diffusion weighted imaging

a practical guide

Alex Kirkham
UCH
DWI: principles


Figure 4. Graph illustrates the logarithm of relative signal intensity ($SI_y$) versus $b$ value (in this case, 0 and 500 sec/mm²) ($x$-axis) for tumor and normal tissue. The slope of the “tumor line” is less than that of the line representing normal tissue, which translates into lower signal on the ADC map.
Usefulness of Apparent Diffusion Coefficient Map in Diagnosing Prostate Carcinoma: Correlation with Stepwise Histopathology

Kengo Yoshimitsu, MD, Keijiro Kiyoshima, MD, Hiroyuki Irie, MD, Tsuyoshi Tajima, MD, Yoshiki Asayama, MD, Masakazu Hirakawa, MD, Kousei Ishigami, MD, Seiji Naito, MD, and Hiroshi Honda, MD

**Purpose:** To elucidate the performance of apparent diffusion coefficient (ADC) map in localizing prostate carcinoma (PC) using stepwise histopathology as a reference.

**Materials and Methods:** Preoperative MR images of 37 patients with PC who had undergone radical prostatectomy were retrospectively evaluated. First, T2-weighted images (T2WI) alone were interpreted (T2WI reading), and then T2WI along with ADC map were interpreted (T2WI/ADC map reading). Sextant-based sensitivity and specificity, and the ratio of the detected volume to the whole tumor volume (% tumor volume) were compared between the two interpretations, and results were also correlated to Gleason’s scores (GS). ADC values were correlated to histological grades.

**Results:** Sensitivity was significantly higher in T2WI/ADC map reading than in T2WI reading (71% vs. 51%), but specificity was similar (61% vs. 60%). By adding ADC map to T2WI, % tumor volume detected increased significantly in transitional zone (TZ) lesions, but not in peripheral zone (PZ) lesions. % tumor volume detected with T2WI/ADC map reading showed a positive correlation with GS of the specimens. Less differentiated PC were associated with lower ADC values and higher detectability.

**Conclusion:** T2WI/ADC map reading was better than T2WI reading in PC detection and localization. This approach may be particularly useful for detecting TZ lesions and biologically aggressive lesions.

**Key Words:** prostate carcinoma; MR; diffusion-weighted image; ADC map; localization


PROSTATE CARCINOMA (PC) is one of the most common malignancies in males, and it accounts for approximately 30,000 new annual deaths in the United States (1). To date, surgical resection of the whole organ has been the only method of eradicating this type of malignancy; however, less invasive alternative local therapies, including intensive modulated radiation therapy (IMRT), high-intensity focused ultrasound (HIFU), and brachytherapy, are being introduced due to the increasing clinical demand for the preservation of functional aspects of the prostate and related organs (2–4).

The current role of MRI in the diagnosis of PC is primarily based on T2-weighted images (T2WI), and this approach has remained relatively limited in terms of usefulness, as it can mainly be used to determine whether or not a lesion extends beyond the confinement of the organ capsule (5), a measure used for determining the indication for radical prostatectomy. Also, in the cases of the less invasive local therapies mentioned above, the current approach is to cover the whole organ, regardless of the location or bulk of the tumor within the organ, provided extracapsular extension of ...
Diffusion weighted imaging should be acquired in the axial plane with an echo planar imaging sequence employing parallel imaging. Motion probing gradients should be applied in three orthogonal directions and adapted to the quality of the SNR. The minimal requirements are b-values of 0, 100, and 800–1000 s/mm². The choice of these values enables calculation of diffusion sensitive ADC values (by excluding the b=0 data from the ADC calculation). For optimal DWI, the b-values are: 0, 100, 500, and 800–1000 s/mm². TE should be as short as achievable (typically <90 ms).

**simple criteria for ADC maps**

- DWI axial: 5 mm at 1.5 T, 4 mm at 3 T; in-plane resolution: 1.5×1.5 mm to 2.0×2.0 mm at 1.5 T and 1.0×1.0 mm to 1.5×1.5 mm at 3 T. ADC map should be calculated. At least 3 b-values should be acquired in three orthogonal directions and adapted to quality of SNR: 0, 100 and 800–1000 s/mm². For calculation of ADC, the highest b-value that should be used is 1000 s/mm².

and an elliptical reference to the utility of very high b values... a long b with many averages is **vital**
PIRADS criteria

B. Diffusion weighted imaging (DWI)
1. No reduction in ADC compared with normal glandular tissue. No increase in SI on any high b-value image (≥b800)
2. Diffuse, hyper SI on ≥b800 image with low ADC; no focal features, however, linear, triangular or geographical features are allowed
3. Intermediate appearances not in categories 1/2 or 4/5
4. Focal area(s) of reduced ADC but iso-intense SI on high b-value images (≥b800)
5. Focal area/mass of hyper SI on the high b-value images (≥b800) with reduced ADC

