup> in the TZ, respectively.

## Conclusions

In prostate lesions with PI-RADS v2.1 category  $\geq 4$ , lesion volume demonstrates superior diagnostic accuracy compared with maximum diameter, mean diameter, and area. Volume-based assessment may serve as a valuable quantitative imaging biomarker to improve the detection of clinically significant prostate cancer, particularly when accounting for zone-specific differences.

## Introduction

In recent years, the global incidence of prostate cancer (PCa) has continued to increase, underscoring the clinical importance of effective screening strategies and accurate risk stratification to guide patient management [1–3]. The Prostate Imaging Reporting and Data System version 2.1 (PI-RADS v2.1) provides a standardized, semi-quantitative framework for prostate lesion assessment based on morphological and signal characteristics observed on multiparametric magnetic resonance imaging (mpMRI) [4–6]. Its diagnostic value in detecting clinically significant prostate cancer (csPCa) has been widely validated, and PI-RADS v2.1 is

currently regarded as a cornerstone of prostate MRI interpretation [7–10]. Nevertheless, inter-study variability in diagnostic performance and the persistence of false-negative findings indicate that further refinement of PI-RADS-based assessment remains warranted [11–14].

Previous studies have demonstrated a stepwise increase in csPCa detection rates with higher PI-RADS categories. Yilmaz et al. [15] reported csPCa detection rates of 0%, 9%, 14%, 37%, and 77% for PI-RADS categories 1 through 5, respectively. Wen et al. [16] found that the area under the receiver operating characteristic (ROC) curve (AUC) of PI-RADS v2.1 alone for csPCa detection was 0.85, which was inferior to the diagnostic performance achieved when combined with prostate-specific antigen density (PSAD). Moreover, van Riel et al. [17] reported that csPCa was still detected in 18.1% of patients with negative mpMRI findings. These observations suggest that PI-RADS classification alone may not fully capture the biological aggressiveness of prostate lesions.

Notably, substantial diagnostic overlap in clinically significant prostate cancer detection persists between PI-RADS category 4 and 5 lesions, highlighting the limitations of size-based stratification alone. In PI-RADS v2.1, these two categories share identical morphological definitions and are primarily distinguished by whether the longest lesion diameter exceeds 1.5 cm or whether extraprostatic extension is present. However, prostate lesions often exhibit irregular morphology and heterogeneous three-dimensional growth patterns. Consequently, reliance on a single-plane longest-diameter measurement may inadequately represent true lesion burden and is susceptible to plane-dependent variability, potentially limiting both reproducibility and discriminatory performance.

Although PI-RADS v2.1 recommends acquiring T2-weighted imaging (T2WI) in at least two orthogonal planes, with the axial plane being mandatory, it remains unclear whether tri-planar measurements provide additional diagnostic value or improve the reliability of lesion size assessment. Furthermore, alternative quantitative morphometric parameters derived from T2WI—such as cross-sectional area and three-dimensional lesion volume—may offer a more comprehensive characterization of lesion extent than the conventional longest diameter alone. Despite their theoretical advantages, these parameters have not been systematically evaluated in PI-RADS v2.1 category  $\geq 4$  lesions, nor have zone-specific thresholds in the peripheral zone (PZ) and transition zone (TZ) been adequately explored.

Therefore, the present study aimed to systematically evaluate the diagnostic performance of quantitative T2-weighted morphometric parameters, including maximum diameter, mean diameter, cross-sectional area, and lesion volume, for detecting clinically significant prostate cancer in PI-RADS v2.1 category  $\geq 4$  lesions. A secondary objective was to investigate the potential role of these parameters in refining size-based differentiation between PI-RADS v2.1 category 4 and 5 lesions across different prostate zones. By addressing the limitations of single-diameter assessment in lesions with complex three-dimensional growth patterns, this study seeks to provide imaging-based evidence to support improved risk stratification beyond the current PI-RADS v2.1 size criterion.

## Materials and methods

### Study Population and Definition of csPCa

This retrospective study was approved by the Ethics Committee of the Fifth Affiliated Hospital of Anhui Medical University (Approval No. KY2025074) and was conducted in accordance with the Declaration of Helsinki. The requirement for written informed consent was waived due to the retrospective nature of the study. Patients who underwent prostate mpMRI between 2019 and 2025 due to suspected prostate cancer (elevated PSA and/or abnormal digital rectal examination) were initially screened csPCa was defined as prostate adenocarcinoma with an International Society of Urological Pathology (ISUP) grade group  $\geq 2$  (corresponding to Gleason score  $\geq 3+4$ ), in accordance with commonly accepted clinical and imaging research criteria. Patients were excluded if they had received prior prostate treatment (including surgery, radiotherapy, or androgen deprivation therapy), had inadequate image quality for reliable PI-RADS v2.1 assessment, or had PI-RADS v2.1 scores  $\leq 3$ . After applying these criteria, a total of 153 patients were included in the final analysis. as detailed in the patient selection flowchart (Fig. 1).

**MRI Acquisition and PI-RADS Assessment**

All mpMRI examinations were performed on a 3.0 T MRI scanner (Vida, Siemens Healthineers) using a combination of a pelvic phased-array surface coil and a spine coil. The imaging protocol included axial T1-weighted imaging (T1WI), axial, coronal, and sagittal T2WI, diffusion-weighted imaging (DWI) with b-values of 50, 800, 1200, and 1500 s/mm<sup>2</sup>, and axial dynamic contrast-enhanced (DCE) imaging. Detailed imaging parameters are provided in Table1. PI-RADS v2.1 scoring of prostate lesions was independently performed by two genitourinary radiologists with formal PI-RADS v2.1 training, each with more than 5 years of experience, who were blinded to all clinical and pathological information. Discrepancies were resolved by consensus discussion to determine the final PI-RADS category.

