**INTRODUCTION**

Tumour localization using magnetic resonance imaging (MRI) is increasingly important for the management of prostate cancer. Pelvic imaging using T1- and T2-weighted MRI has conventionally been used to locally stage prostate cancer following histological confirmation by transrectal ultrasound (TRUS)-guided biopsy.

However, biopsy itself can hamper localization of tumour on anatomical MRI. For example, prostate cancer within the peripheral zone (PZ) is typically of low T2-weighted signal intensity compared with surrounding normal tissue. Consequently, reduction of T2-weighted signal intensity from normal tissue observed after biopsy can mask significant cancer or cause overestimation of disease extent.²

Previous work suggests that TRUS biopsy-induced anatomical MRI signal changes can persist for up to 8 weeks³ and that resolution is unpredictable.¹,⁴ A strategy of delaying MRI following biopsy has therefore evolved, with recommendations, based on available evidence, postponing staging MRI until at least 3 weeks⁴ and up to 8 weeks after biopsy.³

More recently, MRI has emerged as a tool to detect prostate cancer in patients with elevated risk. State-of-the-art multi-parametric MRI (mp-MRI; T2-weighted, diffusion and dynamic contrast-enhanced imaging) performed before biopsy enables biopsy to be targeted, which may be more effective to diagnose clinically significant disease.⁵-⁷ Indeed, the recent update of National Institute for Health and Care Excellence guidelines on prostate cancer management recommend that mp-MRI is used for patients with negative 10–12 cores TRUS biopsy (http://www.nice.org.uk/guidance/cg175/chapter/recommendations). Understanding the extent and duration of mp-MRI changes precipitated by biopsy is central to minimizing their misinterpretation and to identify the most appropriate delay between biopsy and subsequent mp-MRI. However, work assessing the evolution of imaging features following biopsy is limited and, where present, such work has focused on qualitative assessment and compared pre-biopsy mp-MRI with a single, but variable interval post-biopsy mp-MRI. The natural history of mp-MRI signal change following biopsy has not been addressed.¹,⁴

This study systematically and quantitatively describes mp-MRI signal evolution over a period of 6 months following TRUS-guided biopsy.

**BACKGROUND:** To determine the evolution of prostatic multi-parametric magnetic resonance imaging (mp-MRI) signal following transrectal ultrasound (TRUS)-guided biopsy.

**METHODS:** Local ethical permission and informed written consent was obtained from all the participants (n = 14, aged 43–69, mean 64 years). Patients with a clinical suspicion of prostate cancer (PSA range 2.2–11.7, mean 6.2) and a negative (PIRADS 1–2/5) pre-biopsy mp-MRI (pre-contrast T1, T2, diffusion-weighted and dynamic contrast-enhanced MRI) who underwent 10-core TRUS-guided biopsy were recruited for additional mp-MRI examinations performed at 1, 2 and 6 months post biopsy. We quantified mp-MRI peripheral zone (PZ) and transition zone (TZ) normalized T2 signal intensity (nT2-SI); T1 relaxation time (T1); diffusion-weighted MRI, apparent diffusion coefficient (ADC); dynamic contrast-enhanced MRI, maximum enhancement (ME); slope of enhancement (SoE) and area-under-the-contrast-enhancement-curve at 120 s (AUC120). Significant changes in mp-MRI parameters were identified by analysis of variance with Dunnett’s post testing.

**RESULTS:** Diffuse signal changes were observed post-biopsy throughout the PZ. No significant signal change occurred following biopsy within the TZ. Left and right PZ mean nT2-SI (left PZ: 5.73, 5.16, 4.90 and 5.12; right PZ: 5.80, 5.10, 4.84 and 5.05 at pre-biopsy, 1, 2 and 6 months post biopsy, respectively) and mean T10 (left PZ: 1.02, 0.67, 0.78, 0.85; right PZ: 1.29, 0.64, 0.78, 0.87 at pre-biopsy, 1, 2 and 6 months post biopsy, respectively) were reduced significantly (P < 0.05) from pre-biopsy values for up to 6 months post biopsy. Significant changes (P < 0.05) of PZ-ME and AUC120 were observed at 1 month but resolved by 2 months post biopsy. PZ ADC did not change significantly following biopsy (P = 0.23–1.0). There was no significant change of any TZ mp-MRI parameter at any time point following biopsy (P = 0.1–1.0).

