Submitted: 15 May, 2024 Accepted: 05 July, 2024 Online Published: 30 August, 2024 DOI:10.22514/jomh.2024.139

ORIGINAL RESEARCH

JOMH Journal of Men's Health

Value analysis of magnetic resonance imaging in diagnosing prostate cancer capsular invasion

Chong Zhang[1], Xingjun Zhong[2], Yuzhi Cui[1], Liu Yu[1,*]

[1]Department of Radiology, The People's Hospital of Kaizhou District, 405400 Chongqing, China
[2]Department of Peripheral Vascular Intervention, Yubei Hospital, 405400 Chongqing, China

***Correspondence**
yl_ff12@163.com
(Liu Yu)

Abstract

This study aimed to investigate the diagnostic utility of Magnetic Resonance Imaging (MRI) in detecting extracapsular extension (ECE) in prostate cancer (PCa). The data of 120 patients admitted to the hospital was retrieved and assessed. All patients underwent laparoscopic radical prostatectomy, and ECE status was determined by postoperative pathological examination. The results showed that 41 patients exhibited prostatic capsule invasion. Multiple logistic regression analysis identified Prostate-Specific Antigen (PSA) $\geq$10.4 ng/mL, biopsy Gleason score $\geq$7, clinical stage T2c, positive MRI findings, and Apparent Diffusion Coefficient (ADC) value $< 0.75 \times 10^{-3}$ mm^2/s as significant risk factors for prostatic capsule invasion. The predictive model equation was Logit(P) = $-1.325 + 0.469 \times$ PSA $\geq$10.4 ng/mL $+ 0.865 \times$ biopsy Gleason score $\geq 7 + 1.743 \times$ positive MRI findings $+ 1.495 \times$ ADC value $< 0.75 \times 10^{-3}$ mm^2/s. The receiver operating characteristic (ROC) curve yielded an area under the curve (AUC) of 0.769 (95% Confidence Interval (CI): 0.681–0.856, $p < 0.001$). In conclusion, these results indicate that integrating MRI with clinical risk factors in the predictive model demonstrates robust performance in identifying prostatic capsule invasion, demonstrating promising ability to enhance diagnostic and therapeutic strategies for PCa management.

Keywords

Magnetic resonance imaging; Prostate cancer; Extra-capsular extension; Diagnosis

1. Introduction

Prostate cancer (PCa) is a prevalent malignancy of the male reproductive system, with radical prostatectomy being the primary treatment for localized disease. In extracapsular extension (ECE) cases, comprehensive resection of the neurovascular bundle adjacent to the affected lobe can reduce positive surgical margins and enhance long-term survival. Conversely, for patients without capsular invasion, expanding surgical boundaries may increase procedural risks and impact the postoperative quality of life [1–3]. Thus, accurate preoperative prediction of capsular invasion is pivotal for guiding surgical strategies [4, 5]. In this regard, magnetic resonance imaging (MRI) currently represents the optimal imaging modality for PCa diagnosis [6, 7]. Herein, we designed this present study to evaluate the efficacy of multiparametric MRI in predicting ECE in PCa.

2. Objects and methods

2.1 Research subjects

The study enrolled 120 patients diagnosed with PCa admitted to the hospital. The study inclusion criteria were patients aged 40 to 70 years with confirmed PCa based on preoperative transrectal ultrasound-guided systematic prostate biopsies and absence of pelvic lymph node enlargement or distant metastasis on preoperative imaging. All patients underwent laparoscopic radical prostatectomy, with complete clinical data available. Exclusion criteria encompassed patients receiving preoperative endocrine or neoadjuvant therapy for PCa and those with concurrent malignancies.

2.2 Multi-parameter MRI examination

A multiparametric MRI examination was performed one week before surgery using a GE SIGNA Voyager 1.5T MRI scanner (General Electric Company, Boston, MA, USA). The resulting MRI images were of high quality and clarity, suitable for clinical research. Briefly, the patients were placed in the supine position, and the imaging was conducted to encompass the entire prostate gland and bilateral seminal vesicles. The scanning protocol included: (1) Fat-suppressed T2-weighted imaging (T2WI) with parameters: Repetition Time (TR) 2500 ms, Echo Time (TE) 58 ms, slice thickness 3 mm, and 1 mm slice gap; (2) Sagittal T2WI: TR 5300 ms, TE 102 ms, slice thickness 4 mm, and 1 mm slice gap; (3) Diffusion-weighted imaging (DWI) with parameters: TR 4400–4800 ms, TE 63–75 ms, slice thickness 3 mm, 1 mm slice gap, matrix size 112 $\times$ 112, field of view 20 cm $\times$ 20 cm, acquisition