**Table 1** Protocol sequence parameters for multiparametric MRI of the prostate

| Imaging plane                | T1WI      | T2WI       |            |            | DWI              | DCE       |
|------------------------------|-----------|------------|------------|------------|------------------|-----------|
|                              | Axial     | Axial      | Coronal    | Sagittal   | Axial            | Axial     |
| Field of view (FOV) (mm)     | 350x100   | 200x100    | 220x100    | 220x100    | 220x100          | 350x81.3  |
| Matrix size                  | 352x70    | 320x80     | 320x80     | 320x80     | 100x100          | 70x70     |
| Slice thickness/gap (mm)     | 3.0       | 4.0/0.8    | 3.0        | 3.0        | 3.0/1.0          | 3.0       |
| TR/TE (ms)                   | 533.0/8.9 | 3410.0/101 | 5000.0/108 | 5000.0/108 | 5800/78          | 5.47/2.46 |
| Flip angle                   | 110       | 160        | 110        | 110        | -                | 9.0       |
| Bandwidth (Hz/voxel)         | 200       | 200        | 274        | 274        | 1724             | 870       |
| Acquisition time (min)       | 2 :05 min | 2:32 min   | 2:20 min   | 2:20 min   | 2:43 min         | 2:54 min  |
| Average                      | 1         | 3          | 1          | 1          | 4                | -         |
| b value (s/mm <sup>2</sup> ) | -         | -          | -          | -          | 50,800,1200,1500 | -         |

### Measurement of Quantitative Morphometric Parameters

Quantitative morphometric parameters were performed on T2WI for each MRI-detected lesion. For each lesion, the longest diameter was measured independently on axial, coronal, and sagittal planes, and the average of these measurements was calculated. The mean diameter on each plane was defined as the average of the longest diameter and its perpendicular diameter within the same plane.

Lesion cross-sectional area was calculated as the sum of lesion areas across all axial slices in which the lesion was visible. Lesion volume was calculated using the same method as described in previous studies [18–20].

### Biopsy Protocol, MRI–Pathology Correlation, and Pathological Evaluation

All patients underwent ultrasound-guided transrectal prostate biopsy using real-time MRI–ultrasound fusion systems (Toshiba Aplio 500 or Hitachi HI VISION Preirus). The biopsy procedures were performed by an experienced urologist with more than 10 years of clinical experience and over 100 MRI-targeted prostate biopsy cases.

The biopsy protocol consisted of targeted biopsies of MRI-suspicious lesions (typically 2–4 cores per lesion) combined with a systematic 12-core extended template biopsy. No patients underwent radical prostatectomy during the study period.

MRI–pathology correlation was performed at the lesion level by matching biopsy cores to MRI-detected lesions based on prostate sector location and targeted biopsy records. All biopsy specimens were labeled according to prostate zone and biopsy sequence and were processed separately.

Histopathological evaluation was performed by a dedicated uropathologist with more than 10 years of experience. Final lesion-level diagnoses were established through consensus review involving the uropathologist and two genitourinary radiologists, integrating pathological findings with imaging localization.

## **Statistical Analysis**

Statistical analyses were performed using SPSS software (version 23.0; IBM Corp.) and MedCalc Statistical Software. Interobserver agreement for quantitative morphometric measurements was assessed using the intraclass correlation coefficient (ICC), with ICC values >0.75 indicating good agreement. Because multiple lesions could occur in a single patient, lesion-based analyses were performed. To minimize potential clustering effects, descriptive and comparative analyses were interpreted at the lesion level, and results were cautiously interpreted at the patient level during analysis. Continuous variables were tested for normality and are presented as mean  $\pm$  standard deviation or median (interquartile range), as appropriate. Differences between clinically csPCa and benign prostatic hyperplasia (BPH) lesions were compared using the Student's *t* test or the Mann–Whitney *U* test. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. ROC curve analysis was performed to evaluate the diagnostic performance of maximum diameter, mean diameter, lesion area, and lesion volume for the detection of csPCa in PI-RADS v2.1 category  $\geq 4$  lesions. The AUC, sensitivity, specificity, and optimal cut-off values were calculated for each parameter. Optimal thresholds were determined by maximizing Youden's index. A two-sided *P* value <0.05 was considered statistically significant.

## **Results**

### **Interobserver Reliability**

Interobserver agreement between the two radiologists was excellent for all quantitative measurements, with ICC as follows: maximum diameter, 0.990 (95% CI: 0.986–0.993); mean diameter, 0.962 (95% CI: 0.948–0.972); area, 0.899 (95% CI: 0.865–0.925); and volume, 0.847 (95% CI: 0.798–0.885).

### **Clinical and imaging characteristics of patients**

A total of 165 prostate lesions were identified in 153 patients (97 with csPCa and 56 with BPH at the patient level). Of these lesions, 108 were pathologically confirmed as csPCa (69 in the PZ and 39 in the TZ) and 57 were BPH (20 in the PZ and 37 in the TZ). Age and total prostate-specific antigen (tPSA) did not differ significantly between the csPCa and BPH groups (75.00 vs 74.00 years, *P* = 0.224; 22.06 vs 16.83 ng/mL, *P* = 0.119). However, PSAD was significantly elevated in csPCa patients compared with BPH patients (0.53 vs 0.24 ng/mL<sup>2</sup>, *P* < 0.01) (Table 2).