**CONCLUSIONS:** Significant PZ (but not TZ) T2 signal changes persist up to 6 months post biopsy, whereas PZ and TZ ADC is not significantly altered as early as 1 month post biopsy. Caution must be exercised when interpreting T1- and T2-weighted imaging early post biopsy, whereas ADC images are more likely to maintain clinical efficacy.

*Prostate Cancer and Prostatic Diseases (2015) 18, 343–351; doi:10.1038/pcan.2015.33; published online 21 July 2015*
MATERIALS AND METHODS

Permission was obtained from the institutional ethics committee and informed written consent was obtained from all the participants (REC number: 08/H0714/21).

Patient recruitment

Fourteen patients (aged 43–69, mean 64 years) with (i) an elevated PSA (range 2.2–11.7, mean 6.2) and (ii) a negative pre-biopsy prostate mp-MRI report (PI-RADS score of equal or less than 2/5)9 were recruited prospectively. Prostate volume calculated from pre-biopsy T2-weighted images ranged from 17 to 80 cm3 (mean 52.7 cm3). All the patients underwent a standard ultrasound-guided 10-core TRUS biopsy procedure. 9

Inversion recovery echo planar imaging at b0, 150, 500 and 1000 s mm−2 thick diffusion-weighted imaging was performed using short tau inversion recovery echo planar imaging (Dotarem, Guerbet, Villepinte, France) followed by a 10 ml saline flush was injected intravenously at 3 ml s−1 at the start of the sixth measure. Full sequence parameters are provided in Table 1.

Image analysis

Image analysis was performed using Jim software (Jim, Xnapse Systems, Version 6, Leicester, UK) by two observers in consensus, with 10 and 3 years experience of interpretation of prostate MRI, respectively. Pre-contrast multiple flip angle T1-weighted, axial T2-weighted; ADC maps and DCE images were evaluated for each patient at each time point.

To assess cohort level changes, the mean value from whole left and right peripheral zone, and whole left and right transition zone (TZ) on each axial slice depicting the prostate at each time point.

Furthermore, a single region of interest was placed centrally within the right obturator internus muscle on T2-weighted images of each patient to

Table 1. MRI sequence parameters

| T2 TSE | T1 GRE (T10 quantification) | EPI-DWI | T1 GRE (DCE quantification) |
|-------|-----------------------------|---------|-----------------------------|
| TE/TR (ms) | 92/5170 | 2.5/5.61 | 96/2100 | 2.5/5.61 |
| Slice thickness (mm) | 3 | 3 | 3 | 3 |
| Spacing between slices (mm) | 3.3 | NA | 5 | NA |
| Number of averages | 2 | 1 | 16 | 1 |
| Matrix | 256 × 256 | 192 × 192 | 172 × 172 | 192 × 192 |
| Echo train length | 17 | 1 | 1 | 1 |
| Flip angle (degree) | 180 | 5, 10, 20, 25 | 90 | 15 |
| Field of view (mm) | 180 | 258 | 340 | 258 |

Abbreviations: DCE, dynamic contrast enhancement; DWI, diffusion-weighted imaging; EPI, echo planar imaging; GRE, gradient echo; MRI, magnetic resonance imaging; NA, not available; TE, echo time; TR, repetition time; TSE, turbo spin echo.