time 1 min 40 s, using diffusion gradients with b values of 0, 500 and 1400 s/mm^2 to generate apparent diffusion coefficient (ADC) maps; (4) Dynamic contrast-enhanced MRI (DCE-MRI) involved axial scanning following intravenous administration of gadolinium-based contrast agent Gd-DTPA (MR-00P10, BioPAL, Worcester, MA, USA) at 3 mL/s, dose of 0.1 mmol/kg, with a 20 mL saline flush. Parameters for DCE-MRI included: TR 3 ms, TE 1.35 ms, slice thickness 4 mm, slice gap 4 mm, matrix size 320 × 256, bandwidth 88.33 Hz/Px, flip angle 12°, 30 slices per acquisition, 25 acquisitions, each lasting 13 s, totaling 5 min 25 s scanning time.

Two radiologists with at least 5 years of clinical experience were invited to interpret the MRI images using a double-blind method, unaware of the pathological examination results. Capsular invasion was assessed based on criteria outlined in the Prostate Imaging Reporting and Data System (PI-RADS) version 2 [8], which includes evaluating asymmetry or thickening of neurovascular bundles, loss of prostate capsule angle, focal bulging of prostate gland contour, irregularities in the prostate capsule, and abnormal signals indicating tumor invasion around the prostate. Additionally, criteria from DWI and ADC were considered, such as asymmetry of high DWI signal and low ADC signal in neurovascular bundles, high DWI signal and low ADC signal around the prostate, and high DWI signal with low ADC signal indicating tumor invasion beyond the capsule. Capsular invasion was deemed present if any of these criteria were identified; otherwise, it was considered absent. Any discrepancies between the radiologists were resolved through discussion to achieve consensus. Furthermore, tumor ADC values were quantitatively analyzed using regions of interest (ROIs), excluding neurovascular bundles and the urethra, with three measurements obtained at each location and averaged for accuracy.

2.3 Data collection

Data collection included age, preoperative prostate-specific antigen (PSA) levels (measured before prostate biopsy), biopsy Gleason score, clinical staging based on the Tumor Node Metastasis (TNM) staging system of the American Joint Committee on Cancer (AJCC) [9], and postoperative pathology reports. Postoperative pathology involved assessment by two pathologists to determine the presence of capsular invasion. In instances of discordant diagnoses, a consensus was achieved through discussion between the two pathologists.

2.4 Statistical analysis

Data analysis was conducted using SPSS 22.0 (BMI Corporation, Chicago, IL, USA). Continuous variables are reported as means ± standard deviation. Independent samples *t*-tests were conducted to compare the means between groups, while paired *t*-tests assessed changes before and after treatment. Categorical variables are presented as frequencies and analyzed using the chi-square test. Ordinal data were evaluated using the rank-sum test. Binary logistic regression was employed to identify factors influencing capsular invasion, and receiver operating characteristic (ROC) curves were generated. The predictive performance of the risk model for capsular invasion in PCa, derived from binary logistic regression, was evaluated. Statistical significance was defined as $p < 0.05$.

3. Results

3.1 Comparison of clinical parameters between patients with and without capsular invasion

The pathological examination revealed that among the 120 patients with PCa, 41 cases exhibited capsular invasion while the remaining did not. Patients with capsular invasion showed significantly higher pre-biopsy serum PSA levels and Gleason scores compared to those without capsular invasion ($p < 0.05$). Additionally, clinical staging was more advanced in patients with capsular invasion ($p < 0.05$). However, there was no statistically significant difference in age between the two groups ($p > 0.05$) (Table 1).

3.2 Comparison of multiparametric MRI interpretation results

Further data analysis showed that the sensitivity and specificity of MRI interpretation in diagnosing capsular involvement were 82.93% and 50.63%, respectively (Table 2).

3.3 Comparison of ADC values

PCa patients with capsular involvement were found to have significantly lower ADC values in the ROIs compared to those without capsular involvement ($p < 0.05$) (Table 3).

3.4 Multiple logistic regression analysis of factors influencing prostatic cancer capsule invasion

Multiple logistic regression analysis, using capsular invasion as the dependent variable and significant indicators from Tables 1 and 2 as independent variables, identified PSA ≥10.4 ng/mL, biopsy Gleason score ≥7 points, clinical stage T2c, positive MRI findings, and ADC value $< 0.75 \times 10^{-3}$ mm^2/s as risk factors for PCa capsule invasion (Table 4).