T2 low signal and restricted diffusion in an unusual location (median lobe)

the long b clinches it!
artefact
Comparison of different mathematical models of diffusion-weighted prostate MR imaging

Michael Quentin¹,*, Dirk Blondin¹, Janina Klasen¹, Rotem Shlomo Lanzman¹, Falk-Roland Miese¹, Christian Arsov², Peter Albers², Gerald Antoch¹, Hans-Jörg Wittsack¹

¹Department of Diagnostic and Interventional Radiology, University Dusseldorf, Medical Faculty, D-40225 Dusseldorf, Germany
²Department of Urology, University Dusseldorf, Medical Faculty, D-40225 Dusseldorf, Germany

Received 12 January 2012; revised 2 April 2012; accepted 13 April 2012

Abstract

Purpose: To evaluate which mathematical model (monoexponential, biexponential, statistical, kurtosis) fits best to the diffusion-weighted signal in prostate magnetic resonance imaging (MRI).

Materials and Methods: 24 prostate 3-T MRI examinations of young volunteers (YV, n=8), patients with biopsy proven prostate cancer (PC, n=8) and an aged matched control group (AC, n=8) were included. Diffusion-weighted imaging was performed using 11 b-values ranging from 0 to 800 s/mm².

Results: Monoexponential apparent diffusion coefficient (ADC) values were significantly (P<.001) lower in the peripheral (PZ) zone (1.18±0.16 mm²/s) and the central (CZ) zone (0.73±0.13 mm²/s) of YV compared to AC (PZ 1.92±0.17 mm²/s; CZ 1.35±0.21 mm²/s). In PC ADCmono values (0.61±0.06 mm²/s) were significantly (P<.001) lower than in the peripheral of central zone of AC. Using the statistical analysis (Akaike information criteria) in YV most pixels were best described by the biexponential model (82%), the statistical model, respectively kurtosis (93%) each compared to the monoexponential model. In PC the majority of pixels was best described by the monoexponential model (57%) compared to the biexponential model.

Conclusion: Although a more complex model might provide a better fitting when multiple b-values are used, the monoexponential analyses for ADC calculation in prostate MRI is sufficient to discriminate prostate cancer from normal tissue using b-values ranging from 0 to 800 s/mm².

© 2012 Elsevier Inc. All rights reserved.
the mono-exponential curve (as on most MR machines) fits the data pretty well and is adequate for everyday b values
But The absolute ADC value is not reliable

<table>
<thead>
<tr>
<th>Study (Year)</th>
<th>No. of Patients</th>
<th>b Values, s/mm²</th>
<th>ADC Peripheral Zone (PZ)</th>
<th>ADC Central Gland (CG)</th>
<th>ADC of Tumor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pickles et al, 2006</td>
<td>49</td>
<td>0, 500</td>
<td>1.95 ± 0.50</td>
<td>1.38 ± 0.32</td>
<td></td>
</tr>
<tr>
<td>Gibbs et al, 2006</td>
<td>62</td>
<td>0, 500</td>
<td>1.87 ± 0.47</td>
<td>1.33 ± 0.32</td>
<td></td>
</tr>
<tr>
<td>Kim et al, 2007</td>
<td>35</td>
<td>0, 1000</td>
<td>1.97 ± 0.25</td>
<td>1.79 ± 0.19</td>
<td>1.32 ± 0.24 (PZ), 1.37 ± 0.29 (CG)</td>
</tr>
<tr>
<td>Zelhof et al, 2009</td>
<td>32</td>
<td>0, 500</td>
<td>1.90 ± 0.33</td>
<td>1.45 ± 0.27 (PZ)</td>
<td></td>
</tr>
<tr>
<td>Kim et al, 2010</td>
<td>48</td>
<td>0, 1000</td>
<td>2.04 ± 0.34</td>
<td>1.77 ± 0.30</td>
<td>1.19 ± 0.33 (PZ), 1.21 ± 0.23 (CG)</td>
</tr>
<tr>
<td>Studies at 1.5 T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kumar et al, 2007</td>
<td>23</td>
<td>0, 250, 500, 750, 1000</td>
<td>1.34 ± 0.30</td>
<td>1.12 ± 0.15</td>
<td>0.98 ± 0.22 (PZ), 1.00 ± 0.25 (CG)</td>
</tr>
<tr>
<td>deSouza et al, 2007</td>
<td>30</td>
<td>0, 300, 500, 800</td>
<td>1.71 ± 0.16</td>
<td>1.46 ± 0.14</td>
<td>1.30 ± 0.30</td>
</tr>
<tr>
<td>Reinsberg et al, 2007</td>
<td>37</td>
<td>0, 300, 500, 800</td>
<td>1.51 ± 0.27</td>
<td>1.31 ± 0.20</td>
<td>1.03 ± 0.18</td>
</tr>
<tr>
<td>Tamada et al, 2008</td>
<td>90 (controls*)</td>
<td>0, 1000</td>
<td>1.80 ± 0.27*</td>
<td>1.34 ± 0.14*</td>
<td>1.02 ± 0.25 (PZ), 0.94 ± 0.21 (CG)</td>
</tr>
<tr>
<td>Kitajima et al, 2008</td>
<td>26</td>
<td>0, 1000</td>
<td>1.69 ± 0.23</td>
<td></td>
<td>0.82 ± 0.27 (PZ)</td>
</tr>
<tr>
<td>Woodfield et al, 2010</td>
<td>57</td>
<td>0, 1000</td>
<td>1.48 ± 0.29</td>
<td>1.08 ± 0.39 (PZ)</td>
<td>0.74 ± 0.15 (PZ)</td>
</tr>
<tr>
<td>Sato et al, 2005</td>
<td>23</td>
<td>0, 300, 600</td>
<td>1.80 ± 0.41</td>
<td>1.58 ± 0.37</td>
<td>1.13 ± 0.42 (CG)</td>
</tr>
</tbody>
</table>