Table 2. Cohort-based change of quantitative MRI parameters

| Side | Scan | Mean nT2-SI (s.d.) | Mean T10 (s.d.) | Mean ADC (s.d.) | Mean ME (s.d.) | Mean SoE (s.d.) | Mean AUC120 (s.d.) |
|------|------|-------------------|----------------|----------------|---------------|---------------|------------------|
| Peripheral zone | Left | Pre-biopsy | 5.73 (1.15) | 1.02 (0.19) | 1.29 (0.13) | 0.93 (0.27) | 1.28 (0.49) | 1.93 (0.53) |
| | | 1-month | 5.16 (1.03) | 0.67 (0.26) | 1.30 (0.13) | 0.72 (0.32) | 0.91 (0.41) | 1.51 (0.63) |
| | | 2-month | 4.90 (1.00) | 0.78 (0.18) | 1.27 (0.11) | 0.98 (0.21) | 1.14 (0.55) | 1.99 (0.42) |
| | | 6-month | 5.12 (1.35) | 0.85 (0.15) | 1.28 (0.11) | 1.00 (0.24) | 1.28 (0.75) | 2.08 (0.50) |
| Right | Pre-biopsy | 5.8 (1.09) | 1.04 (0.22) | 1.29 (0.14) | 1.01 (0.31) | 0.96 (0.46) | 1.57 (0.39) |
| | | 1-month | 5.10 (1.18) | 0.64 (0.26) | 1.29 (0.14) | 0.76 (0.33) | 1.37 (0.66) | 2.07 (0.90) |
| | | 2-month | 4.84 (1.17) | 0.78 (0.09) | 1.25 (0.18) | 0.93 (0.18) | 1.09 (0.62) | 1.87 (0.44) |
| | | 6-month | 5.05 (1.14) | 0.87 (0.15) | 1.29 (0.13) | 0.99 (0.27) | 1.26 (0.44) | 1.86 (0.57) |
| Transition zone | Left | Pre-biopsy | 3.61 (0.57) | 0.85 (0.14) | 0.89 (0.14) | 1.41 (0.32) | 1.16 (0.68) | 2.12 (0.57) |
| | | 1-month | 3.39 (0.73) | 0.84 (0.15) | 0.92 (0.14) | 1.33 (0.31) | 1.58 (1.08) | 3.39 (1.31) |
| | | 2-month | 3.19 (0.63) | 0.82 (0.08) | 0.91 (0.14) | 1.47 (0.23) | 1.62 (1.41) | 3.09 (1.32) |
| | | 6-month | 3.31 (0.73) | 0.83 (0.08) | 0.94 (0.15) | 1.44 (0.20) | 1.71 (0.82) | 2.68 (0.55) |
| Right | Pre-biopsy | 3.44 (0.58) | 0.87 (0.11) | 0.87 (0.15) | 1.37 (0.33) | 1.32 (0.65) | 2.50 (0.83) |
| | | 1-month | 3.34 (0.64) | 0.88 (0.09) | 0.97 (0.17) | 1.37 (0.20) | 1.29 (0.65) | 2.52 (0.52) |
| | | 2-month | 3.24 (0.61) | 0.87 (0.08) | 0.88 (0.17) | 1.47 (0.17) | 1.85 (0.86) | 2.78 (0.44) |
| | | 6-month | 3.30 (0.56) | 0.84 (0.08) | 0.91 (0.15) | 1.45 (0.24) | 1.34 (0.88) | 2.68 (0.58) |

Abbreviations: ADC, apparent diffusion coefficient; AUC120, area under contrast-enhancement time curve up to 120 s; ME, maximum enhancement of contrast-enhancement time curve; MRI, magnetic resonance imaging; nT2-SI, normalized T2-weighted signal intensity; SoE, slope of enhancement of contrast-enhancement time curve; T10, T1 relaxation time. *Significant change (P < 0.05) compared with pre-biopsy value.
act as a reference for normalization of T2-weighted signal. Normalized T2-weighted signal intensities (nT2-SI) were calculated by deriving a ratio of prostate zone: obturator internus signal.

Curve fitting of signal intensity measurements at multiple flip angles was used to derive $T_1$ relaxation time ($T_{10}$). For dynamic contrast-enhanced images, a single signal intensity time curve was derived from the mean of all voxels within each zone. Initial slope of enhancement (SoE) and maximum enhancement (ME) was extracted as previously reported. In addition, the area under the contrast-enhancement time curve from arrival of contrast within the prostate to 120 s ($AUC_{120}$) was determined.

**Statistical analysis**

A repeated measures analysis of variance followed by Dunnett’s multiple comparison post testing; and a ordinary one-way analysis of variance followed by Dunnett’s multiple comparison post testing was used to identify significant differences between mean mp-MRI parameters for each post-biopsy time point compared with pre-biopsy baseline values on a cohort level and per-patient level, respectively.

**RESULTS**

All the patients attended each of the four mp-MRI scanning sessions. All pre-biopsy mp-MRI studies were prospectively reported negative for significant cancer (PI-RADS 1–2/5). In addition, even with biopsy results available, in retrospect, no tumour was localized on pre-biopsy MRI studies. There was no significant biopsy complication. Five patients were diagnosed with 1 core of 1mm Gleason 3+3 tumour and one patient had 1 core of 3mm of Gleason 3+4. All cores from the remaining patients were benign. No treatment was administered to biopsy-positive patients during the follow-up period. Mean values for all quantitative parameters pre- and post-biopsy time points are given in Table 2.