3.5 Significance of a predictive model for determining prostate capsule invasion

The predictive model for PCa capsule invasion was constructed using the equation: Logit(P) = −1.325 + 0.469 × PSA ≥10.4 ng/mL + 0.865 × Gleason Score ≥7 + 1.743 × Positive MRI Analysis + 1.495 × ADC Value $< 0.75 \times 10^{-3}$ mm^2/s. The ROC curve analysis yielded an area under the curve (AUC) of 0.769 (95% CI: 0.681 to 0.856) for the predictive model, with a sensitivity of 61.00% and specificity of 83.50% (Fig. 1, $p < 0.001$).

4. Discussion

Preoperative multiparametric MRI parameters demonstrated differences between patients with and without capsular invasion. PI-RADS version 1 characterized radiological features of capsular invasion, including proximity of tumors to the prostatic capsule, irregular or thickened neurovascular bundles,

TABLE 1. Comparison of clinical parameters between patients with and without capsular invasion.

Groups	n	Age (yr)	PSA (ng/mL)	Gleason scores	Clinical stage n (%)			
					T1	T2a	T2b	T2c
Capsular invasion	41	54.15 ± 13.58	14.38 ± 2.96	7.77 ± 1.68	6 (14.63)	7 (17.07)	12 (29.27)	16 (39.02)
Without capsular invasion	79	55.37 ± 14.43	6.13 ± 2.76	6.56 ± 1.71	27 (34.18)	35 (44.30)	10 (12.66)	7 (8.86)
t		0.448	15.149	3.698	26.342			
p		0.655	<0.001	<0.001	<0.001			

PSA: prostate-specific antigen.

TABLE 2. Comparison of multiparametric MRI interpretation results.

Results	Pathology results			Sensitivity	Specificity
	Capsular invasion	Without capsular invasion	Total	82.93%	50.63%
Positive	34	39	63		
Negative	7	40	47		
Total	41	79	120		

TABLE 3. Comparison of apparent diffusion coefficient (ADC) values.

Groups	n	ADC value ($\times 10^{-3}$ mm^2/s)
Capsular invasion	41	0.66 ± 0.17
Without capsular invasion	79	0.95 ± 0.23
t		7.121
p		<0.001

TABLE 4. Multiple logistic regression analysis of factors influencing prostatic cancer capsule invasion.

Elements	β	SE	Wald χ^2	OR	95% CI	*p*
PSA ≥10.4 ng/mL	0.469	0.116	16.347	1.589	1.273–2.006	<0.001
Gleason scores ≥7	0.865	0.243	12.671	2.375	1.475–3.824	<0.001
Clinical stage						
T1	--	--	--	1.000	--	--
T2a	0.613	0.441	1.932	1.846	0.778–4.381	0.165
T2b	0.846	0.473	3.199	2.330	0.922–5.889	0.074
T2c	1.315	0.514	6.545	3.725	1.360–10.201	0.011
MRI analysis positive	1.743	0.585	8.877	5.714	1.816–17.986	0.003
ADC value $< 0.75 \times 10^{-3}$ mm^2/s	1.495	0.365	16.776	4.459	2.181–9.119	<0.001
Constant term	−1.325	0.899	2.172	0.266	--	--

SE: Sensitivity; OR: Odds Ratio; CI: Confidence Interval; PSA: prostate-specific antigen; MRI: magnetic resonance imaging; ADC: Apparent Diffusion Coefficient.

and measurable extracapsular lesions [10, 11]. PI-RADS version 2 refined these criteria, incorporating asymmetry or invasion of neurovascular bundles, irregular prostate contour, and capsule morphology irregularities [12, 13]. Using PI-RADS version 2 criteria, independently assessed by two blinded radiologists, MRI achieved sensitivity, specificity, and accuracy rates of 82.93%, 50.63%, and 61.67%, respectively, in detecting capsular invasion. This underscores MRI's high sensitivity but relatively lower specificity and accuracy in identifying capsular invasion in PCa. Limitations include the absence of a quantitative scoring system for capsular invasion in PI-RADS version 2, potential false positives due to inflammatory responses and reactive stromal fibrosis, and occasional microscopic invasion not detectable by MRI, leading to false negatives [14].