so let’s not worry too much about it...
Diagnostic value of ADC in patients with prostate cancer: influence of the choice of $b$ values

Gregor Thörmer · Josephin Otto · Martin Reiss-Zimmermann · Matthias Seiwerts · Michael Moche · Nikita Garrov · Toni Franz · Minh Do · Jens-Uwe Stolzenburg · Lars-Christian Horn · Thomas Kahn · Harald Busse

Received: 9 December 2011 / Revised: 25 January 2012 / Accepted: 13 February 2012 / Published online: 17 April 2012 © European Society of Radiology 2012

Abstract

Objectives To evaluate the influence of the choice of $b$ values on the diagnostic value of the apparent diffusion coefficient (ADC) for detection and grading of prostate cancer (PCa). Methods Forty-one patients with biopsy-proven PCa underwent endorectal 3-T MRI before prostatectomy. Different combinations of $b$ values (0–800 s/mm$^2$) were used to calculate four representative ADC maps. Mean ADCs of tumours and non-malignant tissue were determined. Tumour appearance on different ADC maps was rated by three radiologists as good, fair or poor by assigning a visual score (VS) of 2, 1 or 0, respectively. Differences in the ADC values with the choice of $b$ values were analysed using one-way ANOVA.

Results Choice of $b$ values had a highly ($P<0.001$) significant influence on the absolute ADC in each tissue. Maps using $b=50$, 800 and [0, 800] were rated best (VS = 1.6 ± 0.3) and second best (1.1 ± 0.3, $P<0.001$), respectively. For low-grade carcinomas (Gleason score ≤ 6, 13/41 patients), only the former choice received scores better than fair (VS = 1.4 ± 0.3). Mean tumour ADCs showed significant negative correlation (Spearman’s $\rho = -0.38$ to $-0.46$, $P<0.05$) with Gleason score.

Conclusions Absolute ADC values strongly depend on the choice of $b$ values and therefore should be used with caution for diagnostic purposes. A minimum $b$ value greater than zero is recommended for ADC calculation to improve visual assessment of PCa in ADC maps.

Key Points

- Absolute ADC values are highly dependent on the choice of $b$ values.
- Absolute ADC thresholds should be used carefully to predict tumour aggressiveness.
- Subjective ratings of ADC maps involving $b = 0$ s/mm$^2$ are poor to fair.
- Minimum $b$ value greater than 0 s/mm$^2$ is recommended for ADC calculation.

Keywords Prostate cancer · Gleason score · Magnetic resonance imaging · Diffusion · Echo-planar imaging

Abbreviations

CG central gland
CSI chemical shift imaging
and the relative ADC value may be the best...


**Interpatient Variation in Normal Peripheral Zone Apparent Diffusion Coefficient: Effect on the Prediction of Prostate Cancer Aggressiveness**

*Geert J. S. Litjens, MSc*
*Thomas Hambrock, MD*
*Christina Hulsbergen-van de Kaa, MD, PhD*
*Jelle D. Barentsz, MD, PhD*
*Henkjan J. Huisman, PhD*

**Purpose:** To determine the interpatient variability of prostate peripheral zone (PZ) apparent diffusion coefficient (ADC) and its effect on the assessment of prostate cancer aggressiveness.