In all the patients, diffuse signal changes were evident throughout the PZ following biopsy, whereas no perceptible change was evident within the TZ.

![Figure 1](image1.png)

**Figure 1.** Representative axial T2-weighted images at the mid-gland demonstrate (a) normal peripheral zone T2 signal intensity pre-biopsy; and reduction (white arrows) in the peripheral zone T2 signal intensity at (b) 1 month, (c) 2 months and (d) 6 months post biopsy.

![Figure 2](image2.png)

**Figure 2.** Temporal change of mean (error bars ± s.d.) normalized T2 signal intensity (nT2 SI) in the (a) left peripheral zone (PZ; red line), (b) right peripheral zone (green line), (c) left transition zone (TZ; orange line) and (d) right transition zone (black line). Significant changes are indicated in Table 2.
Normalized T2-weighted signal intensity

A typical example of T2 signal evolution is shown in Figure 1. Two patients were excluded from the analysis of nT2-SI change because baseline T2-weighted MRI imaging parameters violated the required trial protocol defined in Table 1. Temporal change of mean pre-biopsy nT2-SI (n = 12) for left and right peripheral and transition zone is illustrated in Figure 2. For both left and right peripheral zones, nT2-SI was reduced significantly compared with pre-biopsy values at 1, 2 and 6 months (left PZ mean nT2-SI; 5.73, 5.16, 4.90 and 5.12 at pre-biopsy, 1, 2 and 6 months post-biopsy, respectively, P < 0.05; right PZ mean nT2-SI; 5.80, 5.10, 4.84 and 5.05 at pre-biopsy, 1, 2 and 6 months post-biopsy, respectively, P < 0.05). There was no significant difference between transition zone nT2-SI between baseline and any post-biopsy time point (P = 0.10 to 0.82; Table 2). Patient level PZ and TZ nT2-SI change following TRUS biopsy are presented in Table 3 (a) and (b), Table 3.

### Post-biopsy patient level nT2-SI, ADC and T₁₀ signal change

#### (a) Peripheral zone

| Mean nT2-SI | Mean ADC | Mean T₁₀ |
|-------------|----------|----------|
| Baseline vs. 1 month post-biopsy | Baseline vs. 2 month post-biopsy | Baseline vs. 6 month post-biopsy | Baseline vs. 1 month post-biopsy | Baseline vs. 2 month post-biopsy | Baseline vs. 6 month post-biopsy | Baseline vs. 1 month post-biopsy | Baseline vs. 2 month post-biopsy | Baseline vs. 6 month post-biopsy |
| 1            |          |          |          |          |          |          |          |          |
| 2            |          |          |          |          |          |          |          |          |
| 3            |          |          |          |          |          |          |          |          |
| 4            |          |          |          |          |          |          |          |          |
| 5            |          |          |          |          |          |          |          |          |
| 6            |          |          |          |          |          |          |          |          |
| 7            |          |          |          |          |          |          |          |          |
| 8            |          |          |          |          |          |          |          |          |
| 9            |          |          |          |          |          |          |          |          |
| 10           |          |          |          |          |          |          |          |          |
| 11           |          |          |          |          |          |          |          |          |
| 12           |          |          |          |          |          |          |          |          |
| 13           |          |          |          |          |          |          |          |          |
| 14           |          |          |          |          |          |          |          |          |

#### (b) Transition zone

| Mean nT2-SI | Mean ADC | Mean T₁₀ |
|-------------|----------|----------|
| Baseline vs. 1 month post-biopsy | Baseline vs. 2 month post-biopsy | Baseline vs. 6 month post-biopsy | Baseline vs. 1 month post-biopsy | Baseline vs. 2 month post-biopsy | Baseline vs. 6 month post-biopsy | Baseline vs. 1 month post-biopsy | Baseline vs. 2 month post-biopsy | Baseline vs. 6 month post-biopsy |
| 1            |          |          |          |          |          |          |          |          |
| 2            |          |          |          |          |          |          |          |          |
| 3            |          |          |          |          |          |          |          |          |
| 4            |          |          |          |          |          |          |          |          |
| 5            |          |          |          |          |          |          |          |          |
| 6            |          |          |          |          |          |          |          |          |
| 7            |          |          |          |          |          |          |          |          |
| 8            |          |          |          |          |          |          |          |          |
| 9            |          |          |          |          |          |          |          |          |
| 10           |          |          |          |          |          |          |          |          |
| 11           |          |          |          |          |          |          |          |          |
| 12           |          |          |          |          |          |          |          |          |
| 13           |          |          |          |          |          |          |          |          |
| 14           |          |          |          |          |          |          |          |          |