Additionally, the ADC value, reflecting water molecule diffusion, serves as a marker for cell density. Our investigation found a lower ADC value in PCa patients with capsular invasion compared to those without. Specifically, an ADC value below 0.75×10^{-3} mm^2/s emerged as an independent predictor

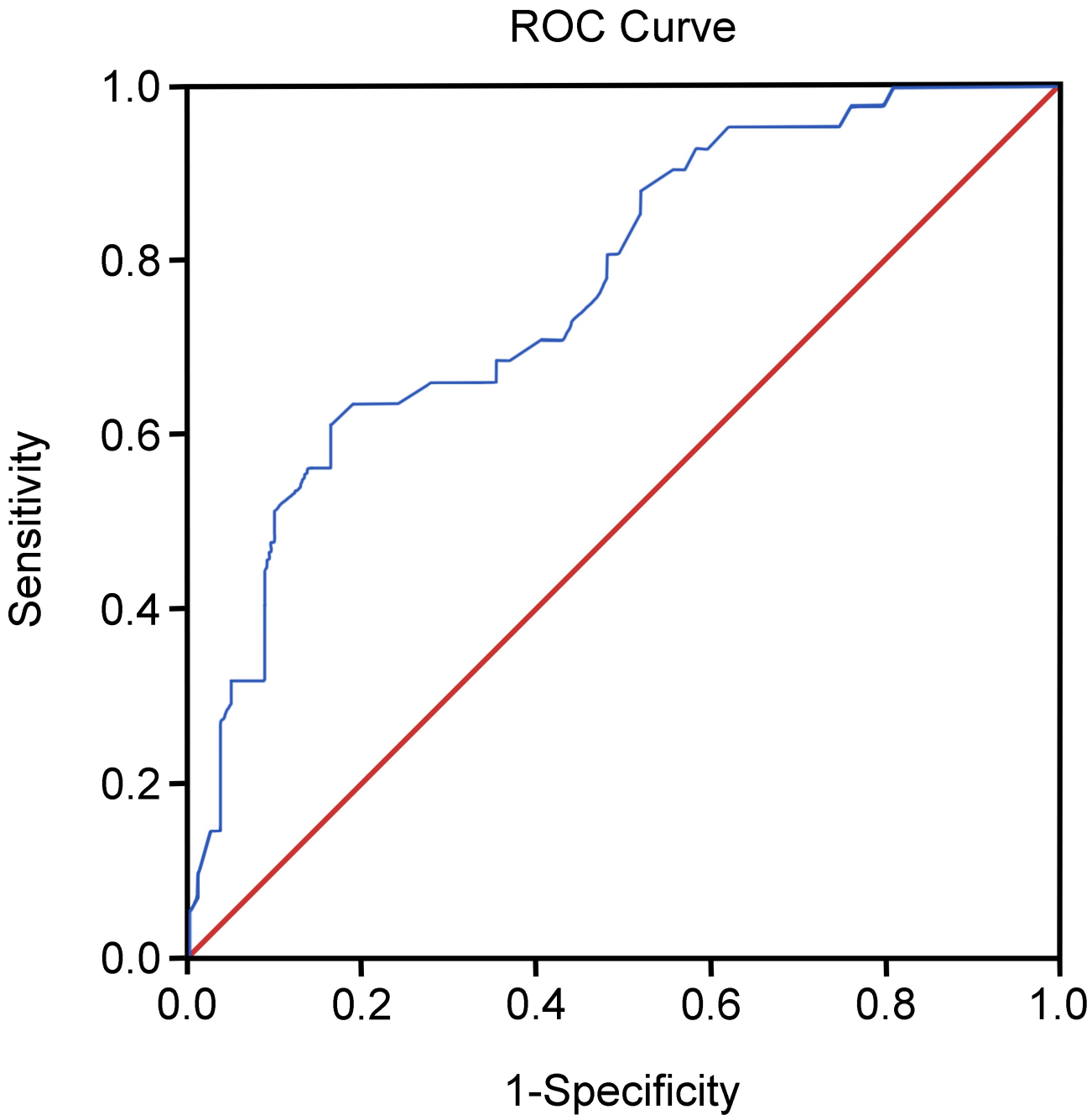

FIGURE 1. Significance of the proposed predictive model for determining prostate capsule invasion. ROC: receiver operating characteristic.

for capsular invasion.

However, this study is limited by its single-center design and small sample size. Furthermore, ADC parameters can vary across different MRI scanners, potentially limiting the generalizability of the predictive models derived from this study in clinical practice. Increasing the sample size, conducting multicenter studies, and evaluating different MRI scanner models are recommended to enhance the robustness and applicability of these predictive models. Moreover, the expertise of radiologists significantly influences study outcomes; thus, involving radiologists with extensive clinical experience in image interpretation is advisable.

The predictive model, integrating clinical risk factors and MRI radiological features, effectively predicts capsular invasion in PCa, achieving an AUC of 0.769 (95% CI: 0.681 to 0.856, $p < 0.001$).