Table 2  
Association of clinical variables with BPH and csPCa

|                           | Group M(P25, P75) |                  | z      | P        |
|---------------------------|-------------------|------------------|--------|----------|
|                           | BPH(n = 57)       | csPCa(n = 108)   |        |          |
| Age(years)                | 74.00(65.3,79.0)  | 75.00(71.0,80.0) | -1.216 | 0.224    |
| tPSA(ng/mL)               | 16.83(10.9,31.3)  | 22.06(10.8,50.2) | -1.558 | 0.119    |
| PSAD(ng/mL <sup>2</sup> ) | 0.24(0.2,0.5)     | 0.53(0.3,1.5)    | -4.338 | p < 0.01 |

## Comparison of Quantitative Morphometric Parameters

In both the TZ and PZ, the maximum and mean diameters of csPCa lesions measured on axial, coronal, and sagittal planes were significantly larger than those of BPH lesions (all  $P < 0.05$ ). For the same lesion (across all zones), no significant differences were found in the maximum or mean diameters measured among the three orthogonal planes (all  $P > 0.05$ ) (Table 3–Table 4).

All evaluated morphometric parameters, including maximum diameter, mean diameter, lesion area, and lesion volume, showed good diagnostic performance for the detection of csPCa in both prostate zones (Fig. 2). For TZ lesions, the sensitivity and specificity were 51.28% and 86.49% for maximum diameter, 69.23% and 72.97% for mean diameter, 66.7% and 67.6% for lesion area, and 82.1% and 67.6% for lesion volume. The corresponding AUC values were 0.701, 0.723, 0.722, and 0.811, with optimal cut-off values of 19.9 mm, 12.8 mm, 7.7 cm<sup>2</sup>, and 1.07 cm<sup>3</sup>. For PZ lesions, the sensitivity and specificity were 50.7% and 90.0% for maximum diameter, 69.6% and 75.0% for mean diameter, 50.7% and 90.0% for lesion area, and 76.8% and 85.0% for lesion volume. The AUC values were 0.733, 0.738, 0.728, and 0.819, with corresponding optimal cut-off values of 21.0 mm, 13.2 mm, 6.4 cm<sup>2</sup>, and 1.23 cm<sup>3</sup> (Table 5).

Respectively, with representative clinical imaging examples presented in Figs. 3 and 4.

Table 3  
Comparison of the maximum diameter of prostate lesions across different scanning planes

|       |                |       |               | P       | F      | P <sup>¶</sup> | F <sup>¶</sup> |
|-------|----------------|-------|---------------|---------|--------|----------------|----------------|
| Total | csPCa(n = 108) | Axial | 19.63 ± 9.88  | < 0.001 | 16.493 | 0.925          | 0.078          |
|       |                | Cor   | 19.54 ± 9.36  | < 0.001 | 22.361 |                |                |
|       |                | Sag   | 20.04 ± 10.55 | < 0.001 | 25.305 |                |                |
|       | BPH(n = 57)    | Axial | 14.85 ± 5.61  |         |        | 0.426          | 0.859          |
|       |                | Cor   | 13.85 ± 5.05  |         |        |                |                |
|       |                | Sag   | 13.68 ± 5.06  |         |        |                |                |
| PZ    | csPCa(n = 69)  | Axial | 19.49 ± 9.74  | 0.001   | 6.062  | 0.924          | 0.079          |
|       |                | Cor   | 19.45 ± 8.64  | < 0.001 | 9.493  |                |                |
|       |                | Sag   | 20.03 ± 10.21 | < 0.001 | 8.721  |                |                |
|       | BPH(n = 20)    | Axial | 13.91 ± 4.47  |         |        | 0.881          | 0.127          |
|       |                | Cor   | 13.98 ± 4.12  |         |        |                |                |
|       |                | Sag   | 13.34 ± 4.72  |         |        |                |                |
| TZ    | csPCa(n = 39)  | Axial | 19.87 ± 10.25 | 0.022   | 15.339 | 0.990          | 0.010          |
|       |                | Cor   | 19.72 ± 10.63 | 0.003   | 20.949 |                |                |
|       |                | Sag   | 20.07 ± 11.26 | 0.003   | 23.479 |                |                |
|       | BPH(n = 37)    | Axial | 15.36 ± 6.14  |         |        | 0.405          | 0.910          |
|       |                | Cor   | 13.78 ± 5.54  |         |        |                |                |
|       |                | Sag   | 13.87 ± 5.28  |         |        |                |                |

csPCa: Clinically significant prostate cancer, BPH: Benign prostate hyperplasia, TZ: Transition zone. PZ: Peripheral zone. The P and F values represent the comparison results of the maximum diameter of prostate lesions in the same scan plane. The P<sup>¶</sup> and F<sup>¶</sup> values indicate the One-way ANOVA comparison results of the mean diameter for the same prostate lesion across axial, coronal, and sagittal planes. All prostate lesion measurements are expressed in millimeters. P < 0.05 indicates a statistically significant difference