Abbreviations: ADC, apparent diffusion coefficient; nT2-SI, normalized T2-weighted signal intensity; T₁₀, T₁ relaxation time. Significant change, compared with baseline, following ordinary one-way analysis of variance and Dunnett’s multiple comparison test, is illustrated by grey boxes. White boxes represent non-significant signal change. Black boxes represent non-evaluable data.
respectively. Significant change from baseline of nT2-SI was evident in the PZ in 12/12 patients, and in the TZ in 9/12 patients at one or more post-biopsy time points.

Diffusion-weighted imaging—apparent diffusion coefficient
An example of temporal ADC and source b-value diffusion-weighted images changes are illustrated in Figures 3 and 4, respectively. Mean pre-biopsy ADC ($n = 14$) for left and right peripheral and transition zone is shown in Table 2 and Figure 5. There was no significant difference in baseline ADC for any zone when compared with post-biopsy time points ($P = 0.23$ to 1.0). Patient level PZ and TZ ADC change following TRUS biopsy are presented in Table 3 (a) and (b), respectively. Significant change from baseline of ADC was evident in the PZ in 7/14 patients, and in the TZ in 7/14 patients at one or more post-biopsy time points.

Pre-contrast T1-weighted MRI
Evolution of T1 signal is illustrated in Figure 6. Mean pre-biopsy T$_{10}$ ($n = 14$) for left and right peripheral and transition zone is depicted in Table 2. T$_{10}$ was significantly lower at 1 month, 2 months and 6 months for the left peripheral zone (mean T$_{10}$: 1.02, 0.67, 0.78, 0.85 at pre-biopsy, 1, 2 and 6 months post biopsy, respectively, $P < 0.05$; Figure 7) and at 1 month and 2 months for the right peripheral zone (mean T$_{10}$: 1.29, 0.64, 0.78, 0.87 at pre-biopsy, 1, 2 and 6 months post biopsy, respectively, $P < 0.05$; Figure 7). There was no significant difference between pre-biopsy T$_{10}$ and 1 month, 2 months and 6 months T$_{10}$ within left and right transition zones ($P = 0.76$ to 1.0; Figure 7). Patient level PZ and TZ T$_{10}$ change following TRUS biopsy are presented in Table 3 (a) and (b), respectively. Significant change from the baseline of T$_{10}$ was evident in the PZ in 12/14 patients and in the TZ in 4/14 patients at one or more post-biopsy time points.

Dynamic contrast-enhanced imaging
There was no consistency between changes on both sides of the gland for DCE MRI parameters. Mean ME ($n = 14$) at 1 month post biopsy was significantly lower within the right peripheral zone (right PZ mean ME: 1.01 and 0.76 at pre-biopsy and 1 month post biopsy, respectively, $P < 0.05$); and mean AUC$_{120}$ ($n = 14$) was significantly higher at 1 month post biopsy ($P < 0.05$) within the left transition zone compared with pre-biopsy values (left TZ mean AUC$_{120}$: 2.12 and 3.39 at pre-biopsy and 1 month post biopsy, respectively). There was no other significant difference for ME, SoE and AUC$_{120}$ between pre-biopsy and post-biopsy time points ($P = 0.06$ to 1.0).

DISCUSSION
Our study documents the natural history of biopsy-induced mp-MRI signal changes and their effect on derived quantitative mp-MRI parameters. We observed significant changes in nT2-SI and T$_{10}$ following biopsy persisting up to 6 months following biopsy. We found no significant change for ADC when pre-biopsy values were compared with any post-biopsy time point. For dynamic contrast-enhanced MRI-derived parameters, we found significant but inconsistent changes.