**Materials and Methods:** The requirement for institutional review board approval was waived. Intra- and interpatient variation of PZ ADCs was determined by means of repeated measurements of normal ADCs at three magnetic resonance (MR) examinations in a retrospective cohort of 10 consecutive patients who had high prostate-specific antigen levels and negative findings at transrectal ultrasonographically-guided biopsy. In these patients, no signs of PZ cancer were found at all three MR imaging sessions. The effect of interpatient variation on the assessment of prostate cancer aggressiveness was examined in a second retrospective cohort of 51 patients with PZ prostate cancer. Whole-mount step-section pathologic evaluation served as reference standard for placement of regions of interest on normal and PZ tissue. Repeated-measures analysis of variance was used to determine the significance of the interpatient variations in ADCs. Linear logistic regression was used to assess whether incorporating normal PZ ADCs improves the prediction of cancer aggressiveness.

**Results:** Analysis of variance revealed that interpatient variability (1.2–2.0 × 10⁻³ mm²/sec) was significantly larger than measurement variability (0.068 × 10⁻³ mm²/sec ± 0.027 [standard deviation]) (P = 0.058). Stand-alone tumor ADCs showed an area under the receiver operating characteristic curve (AUC) of 0.91 for discriminating low-grade versus high-grade tumors. Incorporating normal PZ ADC significantly improved the AUC to 0.90 (P = 0.0401).

**Conclusion:** PZ ADCs show significant interpatient variation, which has a substantial effect on the prediction of prostate cancer aggressiveness. Correcting this effect results in a significant increase in diagnostic accuracy.
Why prostate tumour delineation based on apparent diffusion coefficient is challenging: An exploration of the tissue microanatomy

**ALIE BORREN¹, MAAIKE R. MOMAN¹, GREETJE GROENENDAAL¹, ARTO E. BOEKEN KRUGER², PAUL J. VAN DIEST³, PETRA VAN DER GROEP³,⁴, UULKE A. VAN DER HEIDE¹, MARCO VAN VULPEN¹ & MARIELLE E. P. PHILIPPENS¹**

¹Department of Radiotherapy, University Medical Center Utrecht, Utrecht, The Netherlands, ²Department of Urology, University Medical Center Utrecht, Utrecht, The Netherlands, ³Department of Pathology, University Medical Center Utrecht, Utrecht, The Netherlands, and ⁴Department of Internal Medicine, University Medical Center Utrecht, Utrecht, The Netherlands

**Abstract**

**Background.** Focal boosting of prostate tumours to improve outcome, requires accurate tumour delineation. For this, the apparent diffusion coefficient (ADC) derived from diffusion-weighted MR imaging (DWI) seems a useful tool. On voxel level, the relationship between ADC and histological presence of tumour is, however, ambiguous. Therefore, in this study the relationship between ADC and histological variables was investigated on voxel level to understand the strengths and limitations of DWI for prostate tumour delineation. **Material and methods.** Twelve radical prostatectomy patients underwent a pre-operative 3.0T DWI exam and the ADC was calculated. From whole-mount histological sections cell density and glandular area were retrieved for every voxel. The distribution of all variables was described for tumour, peripheral zone (PZ) and central gland (CG) on regional and voxel level. Correlations between variables and differences between regions were calculated. **Results.** Large heterogeneity of ADC on voxel level was observed within tumours, between tumours and between patients. This heterogeneity was reflected by the distribution of cell density and glandular area. On regional level, tumour was different from PZ having higher cell density (p = 0.007), less glandular area (p = 0.017) and lower ADCs (p = 0.017). ADC was correlated with glandular area (r = 0.402) and tumour volume (r = -0.608), but not with Gleason score. ADC tended to decrease with increasing cell density (r = -0.327, p = 0.073). On voxel level, correlations between ADC and histological variables varied among patients, for cell density ranging from r = -0.439 to r = 0.261 and for glandular area from r = 0.593 to r = 0.207. **Conclusions.** The variation in ADC can to a certain extent be explained by the variation in cell density and glandular area. The ADC is highly heterogeneous, which reflects the heterogeneity of malignant and benign prostate tissue. This heterogeneity might however obscure small tumours or parts of tumours. Therefore, DWI has to be used in the context of multiparametric MRI.

in this study, ADC correlated with cell density, glandular area and tumour volume, but not with Gleason grade.
Fig. 1  Classification of anterior tumors. Schematic prostate axial section at mid-gland. Transition zone tumors confined to one TZ lobe (TZ type 1) mostly at anterolateral location or astride the TZ-AFMS boundary (TZ type 2). Tumor confined to anterior fibro muscular stroma (AFMS). Tumor confined to the anterolateral peripheral zone (PZ) horn.
up to 40% of patients with negative previous biopsy & rising PSA will have an anterior tumour
Transition zone: operator dependence & early results...

78 out of 79 cancers >0.5cc in the TZ were missed...