Table 4  
Comparison of the mean diameter of prostate lesions across different scanning planes

|       |                |       |              | P       | F      | P <sup>¶</sup> | F <sup>¶</sup> |
|-------|----------------|-------|--------------|---------|--------|----------------|----------------|
| Total | csPCa(n = 108) | Axial | 15.9 ± 8.03  | 0.001   | 12.273 | 0.948          | 0.053          |
|       |                | Cor   | 15.77 ± 7.4  | < 0.001 | 18.07  |                |                |
|       |                | Sag   | 16.12 ± 8.51 | < 0.001 | 19.27  |                |                |
|       | BPH(n = 57)    | Axial | 12.10 ± 4.0  |         |        | 0.545          | 0.609          |
|       |                | Cor   | 11.56 ± 4.16 |         |        |                |                |
|       |                | Sag   | 11.38 ± 4.25 |         |        |                |                |
| PZ    | csPCa(n = 69)  | Axial | 15.45 ± 7.85 | 0.002   | 4.866  | 0.959          | 0.042          |
|       |                | Cor   | 15.63 ± 6.91 | 0.001   | 5.533  |                |                |
|       |                | Sag   | 15.82 ± 8.03 | < 0.001 | 6.936  |                |                |
|       | BPH(n = 20)    | Axial | 11.51 ± 3.36 |         |        | 0.716          | 0.337          |
|       |                | Cor   | 11.32 ± 3.95 |         |        |                |                |
|       |                | Sag   | 10.6 ± 3.77  |         |        |                |                |
| TZ    | csPCa(n = 39)  | Axial | 16.68 ± 8.37 | 0.009   | 22.324 | 0.933          | 0.070          |
|       |                | Cor   | 16.03 ± 8.29 | 0.006   | 22.126 |                |                |
|       |                | Sag   | 16.65 ± 9.38 | 0.005   | 24.174 |                |                |
|       | BPH(n = 37)    | Axial | 12.56 ± 4.30 |         |        | 0.649          | 0.434          |
|       |                | Cor   | 11.70 ± 4.31 |         |        |                |                |
|       |                | Sag   | 11.80 ± 4.48 |         |        |                |                |

csPCa: Clinically significant prostate cancer, BPH: Benign prostate hyperplasia, TZ: Transition zone. PZ: Peripheral zone. The P and F values represent the comparison results of the mean diameter of prostate lesions in the same scan plane. The P<sup>¶</sup> and F<sup>¶</sup> values indicate the One-way ANOVA comparison results of the mean diameter for the same prostate lesion across axial, coronal, and sagittal planes. All prostate lesion measurements are expressed in millimeters. P < 0.05 indicates a statistically significant difference

Table 5  
AUC for diagnostic performance of maximum diameter, mean diameter, lesion area, and lesion volume

|       |                      | Sensitivity (%) | Specificity (%) | Cut-off value | AUC (95%CI)        | P                |
|-------|----------------------|-----------------|-----------------|---------------|--------------------|------------------|
| Total | maximum diameter(mm) | 50.0            | 93.0            | 21.0          | 0.728(0.654–0.794) | $P^c < 0.05$     |
|       | mean diameter(mm)    | 71.3            | 71.9            | 13.15         | 0.737(0.663–0.803) |                  |
|       | area(cm2)            | 46.3            | 82.5            | 10.1          | 0.684(0.607–0.754) |                  |
|       | volume(cm3)          | 75.9            | 73.7            | 1.23          | 0.801(0.731–0.859) |                  |
| PZ    | maximum diameter(mm) | 50.7            | 90.0            | 21.0          | 0.733(0.629–0.821) | $P^{e,f} < 0.05$ |
|       | mean diameter(mm)    | 69.6            | 75.0            | 13.2          | 0.738(0.634–0.825) |                  |
|       | area(cm2)            | 50.7            | 90.0            | 6.4           | 0.728(0.623–0.817) |                  |
|       | volume(cm3)          | 76.8            | 85.0            | 1.23          | 0.819(0.723–0.893) |                  |
| TZ    | maximum diameter(mm) | 51.28           | 86.49           | 19.9          | 0.701(0.585–0.801) | $P^e < 0.05$     |
|       | mean diameter(mm)    | 69.23           | 72.97           | 12.8          | 0.723(0.608–0.819) |                  |
|       | area(cm2)            | 66.7            | 67.6            | 7.7           | 0.722(0.608–0.819) |                  |
|       | volume(cm3)          | 82.1            | 67.6            | 1.07          | 0.811(0.705–0.892) |                  |

TZ: Transition zone. PZ: Peripheral zone. a, b, c, d, e, and f represent the comparison of ROC areas between: area and maximum diameter, area and mean diameter, area and volume, maximum diameter and mean diameter, maximum diameter and volume, and mean diameter and volume, respectively.  $P < 0.05$  indicates a statistically significant difference

## Discussion

The present study systematically evaluated quantitative T2-weighted MRI morphometric parameters for the detection of csPCa in PI-RADS v2.1 category  $\geq 4$  lesions and demonstrated that lesion volume provides superior diagnostic performance compared with conventional diameter- and area-based measurements.

Our results showed that, for the same lesion, neither maximum diameter nor mean diameter differed significantly among axial, coronal, and sagittal T2WI planes ( $P > 0.05$ ). This finding supports the PI-RADS v2.1 recommendation that prostate MRI protocols should include at least two orthogonal planes, without requiring mandatory tri-planar diameter assessment for routine lesion size evaluation. Furthermore, although the AUC for mean diameter was numerically higher than that for maximum diameter in both the TZ and PZ, the

difference was modest, suggesting that averaging orthogonal measurements may partially mitigate the limitations of single-axis size assessment in lesions with irregular morphology. Comparative analysis demonstrated that csPCa lesions in both the TZ and PZ exhibited significantly larger maximum and mean diameters, as well as greater cross-sectional area and volume, than BPH lesions. These findings are consistent with the biological behavior of prostate cancer, which is characterized by uncontrolled cellular proliferation and invasive growth, leading to progressive three-dimensional tumor expansion [21, 22]. In contrast, the growth of BPH lesions is primarily driven by hormonally mediated proliferation and tissue remodeling and is typically regulated within physiological limits, reflecting mechanisms distinct from malignant processes [23]. Accordingly, all evaluated morphometric parameters achieved AUC values greater than 0.70, indicating good overall diagnostic performance for csPCa detection in PI-RADS v2.1  $\geq 4$  lesions.

