Open Access

Original Article

Assessment of Apparent Diffusion Coefficient (ADC) Measurements in Diffusion-Weighted Magnetic Resonance Imaging (DW-MRI) to Distinguish Between Prostate Cancer, Prostatitis, and Normal Prostate

Syeda Mariam Zehra, Nazia Dildar, Saima Omar, Uzma Nisar, Adil Qayyum, Fareeha Awan*

Department of Radiology, Combined Military Hospital, Rawalpindi/National University of Medical Sciences (NUMS) Pakistan, *Department of Radiology, Combined Military Hospital, Gilgit/National University of Medical Sciences (NUMS) Pakistan

ABSTRACT

Objective: To evaluate the diagnostic precision of ADC measurements in distinguishing between prostatitis, normal prostate tissue, and prostate cancer through Diffusion-Weighted Imaging (DWI).
Study Design: Comparative Cross-sectional Study
Place and Duration of Study: Radiology department of the CMH Rawalpindi, Pakistan, from Sep to Dec 2023.
Methodology: The study comprised 60 patients with elevated PSA levels of more than 4 ng/ml and a suspicion of prostate cancer. It was decided to use convenience sampling. In order to distinguish between benign prostate tissue, prostatitis, and malignancy, an MRI procedure was put into place. With an ADC cut-off value of 0.92 (x 10-3 mm2/sec), data was collected, entered, and analyzed, and sensitivity and specificity of each cut-off were associated. A one-way ANOVA test was used to compare the ADC values among the groups.
Results: The final analysis included the histopathologic examination of TRUS-guided biopsy for 55 patients. The sample's mean age was 59.93 ±8.76. The mean ADC values for normal tissue, prostatitis, and prostate cancer were 1.16 ±0.10x10-3 mm2/s, 1.50 ±0.07 x 10-3 mm2/s, and 0.85 + 0.10x 10-3 mm2, respectively. The difference was statistically significant (p<0.001).
Conclusion: The combination of DWI and ADC calculation offers more precise detection and characterisation of benign and malignant prostatic lesions. 0.92 (x 10-3 mm2/s) was the optimal threshold ADC value for achieving the maximum diagnostic precision.

Keywords: Apparent Diffusion Coefficient (ADC), Diffusion Magnetic Resonance Imaging (MRI), Prostatic Neoplasms, Benign, Prostatic Neoplasms, Malignant.

How to Cite This Article: *Zehra SM, Dildar N, Omar S, Nisar U, Qayyum A, Awan F. Assessment of Apparent Diffusion Coefficient (ADC) Measurements in Diffusion-Weighted Magnetic Resonance Imaging (DW-MRI) to Distinguish Between Prostate Cancer, Prostatitis, and Normal Prostate. Pak Armed Forces Med J 2026; 76(Suppl-8): S1233-S1238. DOI: https://doi.org/10.51253/pafmj.v76iSUPPL-8.12570*

INTRODUCTION

Prostate cancer is one of the most prevalent cancers in men throughout the world.[1] Timely diagnosis has a significant impact on the prognosis for prostate cancer. The early stages of prostate cancer may be reliably detected with transrectal ultrasonography, a prostate-specific antigen test, or a digital rectal exam.[2] Worldwide, prostate cancer is the fifth most prevalent cause of cancer-related mortality in males and the second most often diagnosed cancer overall.[3] In 112 countries, prostate cancer is the most frequent kind of the disease, and in 48 countries, it is the leading cause of cancer-related mortality. The total occurrence of prostate cancer in Pakistan was 5.2%.[4] The main method used to distinguish between slow-growing and aggressive lesions at the Gleason score is TRUS-guided biopsy, with treatment decisions based on several clinical factors, including the patient's age and the tumour's aggressiveness.[5]

Magnetic resonance imaging (MRI) offers a more accurate preoperative diagnosis compared to digital rectal examination (DRE) or transrectal ultrasound (TRUS) biopsy. When there is a discrepancy between PSA levels and biopsy findings (for instance, high PSA levels with a negative biopsy), magnetic resonance imaging (MRI) may be utilized to locate and guide a subsequent biopsy of a potential cancer site.[6] Diffusion-weighted magnetic resonance imaging (DWI) is a non-invasive method that relies on the movement of water molecules across and through cell membranes. The observable diffusion coefficient (ODC) value, a numerical indicator of diffusion-weighted magnetic resonance imaging, has demonstrated promise in the detection and localization of prostate cancer.[7] A consistent reference source across different systems or individuals can be utilized to compute relative ADC (rADC) or normalized ADC (nADC) with reduced variability. A recent investigation showed that the fluctuation of