...but sensitivity of 75% & specificity of 87% has more recently been reported using mainly T2 weighted images

Homogenous T2 low signal 79%
Polygonal > nodular > lenticular
Ill-defined margins in 89%


Anerior cancers predominate in anterior - mid TZ, invading anterior fibromuscular stroma when small

Sala et al. Transition zone prostate cancers: features, detection, localization, and staging at endorectal MR imaging Radiology 2006; 239: 784-92
40% of men with at least one previous negative biopsy had prostate cancer detected when lesions were targeted using MRI. Three quarters of these cancers were anterior lesions. Strikingly, of 17 lesions detected on the diffusion-weighted sequence at 3T, only 6 were seen on T2 weighted images\(^3\).

Prostate cancer detection with MRI: is dynamic contrast-enhanced imaging necessary in addition to diffusion-weighted imaging?

Jin Iwazawa, Takashi Mitani, Seitaro Sassa, Shoichi Ohue

RESULTS
Prostate cancer was detected in 72 (40.4%) of the 178 patients. For the entire prostate, the diagnostic performances of DWI ($A_z = 0.848$) ($P < 0.001$) and the combined technique ($A_z = 0.845$) ($P < 0.001$) were significantly more accurate than that of DCEI ($A_z = 0.746$). DWI (74.8%) ($P < 0.001$) and the combined technique (72.9%) ($P < 0.001$) were significantly more sensitive than DCEI (52.8%). The numbers of cancer lesions that were interpreted using only DWI or DCEI were 83 (26.1%) and 13 (4.1%) of the 318 study lesions, respectively.
Transition Zone Prostate Cancer: Detection and Localization with 3-T Multiparametric MR Imaging

Purpose: To retrospectively compare transition zone (TZ) cancer detection and localization accuracy of 3-T T2-weighted magnetic resonance (MR) imaging with that of multiparametric (MP) MR imaging, with radical prostatectomy specimens as the reference standard.

Materials and Methods: The informed consent requirement was waived by the institutional review board. Inclusion criteria were radical prostatectomy specimen TZ cancer larger than 0.5 cm³ and 3-T endorectal presurgery MP MR imaging (T2-weighted imaging, diffusion-weighted [DW] imaging apparent diffusion coefficient [ADC] maps [b < 1000 sec/mm²], and dynamic contrast material–enhanced [DCE] MR imaging). From 197 patients with radical prostatectomy specimens, 28 patients with TZ cancer were included. Thirty-five patients without TZ cancer were randomly selected as a control group. Four radiologists randomly scored T2-weighted and DW ADC images, T2-weighted and DCE MR images, and T2-weighted, DW ADC, and DCE MR images. TZ cancer suspicion was rated on a five-point scale in six TZ regions of interest (ROIs). A score of 4–5 was considered a positive finding. A score of 4 or higher for any ROI containing TZ cancer was considered a positive detection result at the patient level. Generalized estimating equations were used to analyze detection and localization accuracy by using ROI-receiver operating characteristics (ROC) curve analyses for the latter. Gleason grade (GG) 4–5 and GG 2–3 cancers were analyzed separately.

Results: Detection accuracy did not differ between T2-weighted and MP MR imaging for all TZ cancers (68% vs 68%, P = .85), GG 4–5 TZ cancers (79% vs 72%–75%, P = .13), and GG 2–3 TZ cancers (66% vs 62%–65%, P = .47). MP MB imaging (area under the ROC curve, 0.70–0.77) did not improve T2-weighted imaging localization accuracy (AUC = 0.72) (P > .05).

Conclusion: Use of 3-T MP MR imaging, consisting of T2-weighted imaging, DW imaging ADC maps (b values, 50, 500, and 800 sec/mm²), and DCE MR imaging may not improve TZ cancer detection and localization accuracy compared with T2-weighted imaging.
Multiparametric Prostate MR Imaging with T2-weighted, Diffusion-weighted, and Dynamic Contrast-enhanced Sequences: Are All Pulse Sequences Necessary to Detect Locally Recurrent Prostate Cancer after Radiation Therapy?

Olivio F. Donati, MD, Sung Il Jung, MD1, Hebert Alberto Vargas, MD, David H. Gultekin, PhD, Junting Zheng, MS, Chaya S. Moskowitz, PhD, Hedvig Hricak, MD, PhD, Dr(hc), Michael J. Zelefsky, MD and Oguz Akin, MD

From the Departments of Radiology (O.F.D., S.I.J., H.A.V., H.H., O.A.), Medical Physics (D.H.G.), Epidemiology and Biostatistics (J.Z., C.S.M.), and Radiation Oncology (M.J.Z.), Memorial Sloan-Kettering Cancer Center, 1275 York Ave, New York, NY 10065.

Address correspondence to O.A. (e-mail: akino@mskcc.org).

Author contributions: Guarantors of integrity of entire study, O.F.D., M.J.Z., O.A.; study concept/idea design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; literature research, O.F.D., H.A.V., D.H.G., O.A.; clinical studies, S.I.J., D.H.G., O.A.; statistical analysis, J.Z., C.S.M.; and manuscript editing, O.F.D., S.I.J., H.A.V., D.H.G., H.H., M.J.Z., O.A.