Notably, lesion volume consistently demonstrated the highest diagnostic accuracy in both prostate zones, with AUC values of 0.811 in the TZ and 0.819 in the PZ. This superior performance likely reflects the intrinsic advantages of volumetric assessment over one- or two-dimensional measurements. Maximum and mean diameters provide only linear information, while lesion area remains a planar metric; both are limited in their ability to capture complex three-dimensional tumor morphology and heterogeneous growth patterns. In contrast, lesion volume integrates information across multiple imaging planes and more comprehensively represents true tumor burden and spatial growth, underscoring the added value of volumetric analysis and the importance of multiplanar MRI acquisition in prostate cancer evaluation. Based on ROC analysis, we further proposed zone-specific volumetric thresholds for differentiating csPCa from BPH in PI-RADS v2.1  $\geq 4$  lesions, namely 1.23 cm<sup>3</sup> for the PZ and 1.07 cm<sup>3</sup> for the TZ. These thresholds provide preliminary quantitative references that may help refine risk stratification between PI-RADS category 4 and 5 lesions, in which substantial overlap in cancer detection persists under the current size-based criteria. However, these findings should be interpreted cautiously and require validation in larger, multicenter prospective cohorts. This quantitative advantage is particularly relevant in clinical practice, where differentiation between PI-RADS category 4 and 5 lesions often directly influences biopsy strategy and patient counseling.

## Limitations

Several limitations of this study should be acknowledged. First, this was a single-center retrospective analysis based on a single dataset, without internal or external validation, which may limit generalizability. Second, pathological confirmation was based on biopsy rather than whole-mount prostatectomy, and sampling error may have resulted in underestimation of some csPCa cases. Third, although lesion-level analyses were performed, more advanced statistical approaches, such as mixed-effects modeling, may further improve adjustment for within-patient correlations. In addition, correlations between quantitative morphometric parameters and clinicopathological features such as Gleason grade or tumor stage were not explored and warrant investigation in future studies.

## Conclusion

In conclusion, among PI-RADS v2.1 category  $\geq 4$  prostate lesions, lesion volume demonstrates superior diagnostic performance compared with maximum diameter, mean diameter, and lesion area, significantly improving the detection of clinically significant prostate cancer. With ongoing advances in multiplanar

reconstruction and artificial intelligence–assisted image analysis, volumetric assessment is expected to become a clinically feasible and standardized adjunct to the PI-RADS v2.1 framework, supporting more accurate risk stratification and informed clinical decision-making.

## Abbreviations

|           |                                            |
|-----------|--------------------------------------------|
| AUC       | Area Under the Curve                       |
| BPH       | Benign prostatic hyperplasia               |
| CI        | Confidence Interval                        |
| csPCa     | Clinically significant prostate cancer     |
| DCE       | Dynamic contrast-enhanced                  |
| DRE       | Digital rectal examination                 |
| DWI       | Diffusion-weighted imaging                 |
| FOV       | Field of view                              |
| ICC       | Intraclass correlation coefficient         |
| mpMRI     | Multiparametric MRI                        |
| non-csPCa | non-Clinically significant prostate cancer |
| PCa       | Prostate cancer                            |
| PI-RADS   | Prostate Imaging and Reporting Data System |
| PSA       | Prostate-specific antigen                  |
| PSAD      | Prostate-specific antigen density          |
| PZ        | Peripheral zone                            |
| ROC       | Receiver operating characteristic          |
| TE        | Time of Echo                               |
| tPSA      | Total prostate-specific antigen            |
| TR        | Time of Repetition                         |
| T1WI      | T1-weighted imaging                        |
| T2WI      | T2-weighted imaging                        |

## Declarations

### Acknowledgements

Not applicable.

### Author contributions

XY Zhang conceptualized the study, developed the methodology, administered the project, curated the data, conducted the formal analysis, carried out the investigation, and wrote the original draft. L Xu and P Han participated in data curation, formal analysis and investigation; WY Liu joined the investigation and visualization work. MH Sun acquired the funding, provided resources, managed the software, supervised the study, validated the results, and reviewed the manuscript. L Xu, WY Liu and P Han were responsible for visualization. All authors reviewed and edited the final version of the manuscript.

### Funding

This work was supported by grants from the Natural Science Research Projects in Higher Education Institutions in Anhui Province (Grant Number: 2023AH050584) and Natural Science Foundation of Anhui Medical University (Grant Number:2022xkj214).

### Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to institutional restrictions but are available from the corresponding author on reasonable request.

### Ethics approval

This retrospective study was approved by the Ethics Committee of the Fifth Affiliated Hospital of Anhui Medical University (Approval No. KY2025074) and was conducted in accordance with the Declaration of Helsinki. The requirement for written informed consent was waived due to the retrospective nature of the study.

### Consent for publication

Not applicable.

### Competing interests

The authors declare no competing interests.