Correspondence: Dr Syeda Mariam Zehra, Department of Radiology, Combined Military Hospital, Rawalpindi Pakistan
Received: 06 Jun 2024; revision received: 29 Dec 2024; accepted: 04 Jan 2025

ADC is minimized by normalized ADC (utilizing the spleen) when considering the choice of b values for both benign and malignant liver lesions.[8]

ADC levels are diminished in a wide range of cancers impacting different organs. Recent studies have shown that the ADC assessment on DWMRI can distinguish between non-cancerous and cancerous prostate lesions.[9,10] To assess the diagnostic accuracy of ADC measurements in distinguishing prostate cancer, healthy prostatic tissue, and prostatitis.

METHODOLOGY

The design of this research was cross-sectional and was conducted at the Radiology department of Combined Military Hospital, Rawalpindi, Pakistan, from Sep to Dec 2023. The study protocol was reviewed and approved by the Research and Ethical Committee of CMH RAWALPINDI (Re: 287.A). The study population comprised individuals presenting with a clinically solid prostate on digital rectal examination, a family history of prostate cancer, lower urinary tract symptoms, and prostate-specific antigen (PSA) levels exceeding 4 ng/ml.

Inclusion Criteria: Patients aged 40 years or older who exhibited a solid prostate on examination, PSA levels above 4 ng/ml, symptoms such as frequency, urgency, or nocturia, and a documented family history of prostate cancer.

Exclusion Criteria: Participants were excluded if they had a history of prior prostate surgery or treatment, recurrent prostate cancer confirmed through biopsy or imaging, other malignancies or comorbidities that could interfere with MRI interpretation, or contraindications to MRI, such as pacemakers, metallic implants, or severe claustrophobia.

The sample size for the study was calculated using the WHO online sample size calculator. The calculation was based on a 95% confidence level and a margin of error of 5%. Using a population proportion of 4.1% as reported by a local study by Hanif et al.[11] the estimated sample size was 60.

The study followed organizational protocols and employed a 1.5 Tesla (1.5T) MRI machine (Ingenia 1.5T Netherlands) along with "Philips Intellispace Portal", a Windows Workstation, and software for MR Imaging. A multiparametric MRI (mpMRI) approach was utilized in this study to distinguish among prostate cancer, prostatitis, and healthy prostate tissue. The procedure involved creating Apparent Diffusion Coefficient (ADC) maps for quantitative assessment, utilizing diffusion-weighted imaging (DWI) to identify tissue cellularity, and employing T2-weighted imaging for comprehensive anatomical details. T1-weighted scans were utilized to aid in the characterization of lesions, while Dynamic Contrast-Enhanced Imaging (DCE) was used to observe tissue enhancement patterns.

The existing imaging protocol employed multiple pulses, sequences, and imaging orientations to perform a comprehensive assessment of prostate conditions. To achieve detailed anatomical information, a quick spin echo sequence was utilized to capture T2-weighted images in the axial orientation.

To achieve a thorough perspective of the prostate, a single-shot echo-planar image was utilized, incorporating two rectangular gradient pulses in three perpendicular orientations. The specifications for the image were as outlined: TR/TE = 2800/74; Field of View = 38 cm^2; slice thickness = 3 mm; and the gap between segments was 1 mm. The dimensions of the matrix were 256 by 256. The angle of reversal measured 90 degrees, and the diffusion sensitizing factor (b) varied from 0 to 1000 s/mm2. DWI was utilized to assess tissue cellularity at 0 and 1000 sec/mm^2, and maps of the ADC were generated. When many lacerations be located, the most significant or largest one was considered, and irregularities were noted. The axial plane underwent DCE following the administration of a contrast dye to evaluate tissue perfusion and enhancement characteristics. Additionally, to aid in the characterization of lesions, T1-weighted imaging was utilized in the axial orientation. The effectiveness of the MRI assessment was enhanced through careful choice of particular pulses, sequences, and imaging orientations to distinguish between prostate cancer, prostatitis, and healthy prostate tissue. Target regions were physically delineated on the ADC maps by three radiologists who were unaware of clinical details. The automation of ADC measurements and analysis was integrated into the scanner as an application. We calculated the mean ADC values for prostate tissues.