Abstract

Purpose: To compare diagnostic accuracy of T2-weighted magnetic resonance (MR) imaging with that of multiparametric (MP) MR imaging combining T2-weighted imaging with diffusion-weighted (DW) MR imaging, dynamic contrast material-enhanced (DCE) MR imaging, or both in the detection of locally recurrent prostate cancer (PCa) after radiation therapy (RT).

Materials and Methods: This retrospective HIPAA-compliant study was approved by the institutional review board; informed consent was waived. Fifty-three men (median age, 70 years) suspected of having post-RT recurrence of PCa underwent MP MR imaging, including DW and DCE sequences, within 6 months after biopsy. Two readers independently evaluated the likelihood of PCa with a five-point scale for T2-weighted imaging alone, T2-weighted imaging with DW imaging, T2-weighted imaging with DCE imaging, and T2-weighted imaging with DW and DCE imaging, with at least a 4-week interval between evaluations. Areas under the receiver operating characteristic curve (AUC) were calculated. Interreader agreement was assessed, and quantitative parameters (apparent diffusion coefficient [ADC], volume transfer constant [Ktrans], and rate constant [Kep]) were assessed at sextant- and patient-based levels with generalized estimating equations and the Wilcoxon rank sum test, respectively.

Results: At biopsy, recurrence was present in 35 (66%) of 53 patients. In detection of recurrent PCa, T2-weighted imaging with DW imaging yielded higher AUCs (reader 1, 0.79-0.86; reader 2, 0.75-0.81) than T2-weighted imaging alone (reader 1, 0.63-0.67; reader 2, 0.46-0.49 [P ≤ .014 for all]). DCE sequences did not contribute significant incremental value to T2-weighted imaging with DW imaging (reader 1, P > .99; reader 2, P = .35). Interreader agreement was higher for combinations of MP MR imaging than for T2-weighted imaging alone (κ = 0.34-0.63 vs κ = 0.17-0.20). Medians of quantitative parameters differed significantly (P < .0001 to P = .0233) between benign tissue and PCa (ADC, 1.64 × 10⁻³ mm²/sec vs 1.13 × 10⁻³ mm²/sec; Ktrans, 0.16 min⁻¹ vs 0.33 min⁻¹; Kep, 0.36 min⁻¹ vs 0.62 min⁻¹).

Conclusion: MP MR imaging has greater accuracy in the detection of recurrent PCa after RT than T2-weighted imaging alone, with no additional benefit if DCE is added to T2-weighted imaging and DW imaging.
Prostate cancer recurrence after radical prostatectomy: the role of 3-T diffusion imaging in multi-parametric magnetic resonance imaging

Valeria Panebianco · Flavio Barchetti · Alessandro Sciarra · Daniela Musio · Valerio Forte · Vincenzo Gentile · Vincenzo Tombolini · Carlo Catalano

Received: 17 August 2012 / Revised: 4 December 2012 / Accepted: 10 December 2012 © European Society of Radiology 2013

Abstract
Objectives To validate the role of 3-T diffusion-weighted imaging (DWI) in the detection of local prostate cancer recurrence after radical prostatectomy (RP).
Methods T2-weighted imaging, DWI and dynamic contrast-enhanced MRI (DCE-MRI) were performed with a 3-T magnet in 262 patients after RP. Twenty out of 262 patients evaluated were excluded. MRI results were validated by prostate-specific antigen (PSA) reduction after external beam radiotherapy in group A (126 patients, local recurrence size range 4–8 mm) and by transrectal ultrasound biopsy in group B (116 patients, local recurrence size range 9–15 mm).
Results In group A combined T2-weighted and DCE-MRI (T2+DCE) shows 98 % sensitivity, 94 % specificity and 93 % accuracy in identifying local recurrence; combined T2-weighted and DWI with a b value of 3,000 s/mm² (T2+DW3) displays 97 % sensitivity, 95 % specificity and 92 % accuracy, while with a b value of 1,000 s/mm² (T2+DW1) affords 93 % sensitivity, 89 % specificity and 88 % accuracy. In group B T2+DCE shows 100 % sensitivity, 97 % specificity and 91 % accuracy in detecting local cancer recurrence; T2+DW3 displays 98 % sensitivity, 96 % specificity and 89 % accuracy; T2+DW1 has 94 % sensitivity, 92 % specificity and 86 % accuracy.
Conclusion DCE-MRI is the most reliable technique in detecting local prostate cancer recurrence after RP, though DWI can be proposed as a reliable alternative.
Key Points
- Diffusion-weighted magnetic resonance imaging (DWI-MRI) is being increasingly used in oncology.
- PSA analysis does not distinguish prostate cancer recurrence from distant metastasis.
- DWI-MR can diagnose local prostate cancer recurrence after radical prostatectomy.
- DWI-MR is almost comparable to DCE-MRI in detecting local recurrence.