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## Figures

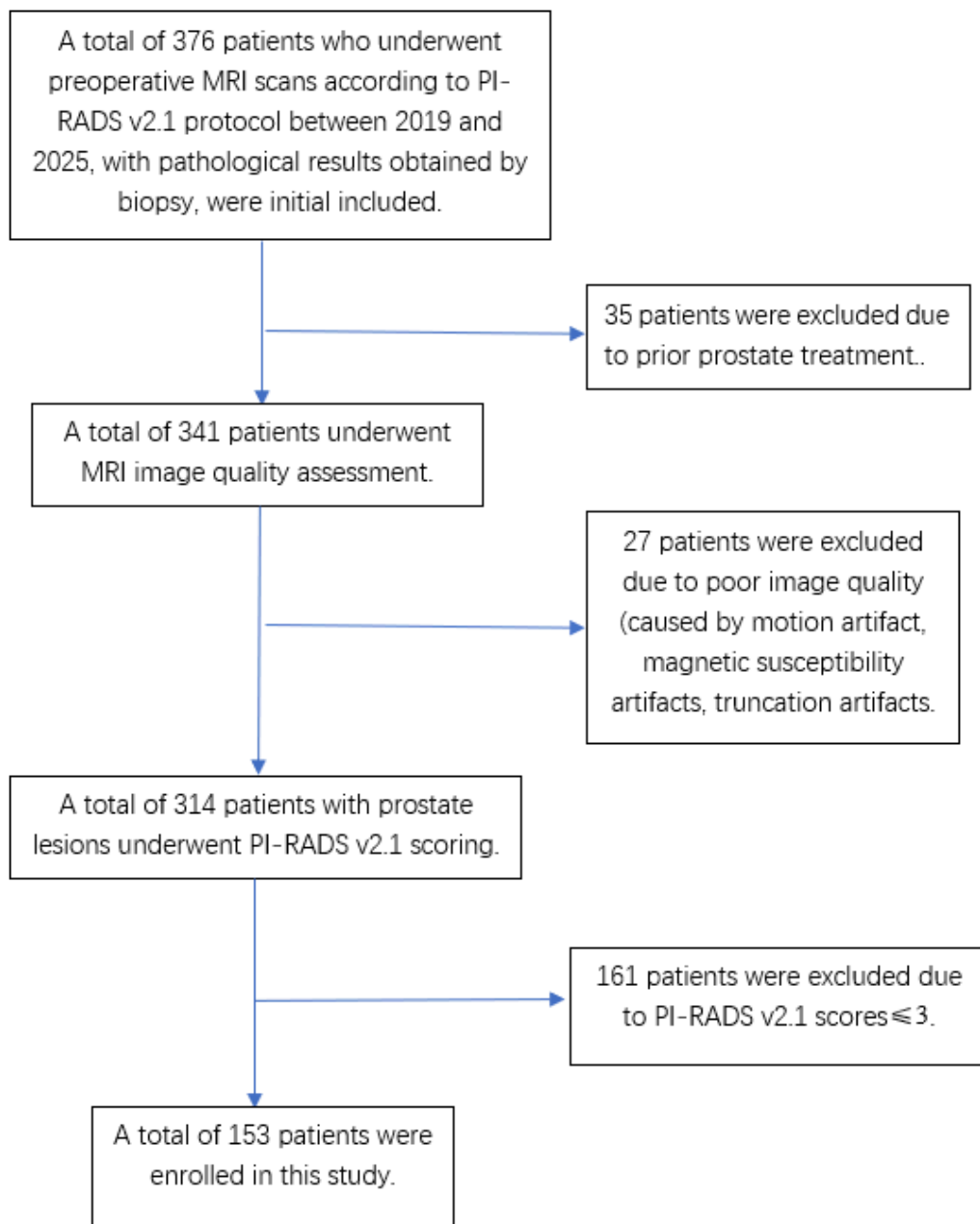


**Fig.1**

**Figure 1**

Patient enrollment flowchart for this consecutive retrospective cohort study.