Patients underwent TRUS biopsy or prostatectomy following their MRI scans, based on the clinical evaluation. Following this, skilled pathologists who did not have knowledge of the MRI findings performed histopathological analyses on the tissue samples. The benchmark for recognizing and defining prostate lesions was based on histopathological results. The tissue specimens were categorized into

three sections: I, II, and III, corresponding to prostate cancer, prostatitis, and healthy prostate tissue, respectively. An organized evaluation was performed to determine the "sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy" of ADC measurements in differentiating among the three tissue types, based on the relationship between ADC values derived from MRI scans and histopathological findings.

Data analysis was performed using SPSS v.26. Demographic information of patients was presented through descriptive statistics. To compare the ADC values of the three groups, the Kruskal-Wallis test or the one-way ANOVA were used. To determine specific differences among groups, post-hoc analyses were conducted. The precision and accuracy of each threshold were assessed by using the ADC threshold value of 0.92 (x 10-3 mm2/sec) to evaluate the data. Variations in the ADC values were considered statistically meaningful when the p-value fell below 0.05. The effectiveness of ADC measurements was assessed by determining the "sensitivity, specificity, positive predictive value, negative predictive value.

RESULTS

In the current study, 60 patients were initially recruited in the study; however, reports of Histopathologic examination of TRUS-guided biopsy were available for 55 patients and were encompassed in the final analysis. The average age of the sample was 59.93 ±8.76. The period between the initial diagnostic MRI examination and the biopsy session varied from 0 to 28 weeks.

Prostate abscess was seen as a lesion with multiple compartments affecting both the peripheral and transitional areas.. It restricts diffusion, meaning limited movement of water molecules. The apparent diffusion coefficient (ADC) estimates on ADC pictures are decreased, resulting in an average ADC value of 1.16 x 10-3 mm²/sec. The T1FS contrast pictures show extensive enhancement at the margins, whereas the middle region, where diffusion is limited, remains unaffected by enhancement.

T1-weighted imaging (T1WI) revealed a diffuse abnormality, and magnetic resonance imaging (MRI) confirmed prostatitis along with "benign prostatic hyperplasia (BPH). On T2-weighted imaging (T2WI), several dark spots with amorphous forms and hazy boundaries pop up in both the periphery and transitional zones. The signal strength on T2Wi varies inside the expanded transitional zone of BPH. It has a PIRADS score of 2 due to the absence of diffusion limitation and an average ADC value of 1.50 ± 0.07993 x10-3 mm²/sec seen on the related ADC map.

When adenocarcinoma is present, it darkens T1Wi and spreads into the transitional and peripheral areas. Throughout the prostate, T2Wi shows several dark patches that are uneven in form and have fuzzy borders. About 13x9x10 mm is the measurement of the biggest lesion. With DWi, the diffusion is limited, and the ADC value is modest, averaging 0.85 x10-3 mm²/sec. For this reason, it receives a PIRADS score of 3 or above.

Histopathologic classifications were used to classify biopsy specimens into three categories: normal prostate tissue, prostatitis, and prostate cancer. In the research sample, 28(or 50.90%) biopsy findings showed a malignant aetiology, 11(or 20%) showed normal prostate parenchyma, and 16(or 29.09%) showed prostatitis.

An average ADC value of 1.16 ±.10x10-3 mm2/s was recorded for normal tissue, 1.50 ±.07 x 10-3 mm²/s for prostatitis, and 0.85 + 0.1x 10-3 mm²/s for prostate cancer. The mean ADC of malignant lesions was 0.85, which is lower than the mean ADC of benign lesions (1.50), and this difference was determined to be statistically significant with a *p*-value of less than 0.001 (Table-I).