Keywords MRI · Prostate cancer · Prostatectomy · Diffusion magnetic resonance imaging · Local neoplasm recurrence
16 benign cases, 15 malignant...

<table>
<thead>
<tr>
<th>Histology</th>
<th>Abutting / based on the FMS</th>
<th>Causing contour Bulge</th>
<th>Enhancment hyper compared to TZ</th>
<th>Enhancment similar compared to TZ</th>
<th>Enhancment hypo compared to TZ</th>
<th>Enhancment homogenous</th>
<th>Enhancment heterogenous</th>
<th>Pseudo capsule</th>
<th>Higher B1400 brightness compared to TZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benign</td>
<td>6/16</td>
<td>1/16</td>
<td>5/16</td>
<td>10/16</td>
<td>1/16</td>
<td>14/16</td>
<td>2/16</td>
<td>7/16</td>
<td>5/16</td>
</tr>
<tr>
<td></td>
<td>37.5%</td>
<td>6.25%</td>
<td>31.25%</td>
<td>62.5%</td>
<td>6.25%</td>
<td>87.5%</td>
<td>12.5%</td>
<td>43.75%</td>
<td>31.25%</td>
</tr>
<tr>
<td>Malignant</td>
<td>15/15</td>
<td>12/15</td>
<td>0/15</td>
<td>9/15</td>
<td>6/15</td>
<td>13/15</td>
<td>2/15</td>
<td>0/16</td>
<td>14/15</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>80%</td>
<td>0%</td>
<td>60%</td>
<td>40%</td>
<td>86.6%</td>
<td>13.3%</td>
<td>0%</td>
<td>93.3</td>
</tr>
</tbody>
</table>

UCH, not yet published
Detectability of low and intermediate or high risk prostate cancer with combined T2-weighted and diffusion-weighted MRI

Kyung Won Doo · Deuk Jae Sung · Beom Jin Park · Min Ju Kim · Sung Bum Cho · Yu Whan Oh · Young Hwi Ko · Kyung Sook Yang

Received: 6 November 2011 / Accepted: 22 February 2012 / Published online: 1 April 2012
© European Society of Radiology 2012

Abstract

Objectives To evaluate the incremental value of diffusion-weighted imaging (DWI) in combination with T2-weighted imaging to detect low (Gleason score, ≤6) and intermediate or high risk (Gleason score, ≥7) prostate cancer.

Methods Fifty-one patients who underwent MRI before prostatectomy were evaluated. Two readers independently scored the probability of tumour in eight regions of prostate on T2-weighted images (T2WI) and T2WI combined with apparent diffusion coefficient (ADC) maps. Data were divided into two groups—low risk and intermediate or high risk prostate cancer—and correlated with histopathological results. Diagnostic performance parameters, areas under the receiver-operating characteristic curve (AUCs) and inter-reader agreement were calculated.

Results For both readers, AUCs of combined T2WI and ADC maps were greater than those of T2WI in intermediate or high risk (reader 1, 0.887 vs. 0.859; reader 2, 0.732 vs 0.662, P<0.05) prostate cancers, but not in low risk (reader 1, 0.719 vs 0.725; reader 2, 0.685 vs. 0.680, P>0.05) prostate cancers. Weighted κ value of combined T2WI and ADC maps was 0.689.

Conclusions The addition of DWI to T2-weighted imaging improves the accuracy of detecting intermediate or high risk prostate cancers, but not for low risk prostate cancer detection.

Key Points
- Gleason scores influence diagnostic performance of MRI for prostate cancer detection.
- Addition of DWI does not improve low risk prostate cancer detection.
- Combined T2WI and DWI may help select intermediate or high risk patients.

Keywords Prostate neoplasms · Magnetic resonance imaging · Diffusion-weighted magnetic resonance imaging · Gleason score · ROC curve
in this study, ADC correlated with cell density, glandular area and tumour volume, but not with Gleason grade
contamination from adjacent voxels. The nominal voxel size before apodization with the Hanning function was either $5 \times 5 \times 5 \text{ mm}$ or $6 \times 6 \times 6 \text{ mm}$; after apodization, voxel size was best approximated by a sphere with a volume of 0.37 or 0.64 mL, respectively (31).
MR Spectroscopic Imaging and Diffusion-Weighted Imaging of Prostate Cancer With Gleason Scores

Rajakumar Nagarajan, PhD,1 Daniel Margolis, MD,1 Steven Raman, MD,1 Manoj K. Sarma, PhD,1 Ke Sheng, PhD,2 Christopher R. King, MD, PhD,2 Gaurav Verma, PhD,1 James Sayre, PhD,1 Robert E. Reiter, MD,3 and M. Albert Thomas, PhD1*

Purpose: To investigate functional changes in prostate cancer patients with three pathologically proven different Gleason scores (GS) (3+3, 3+4, and 4+3) using magnetic resonance spectroscopic imaging (MRSI) and diffusion-weighted imaging (DWI).