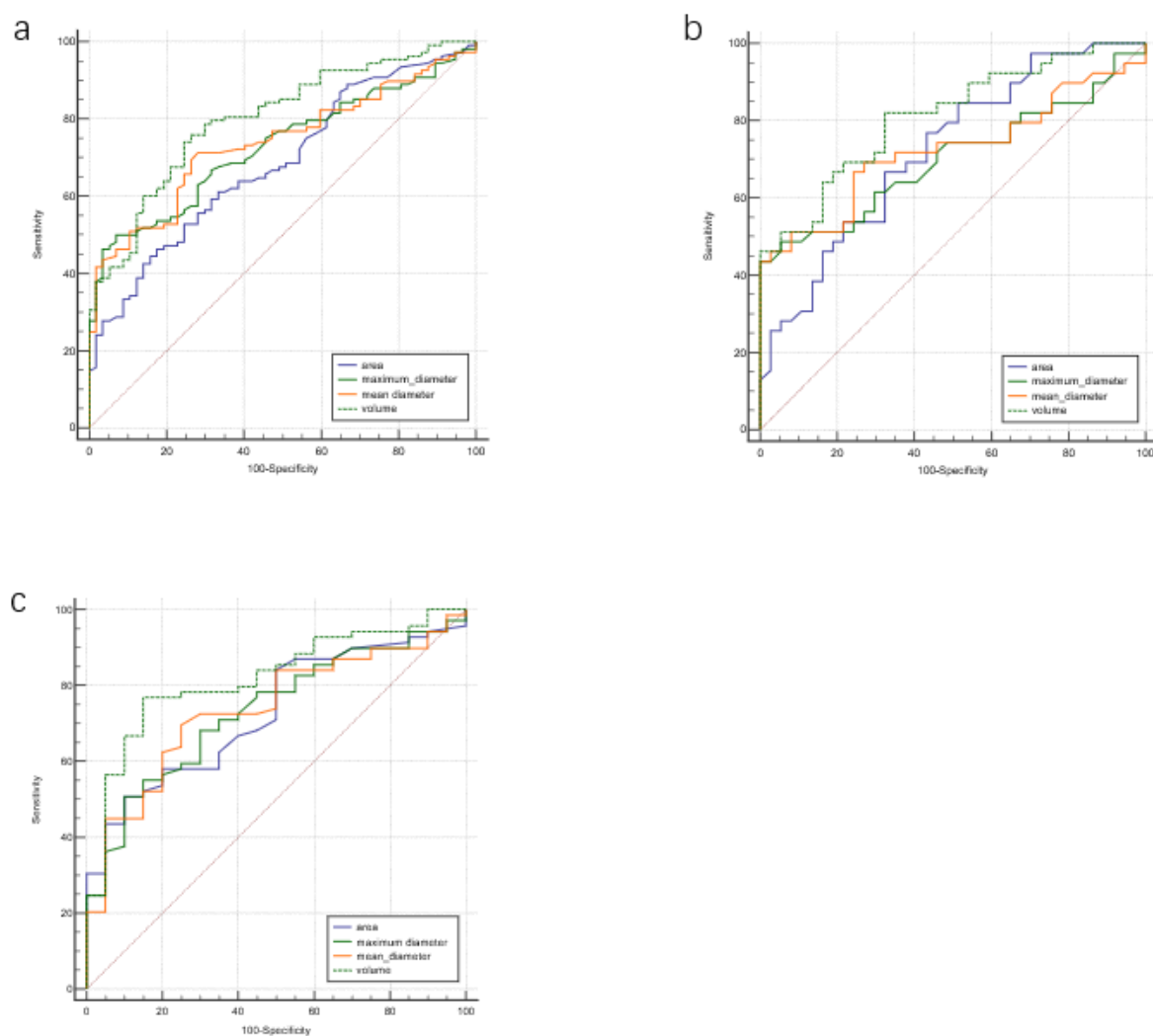


**Fig.2**

## Figure 2

ROC curves comparing diagnostic performance for csPCa detection using four lesion parameters.

Notes: (a) whole prostate, (b) transitional zone, and (c) peripheral zone. For each anatomical region, the following parameters were evaluated: maximum diameter, mean diameter, area, and volume.

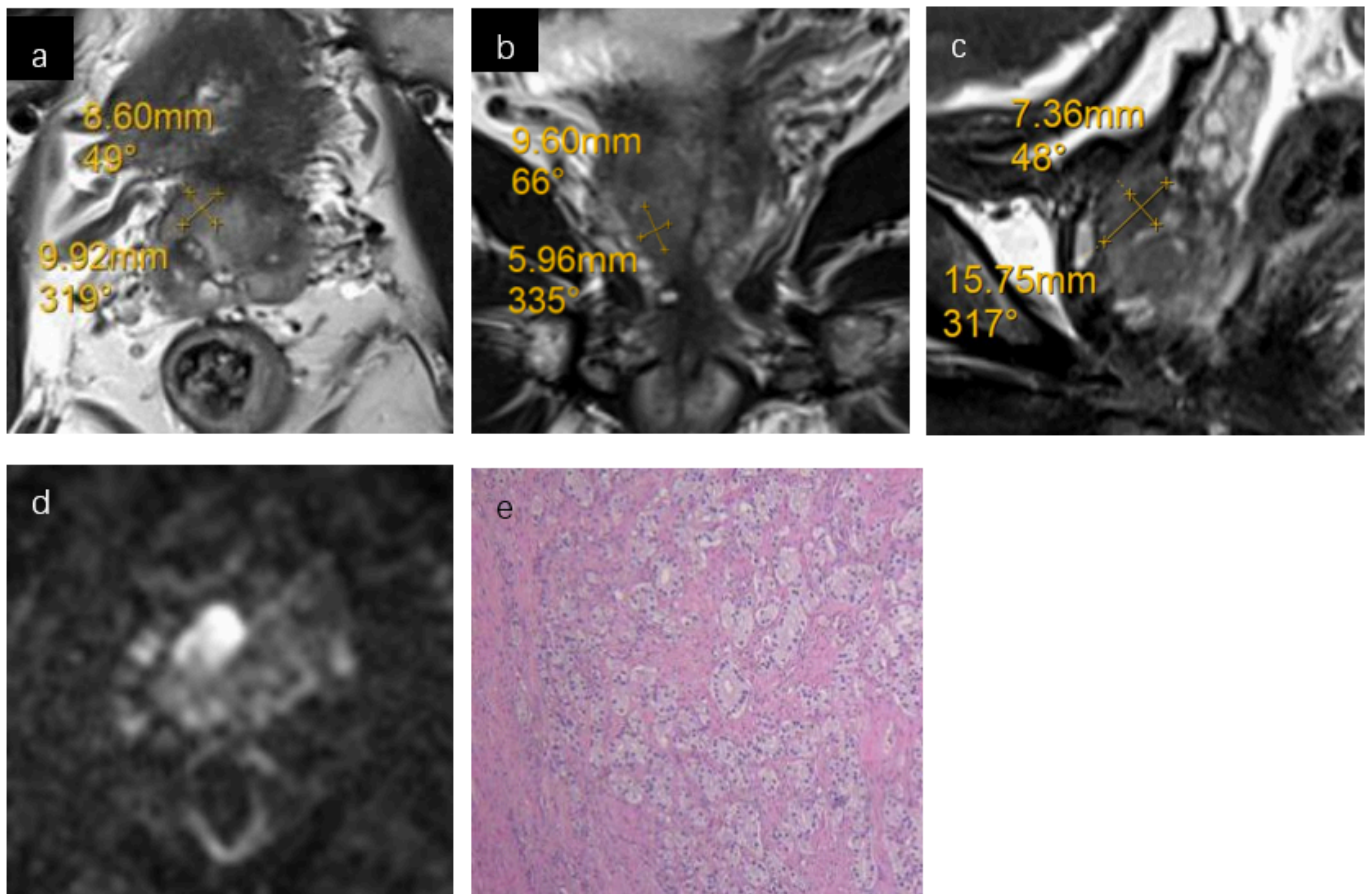


**Fig.3**

### Figure 3

Presentation of Clinical Cases.