Table-I: Histopathology Findings of the sample (n=55)

Group	No. of Patients	Average ADC ± SD (* 10-3mm2/s)	*p*-value
Normal Prostate Tissue	11	1.16±0.10	< 0.001
Prostatitis	16	1.50±0.07	
Prostrate Cancer	28	0.85±0.07	

**The average ADC value is determined by summing all of the ADC values from 'n' patients and then dividing the total by 'n'.*

The PIRADS scores were correlated with histopathologic findings, indicating the number of cases classified as malignant and benign for each score.

The DWI results were stratified based on the presence of malignancy in histopathology, with hyperintense indicating diffusion restriction with corresponding low ADC and hypointense suggesting otherwise.

The sensitivity of DWI with low ADC values in distinguishing malignant from benign prostate lesions was 89.2%, specificity was 74.07%, PPV was 78.1%, and NPV was 86.96% (Table- III).

The sensitivity of ADC values in diagnosing prostate lesions was 85.7%, specificity was 66.7%, PPV was 72.7%, and NPV was 81.8% (Table-IV).

Table-II: PIRADS Score with Histopathology Findings (n=55)

PIRADS score	Histopathology		Total
	Malignant	Benign	
1	0	2	2
2	0	4	4
3	1	5	6
4	7	6	13
5	21	9	30

Table-III: Two-by-Two Table of DMI in Diagnosis of Malignant Prostate Lesions versus Histopathology as Gold Standard (n=55)

Dwi	Malignancy on histopathology		Total number
	Yes	No	
Hyperintense	25	7	32
Hypointense	3	20	23
Total Number	28	27	55
Parameter		Percent	
Sensitivity		89.29%	
Specificity		74.07%	
Positive Predictive Value		78.13%	
Negative Predictive Value		86.96%	

**Highly intense on DWI, who demonstrate diffusion limitation with a matching low ADC*

Table-IV: Two-by-two table of ADC (0.92 cut-off value) in Diagnosis of Malignant Prostate Lesions versus Histopathology as Gold Standard

ADC	Malignancy on Histopathology		Total Number
	Yes	No	
≤ 0.92	24	9	33
>0.92	4	18	22
Total Number	28	27	55
Parameter		Percent	
Sensitivity		85.70%	
Specificity		66.70%	
PPV		72.70%	
NPV		81.81%	

DISCUSSION

The present prospective study evaluated the diagnostic performance of apparent diffusion coefficient (ADC) measurements and diffusion-weighted magnetic resonance imaging (DW-MRI) for differentiating benign from malignant prostate lesions. Our findings demonstrated that ADC measurements provide good diagnostic performance, with a sensitivity of 85.7% and a specificity of 66.7% for the detection of malignant prostate lesions. These findings are in agreement with those reported by Gibbons et al., who established the value of diffusion-weighted imaging and quantitative ADC analysis in the characterization of prostatic tissue, particularly for distinguishing benign from malignant lesions.[12] The diagnostic accuracy observed in our study is also consistent with investigations conducted by Lemberskiy et al., who identified DW-MRI as a reliable, non-invasive imaging technique for prostate lesion characterization.[13]

Pre-biopsy MRI has revolutionised the diagnostic pathway for PCa, and optimising the biopsy process is now a focus. Combining MR imaging, TP biopsy, and a more widespread use of LA in an outpatient setting seems a reasonable solution to balance health-care costs and benefits; however, local choices are likely to depend on the expertise and experience of clinicians and on the technology available.[14] Similarly, AbdelMaboud *et al.,* reported a specificity of 71% and an overall diagnostic accuracy of 83%, values that closely parallel those obtained in the present study, thereby reinforcing the reproducibility and clinical utility of ADC-based assessment.[15]

Our findings further support the evidence in the literature demonstrating that malignant prostate lesions exhibit significantly lower ADC values than benign lesions and normal prostatic tissue. This observation is consistent with the biological characteristics of prostate cancer, in which increased cellular density, reduced extracellular space, and restricted diffusion of water molecules result in lower ADC values. These findings have been reported by Litjens *et al.,* who showed that normalized ADC values improve the discrimination between low- and high-grade peripheral zone prostate cancer, thereby enhancing diagnostic confidence.[16] Likewise, Cimadamore et al., and Saito et al., reported significantly reduced ADC values in malignant prostate lesions compared with non-cancerous tissue, supporting the role of quantitative diffusion imaging as a valuable imaging biomarker for prostate cancer detection and characterization.[17,18] Collectively, these studies and our findings highlight the importance of ADC measurements in improving lesion characterization and facilitating early diagnosis.