Key Words: MR spectroscopy; prostate cancer; diffusion weighted imaging; apparent diffusion coefficient; Gleason scores


Figure 1. Box-and-whisker plot shows the MR spectroscopic ratios of three Gleason scores (GS 3+3, GS 3+4, and GS 4+3).

Figure 2. Box-and-whisker plot shows the ADC map of three Gleason scores (GS 3+3, GS 3+4, and GS 4+3).
Spectroscopy

Diffusion

T2 signal

peripheral zone

transition zone

Kobus et al Radiology 2012

Wang et al Radiology 2008
terms in the square root are proportional to the time of the acquisition
effect on time
voxel volume
field strength

but actually TSE: 1.8x SNR at 3T vs 1.5T
and gradient echo: 1.6x SNR at 3T vs 1.5T

\[ SNR_{SE} \propto B_0 V \sqrt{N_{PE} N_{PA} N_{AV} \left(1 - e^{-TR/T1}\right)e^{-TE/T2}} \]
all sequences (including diffusion) are better at 3T
Diffusion-Weighted Imaging of the Prostate: Comparison of b1000 and b2000 Image Sets for Index Lesion Detection

Andrew B. Rosenkrantz, MD, 1, * Nicole Hindman, MD, 1 Ruth P. Lim, MD, 1 Kasturi Das, MD, 2 James S. Babb, PhD, 1 Thais C. Mussi, MD, 1 and Samir S. Taneja, MD 3

Purpose: To compare tumor detection on acquired diffusion-weighted (DW) images and apparent diffusion coefficient (ADC) maps, obtained using b-values of 1000 s/mm² and 2000 s/mm², using radical prostatectomy as the reference.

Materials and Methods: In all, 29 prostate cancer patients who underwent 3T magnetic resonance imaging (MRI) including DW imaging using b-values of 1000 s/mm² and 2000 s/mm² were included. Two radiologists independently evaluated four image sets during different sessions and recorded the location and diameter of the dominant lesion: DW images acquired using b-values of 1000 s/mm² and 2000 s/mm² and ADC maps calculated using maximal b-values of 1000 s/mm² and 2000 s/mm². Findings were correlated with the location and diameter of the dominant lesion at prostatectomy. Tumor-to-PZ contrast was also calculated, unblinded to pathology.

Results: Both readers achieved significantly higher sensitivity for DW images obtained using a b-value of 2000 s/mm² than 1000 s/mm² (P < 0.001), although there was no difference in sensitivity between ADC maps calculated using the two b-values (P ≥ 0.309). Tumor-to-PZ contrast was higher for DW images using a b-value of 2000 s/mm² (P = 0.067), although it was not different between the two corresponding ADC maps (P = 0.544). For both readers, correlations with tumor diameters were higher for either ADC map (r = 0.59–0.73) than for either acquired DW image set (r = 0.03–0.57).

Conclusion: Use of a b-value of 2000 s/mm² compared with a b-value of 1000 s/mm² resulted in improved tumor sensitivity and higher tumor-to-PZ contrast on the acquired DW images, although performance of the ADC maps corresponding with the two b-values was similar. Correlation with tumor size was greater for either ADC map than for either acquired DW image set.

Key Words: prostate cancer; MRI; diffusion-weighted imaging; prostatectomy
J. Magn. Reson. Imaging 2013;000:000–000.
© 2013 Wiley Periodicals, Inc.
Diffusion-Weighted Imaging of the Prostate: Comparison of b1000 and b2000 Image Sets for Index Lesion Detection

Figure 1. A 63-year-old man with 8 mm Gleason 3–4 index tumor in lateral left midgland peripheral zone at prostatectomy. a: DWI with b-value of 1000 s/mm² shows mild increased signal throughout peripheral zone bilaterally (dashed arrows) that obscures region of tumor in left peripheral zone. b: On DWI with b-value of 2000 s/mm², there is now greater suppression of benign peripheral zone on right, and tumor on left is more apparent (solid arrow). ADC maps obtained with b-values of 1000 s/mm² (c) and 2000 s/mm² (d) both show tumor as circumscribed focus of decreased ADC (solid arrow, both images).
the effects of biopsy in one patient...
diffusion is fairly immune
T2 & contrast changes often outlived visible hemorrhage contrast was worst affected, then T2, with diffusion relatively immune some changes were worse at 8 weeks than 4 even at 20 weeks, the post biopsy scan is not as good as the pre
but remember

Diffusion often does not detect low grade tumours

It is of lower resolution than other techniques

It is prone to artefact from metal & air...

... but not so much from hemorrhage