Notes: A patient with a lesion in the right transition zone of the prostate. Images a (axial T2WI), b (coronal T2WI), and c (sagittal T2WI) demonstrate a hypointense lesion in the right transition zone with ill-defined margins and an incomplete capsule. Image d (DWI) shows the lesion as hyperintense. Two radiologists measured the maximum diameter of the lesion using axial and coronal images and assigned a PI-RADS v2.1 score of 4. Based on the sagittal image (c), the lesion was upgraded to PI-RADS v2.1 score 5. Image e (prostate biopsy histopathology) confirms prostatic acinar adenocarcinoma.

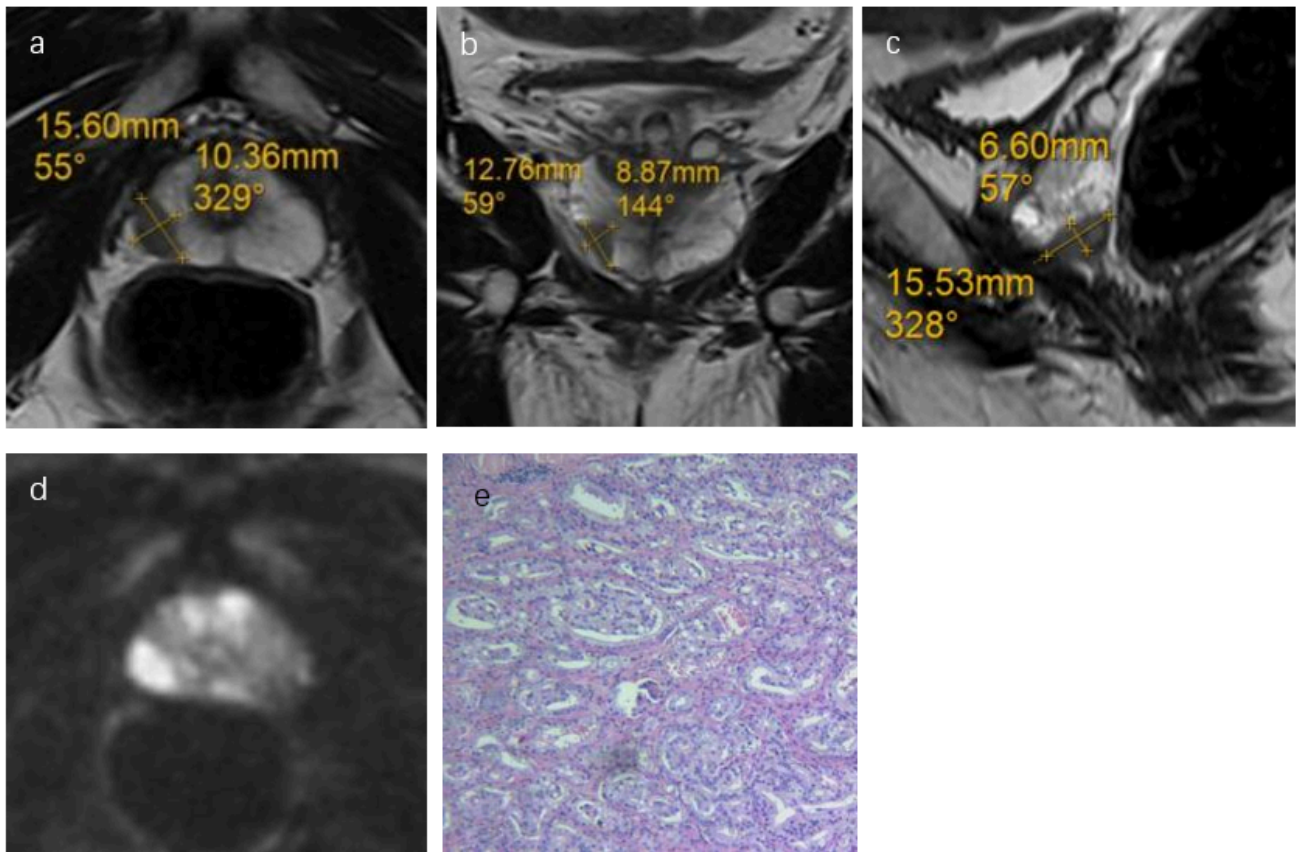


**Fig.4**

## Figure 4

Presentation of Clinical Cases.

Notes: A patient with a lesion in the right peripheral zone of the prostate. Images a (axial T2WI), b (coronal T2WI), and c (sagittal T2WI) show a hypointense lesion in the right peripheral zone with relatively clear margins but an ill-defined capsule. Image d (DWI) demonstrates marked hyperintensity of the lesion. Two radiologists measured the maximum diameter of the lesion using axial and sagittal images and classified it as PI-RADS v2.1 score 5. According to the coronal image (b), the lesion was downgraded to PI-RADS v2.1 score 4. Image e (prostate biopsy histopathology) confirms prostatic acinar adenocarcinoma.