An important finding of the present study was the identification of an ADC threshold value of 0.92 × 10^{-3} mm^2/s for differentiating benign from malignant

prostate lesions. This cut-off was lower than the threshold values reported by Falaschi *et al.*, and Spadarotto et al., reflecting the variability in optimal ADC thresholds across different studies.[19,20] Such variability may be attributed to differences in MRI field strength, diffusion-weighting protocols, b-values, scanner manufacturers, image acquisition techniques, patient characteristics, lesion composition, and reference standards used for histopathological confirmation. These methodological differences continue to limit the establishment of a universally applicable ADC cut-off value. Nevertheless, despite these variations, the consistently high diagnostic performance of ADC measurements across studies underscores their value as a robust quantitative biomarker for prostate lesion assessment. Future multicenter studies employing standardized MRI acquisition protocols and larger patient cohorts are warranted to establish uniform ADC threshold values and further optimize the integration of DW-MRI into routine clinical evaluation of suspected prostate cancer.

LIMITATION OF STUDY

The present study has certain limitations, including its single-center design and relatively small sample size, which may limit the generalizability of the findings. In addition, the ADC threshold identified may not be universally applicable because of variations in MRI acquisition protocols, scanner characteristics, and patient populations.

CONCLUSION

The current investigation has determined that the identification and characterisation of benign and malignant prostatic lesions are more precise when a combination of DWI and ADC computation is employed. The optimal cut-off ADC value was 0.92 (x 10-3 mm^2/s), which demonstrated the greatest diagnostic precision and sufficient specificity. The average ADC values for healthy tissue, prostatitis, and prostate cancer were recorded at 1.16 ± 0.10 x 10-3 mm^2/s and 1.50 ± 0.07 x 10-3 mm^2/s, respectively.

Conflict of Interest: None.

Funding Source: None.

Authors' Contribution

Following authors have made substantial contributions to the manuscript as under:

SMZ & ND: Data acquisition, data analysis, critical review, approval of the final version to be published.

SO & UN: Study design, data interpretation, drafting the manuscript, critical review, approval of the final version to be published.

AQ & FA: Conception, data acquisition, drafting the manuscript, approval of the final version to be published.

Authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

REFERENCES

1. Yoo S, Gujrathi I, Haider MA, Khalvati F. Prostate cancer detection using deep convolutional neural networks. Sci rep 2019; 9(1): 19518. https://doi.org/10.1038/s41598-019-55972-4
2. Descotes JL. Diagnosis of prostate cancer. Asian J Urol 2019; 6(2): 129-136. https://doi.org/10.1016/j.ajur.2018.11.007
3. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin 2021; 71(3): 209-249. https://doi.org/10.3322/caac.21660
4. Akhtar S, Hassan F, Ahmad S, El-Affendi MA, Khan MI. The prevalence of prostate cancer in Pakistan: A systematic review and meta-analysis. Heliyon 2023; 9(10): e20350. https://doi.org/ 10.1016/j.heliyon.2023.e20350
5. Radovanović M, Zubelić A, Šantrić V, Milojević B, Bumbaširević U, Stanković B. Evaluating the clinical application of PAMD score in the assessment of TRUS-biopsy-positive outcomes in patients with PSA 4-10 ng/ml treated in Serbia. Med Istraž 2023; 56(1): 15-20. https://doi.org/10.5937/medi55-41565
6. Obino M. Diagnostic accuracy of multi-parametric MRI in diagnosis of clinically significant prostate cancer [master's dissertation]. Nairobi (Kenya): Aga Khan University, East Africa; 2019. https://ecommons.aku.edu/cgi/viewcontent.cgi?article=3017&context=theses_dissertations
7. Ragheb SR, Bassiouny RH. Can mean ADC value and ADC ratio of benign prostate tissue to prostate cancer assist in the prediction of clinically significant prostate cancer within the PI-RADSv2 scoring system? Egypt J Radiol Nucl Med 2020; 51: 1-2. https://doi.org/10.1186/s43055-020-00347-3
8. Raspe J, Harder FN, Rupp S, McTavish S, Peeters JM, Weiss K, et al. Retrospective Motion Artifact Reduction by Spatial Scaling of Liver Diffusion-Weighted Images. Tomography 2023; 9(5): 1839-1856. https://doi.org/10.3390/tomography9050146
9. Soydan L, Demir AA, Torun M, Cikrikcioglu MA. Use of diffusion-weighted magnetic resonance imaging and apparent diffusion coefficient in gastric cancer staging. Curr Med Imaging 2020; 16(10): 1278-1289. https://doi.org/10.2174/1573405616666200218124926
10. Lucarelli NM, Villanova I, Maggialetti N, Greco S, Tarantino F, Russo R, et al. Quantitative ADC: An Additional Tool in the Evaluation of Prostate Cancer?. J Pers Med 2023; 13(9): 1378. https://doi.org/10.3390/jpm13091378
11. Hanif M, Zaidi P, Kamal S, Hameed A. Institution-based cancer incidence in a local population in Pakistan: nine year data analysis. Asian Pac J Cancer Prev 2009 Apr 1; 10(2) : 227-230.
12. Gibbons M, Starobinets O, Simko JP, Kurhanewicz J, Carroll PR, Noworolski SM. Identification of prostate cancer using multiparametric MR imaging characteristics of prostate tissues referenced to whole-mount histopathology. Magn Reson Imaging 2022; 85: 251-261. https://doi.org/10.1016/j.mri.2021.10.008
13. Lemberskiy G, Chandarana H, Bruno M, Ginocchio LA, Huang C, Tong A, et al. Feasibility of accelerated prostate diffusion-weighted imaging on 0.55 T MRI enabled with random matrix theory denoising. Invest Radiol 2023; 58(10): 720-729. https://doi.org/10.1097/RLI.0000000000000979
14. Ippoliti S, Fletcher P, Orecchia L, Miano R, Kastner C, Barrett T. Optimal biopsy approach for detection of clinically significant prostate cancer. Br J Radiol 2022;95(1131):20210413. https://doi.org/10.1259/bjr.20210413

15. AbdelMaboud NM, Elsaid HH, Aboubeih EA. The role of diffusion–Weighted MRI in evaluation of prostate cancer. Egypt J Radiol Nucl Med 2014; 45(1): 231-236. https://doi.org/10.1016/j.ejrnm.2013.11.010
16. Litjens GJ, Hambrock T, Hulsbergen–van de Kaa C, Barentsz JO, Huisman HJ. Interpatient variation in normal peripheral zone apparent diffusion coefficient: effect on the prediction of prostate cancer aggressiveness. Radiol 2012; 265(1): 260-266. https://doi.org/10.1148/radiol.12112374
17. Cimadamore A, Cheng L, Lopez-Beltran A, Mazzucchelli R, Lucianò R, Scarpelli M, et al. Added clinical value of whole-mount histopathology of radical prostatectomy specimens: a collaborative review. Euro Urol Oncol 2021; 4(4): 558-569. https://doi.org/10.1016/j.euo.2020.08.003
18. Saito S, Koyama Y, Ueda J, Hashido T. Relationship between apparent diffusion coefficient distribution and cancer grade in prostate cancer and benign prostatic hyperplasia. Diagnostics 2022; 12(2): 525. https://doi.org/10.3390/diagnostics12020525
19. Falaschi Z, Tricca S, Attanasio S, Billia M, Airoldi C, Percivale I, et al. Non-timely clinically applicable ADC ratio in prostate mpMRI: a comparison with fusion biopsy results. Abdom Radiol 2022; 47(11): 3855-3867. https://doi.org/10.1007/s00261-022-03627-w
20. Spadarotto N, Sauck A, Hainc N, Keller I, John H, Hohmann J. Quantitative Evaluation of Apparent Diffusion Coefficient Values, ISUP Grades and Prostate-Specific Antigen Density Values of Potentially Malignant PI-RADS Lesions. Cancers 2023; 15(21): 5183. https://doi.org/10.3390/cancers15215183