5. Conclusions

In conclusion, the MRI-based predictive model, combined with clinical risk factors, demonstrates substantial utility in forecasting capsular invasion in PCa, thereby providing valuable insights for both diagnosis and subsequent treatment strategies for PCa patients.

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

CZ and LY—designed the study and carried them out; interpreted the data; prepared the manuscript for publication and reviewed the draft of the manuscript. CZ, LY, XJZ and YZC—supervised the data collection. CZ, LY and XJZ—analyzed 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 The People's Hospital of Kaizhou District (Approval no. 202402(ZP)). Written informed consent was obtained from a legally authorized representative 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.

REFERENCES

[1] Yuk HD, Byun SS, Hong SK, Lee H. The tumor volume after radical prostatectomy and its clinical impact on the prognosis of patients with localized prostate cancer. Scientific Reports. 2022; 12: 6003.

[2] Wang JG, Huang BT, Huang L, Zhang X, He PP, Chen JB. Prediction of extracapsular extension in prostate cancer using the Likert scale combined with clinical and pathological parameters. Frontiers in Oncology. 2023; 13: 1229552.

[3] Shiradkar R. Editorial for "multiparametric MRI-based peritumoral radiomics for preoperative prediction of the presence of extracapsular extension with prostate cancer". Journal of Magnetic Resonance Imaging. 2021; 54: 1231–1232.

[4] He D, Wang X, Fu C, Wei X, Bao J, Ji X, *et al.* MRI-based radiomics models to assess prostate cancer, extracapsular extension and positive surgical margins. Cancer Imaging. 2021; 21: 46.

[5] Merder E, Ariman A, Altunrende F. A modified partin table to better predict extracapsular extension in clinically localized prostate cancer. Urology Journal. 2021; 18: 74–80.

[6] Guerra A, Alves FC, Maes K, Joniau S, Cassis J, Maio R, *et al.* Early biomarkers of extracapsular extension of prostate cancer using MRI-derived semantic features. Cancer Imaging. 2022; 22: 74.

[7] Blas L, Shiota M, Nagakawa S, Tsukahara S, Matsumoto T, Lee K, *et al.* Validation of user-friendly models predicting extracapsular extension in prostate cancer patients. Asian Journal of Urology. 2023; 10: 81–88.

[8] Kang Z, Margolis DJ, Wang S, Li Q, Song J, Wang L. Management strategy for prostate imaging reporting and data system category 3 lesions. Current Urology Reports. 2023; 24: 561–570.

[9] Desai MM, Cacciamani GE, Gill K, Zhang J, Liu L, Abreu A, *et al.* Trends in incidence of metastatic prostate cancer in the US. JAMA Network Open. 2022; 5: e222246.

[10] Cybulski AJ, Catania M, Brancato S, Cogo N, di Paola V, Pozzi Mucelli R, *et al.* Added value of MRI tractography of peri-prostatic nerve plexus to conventional T2-WI in detection of extra-capsular extension of prostatic cancer. Radiologia Medica. 2019; 124: 946–954.

[11] Zhu Z, Zhu Y, Xiao Y, Hu S. Indications for nerve-sparing surgery for radical prostatectomy: results from a single-center study. Frontiers in Oncology. 2022; 12: 896033.

[12] Panebianco V, Villeirs G, Weinreb JC, Turkbey BI, Margolis DJ, Richenberg J, *et al.* Prostate magnetic resonance imaging for local recurrence reporting (PI-RR): international consensus-based guidelines on multiparametric magnetic resonance imaging for prostate cancer recurrence after radiation therapy and radical prostatectomy. European Urology Oncology. 2021; 4: 868–876.

[13] Scialpi M, Martorana E, Scialpi P, Scalera GB, Belatti E, Aisa MC, *et al.* S-PI-RADS and PI-RRADS for biparametric MRI in the detection of prostate cancer and post-treatment local recurrence. Anticancer Research. 2023; 43: 297–303.

[14] Yilmaz EC, Shih JH, Belue MJ, Harmon SA, Phelps TE, Garcia C, *et al.* Prospective evaluation of PI-RADS version 2.1 for prostate cancer detection and investigation of multiparametric MRI-derived markers. Radiology. 2023; 307: e221309.

How to cite this article: Chong Zhang, Xingjun Zhong, Yuzhi Cui, Liu Yu. Value analysis of magnetic resonance imaging in diagnosing prostate cancer capsular invasion. Journal of Men's Health. 2024; 20(8): 131-135. doi: 10.22514/jomh.2024.139.