Our work confirms that, as observed in the works of others, peripheral zone T2-weighted signal intensity is reduced significantly 1 month following TRUS biopsy.$^{11}$ Moreover, we found that a small (mean 12%) but significant reduction in T2 signal persists

![Figure 3.](image-url) Representative axial apparent diffusion coefficient (ADC) maps at the mid-gland level from a patient within the cohort demonstrate (a) normal peripheral zone ADC pre-biopsy; and stable ADC at (b) 1 month, (c) 2 months and (d) 6 months post biopsy.
even at 6 months afterwards. Furthermore, we confirmed that nT2-SI within the transition zone does not change significantly following TRUS biopsy. One possible explanation is that the absence of significant change within the transition zone likely reflects undersampling of the anterior gland by the biopsy procedure. Previous work illustrates that the T2 signal of PZ tumour is on average reduced by 25% compared with normal PZ and TZ. We demonstrated maximum average change of 15–17% in T2 signal of normal PZ at 2 months post biopsy and 11–13% at 6 months post biopsy. It is possible that persistent changes of T2 signal intensity even after 6 months could potentially hinder MRI diagnostic performance, especially for low-grade and/or diffuse tumour.

Although studies have described changes in T1 signal intensity within the prostate following biopsy, quantitative changes in T1 relaxation time have not been described previously. We found that T1 decreased significantly after biopsy, consistent with the increase in T1 signal intensity reported previously and ascribed to post-biopsy haemorrhage. In keeping with the evolution of T2 signal changes, T1 signal changes also start to normalize by 6 months post biopsy and remain significantly different compared with pre-biopsy values.

We observed that ADC was not significantly different from pre-biopsy values at 1, 2 and 6 months post biopsy. Rosenkrantz et al. previously compared ADC of normal benign, haemorrhagic peripheral zone and peripheral zone prostate cancer, and found that ADC was reduced in the areas of haemorrhage. They did not report the temporal evolution of ADC change, and patients recruited were imaged at a wide range of intervals following biopsy but grouped for analysis (range 10 to 241 days, mean 63 days). In contrast, our biopsy cohort mp-MRI scans were acquired at pre-specified time points and did not demonstrate any significant change following biopsy at our earliest interval of 1 month. However, we acknowledge that ADC changes have been associated with haemorrhage in neuroimaging, with hyperacute, acute and early subacute stages causing reduced ADC, which then
normalize at subacute and chronic stages. It is possible that Rosenkrantz et al. included post-biopsy patients with acute haemorrhage, while our earliest post-biopsy imaging mp-MRI corresponds to the subacute/chronic stage. Combined with our study, results suggest that ADC change does occur but normalizes in 1 month.

It is difficult to draw firm conclusions from our DCE results. We hypothesized that TRUS biopsy should affect both sides of the

**Figure 5.** Temporal changes of mean apparent diffusion coefficient (ADC; error bars ± s.d.) in the (a) left peripheral zone (PZ; red line), (b) right peripheral zone (green line), (c) left transition zone (TZ; orange line) and (d) right transition zone (black line). No significant changes were observed in any zone (Table 2).

**Figure 6.** Representative axial T1-weighted images at the mid-gland level demonstrate (a) normal peripheral zone T1 signal intensity pre-biopsy; and increase (white arrows) in the peripheral zone T1 signal intensity at (b) 1 month, (c) 2 months and (d) 6 months post biopsy.

**Figure 7.** Temporal changes of mean T1 relaxation rate ($T_{10}$; error bars ± s.d.) in the (a) left peripheral zone (PZ; red line), (b) right peripheral zone (green line), (c) left transition zone (TZ; orange line) and (d) right transition zone (black line). Significant changes are indicated in Table 2.
Prostate biopsy-associated MRI changes
A Latifoltojar et al

Prostate Cancer and Prostatic Diseases (2015), 343 – 351

© 2015 Macmillan Publishers Limited

CONFLICT OF INTEREST
The authors declare no conflict of interest.

ACKNOWLEDGEMENTS
This work was undertaken at UCLH/ UCL, which received a proportion of the funding from the NIHR Biomedical Research Centres funding scheme of the UK Department of Health. AL was supported by the KCL/UCL Comprehensive Cancer Imaging Centre. The study was funded by the Radiological Research Trust.

REFERENCES
1 Tamada T, Sone T, Jo Y, Yamamoto T, Egashira N, Imai S et al. Prostate cancer: relationships between postbiopsy hemorrhage and tumor detectability at MR diagnosis. Radiology 2008; 248: 531–539.
2 Kaji Y, Kurhanewicz J, Hricak H, Sokolov DL, Huang LR, Nelson SJ et al. Localizing prostate cancer in the presence of postbiopsy changes on MR images: role of proton MR spectroscopic imaging. Radiology 1998; 206: 785–790.
3 Qayyum A, Coakley FV, Lu Y, Okpin JD, Wu L, Yeh BM et al. Organ-confined prostate cancer: effect of prior transrectal biopsy on endorectal MRI and MR spectroscopic imaging. AJR Am J Roentgenol 2004; 187: 1079–1083.
4 Ikonen S, Kivisaari L, Vehmas T, Tervahartiala P, Salo JO, Taari K et al. Optimal timing of post-biopsy MR imaging of the prostate. Acta Radiol 2001; 42: 70–73.
5 Haffner J, Lemaître L, Puech P, Haber GP, Leroy X, Jones JS et al. Role of magnetic resonance imaging before initial biopsy: comparison of magnetic resonance imaging-targeted and systematic biopsy for significant prostate cancer detection. BJU Int 2011; 108: E171–E178.
6 Roetkhe M, Anastasidis AG, Lichy M, Werner M, Wagner P, Knuck S et al. MRI-guided prostate biopsy detects clinically significant cancer: analysis of a cohort of 100 patients after previous negative TRUS biopsy. World J Urol 2012; 30: 213–218.
7 Moore C M, Kasivisvanathan K, Eggener S, Emberton M, Futterje J, Gill IS et al. Standards of reporting for MRI-targeted biopsy studies (START) of the prostate: recommendations from an International Working Group. Eur Urol 2013; 64: 477–494.
8 Westphalen AC, Rosenkranz AB. Prostate imaging reporting and data system (PI-RADS): reflections on early experience with a standardized interpretation scheme for multiparametric prostate MRI. AJR Am J Roentgenol 2014; 202: 12.
9 Fink KG, Hutarew G, Pyltel A, Esterner B, Jungwirth A, Dietze O et al. One core prostate biopsy is superior to two sets of sextant prostate biopsies. BJU Int 2003; 92: 385–388.
10 Zelhof B, Lowry M, Rodrigues G, Kraus S, Turnbull L. Description of magnetic resonance imaging-derived enhancement variables in pathologically confirmed prostate cancer and normal peripheral zone regions. BJU Int 2009; 104: 621–627.
11 Rosenkranz AB, Kopeck M, Kong X, Melamed J, Dakwar G, Babb JS et al. Prostate cancer vs. post-biopsy hemorrhage: diagnosis with T2- and diffusion-weighted imaging. J Magn Reson Imaging 2010; 31: 1387–1394.
12 Chen ME, Troncoso P, Johnston DA, Tang K, Babiyan RJ. Optimization of prostate biopsy strategy using computer based analysis. J Urol 1997; 158: 2168–2175.
13 Dikaios N, Alkalbani J, Abd-Alazeez M, Singh Sidhu H, Kirkham A, Ahmed H U et al. Zone-specific logistic regression models improve classification of prostate cancer on multi-parametric MRI. Eur Radiol 2015; 25: 523–532.
14 Mirowitz SA, Brown JJ, Heiken JP. Evaluation of the prostate and prostatic carcinoma with gadolinium-enhanced endorectal coil MR imaging. Radiology 1993; 186: 153–157.
15 White S, Hricak H, Forstner R, Kurhanewicz J, Vigneron DB, Zaloudek CJ et al. Prostate cancer: effect of postbiopsy hemorrhage on interpretation of MR images. Radiology 1995; 195: 385–390.
16 Rosenkranz AB, Kong X, Niver BE, Berlman DS, Melamed J, Babb JS et al. Prostate cancer: comparison of tumor visibility on trace diffusion-weighted images and the apparent diffusion coefficient map. AJR Am J Roentgenol 2011; 196: 123–129.
17 Atlas SW, Dullois P, Singer MB, Lu D. Diffusion measurements in intracranial hematomas: implications for MR imaging of acute stroke. AJNR Am J Neuroradiol 2000; 21: 1190–1194.
18 Di Giovanni P, Azlan CA, Ahearn TS, Sempie SJ, Gilbert FJ, Redpath TW. The accuracy of pharmacokinetic parameter measurement in DCE-MRI of the breast at 3 T. Phys Med Biol 2010; 55: 121–132.
19 Lu TL, Meuli RA, Marques-Vidal PM, Bize P, Denys A, Schmidt S. Interobserver and intraobserver variability of the apparent diffusion coefficient in treated malignant hepatic lesions on a 3.0 T machine: measurements in the whole lesion versus in the area with the most restricted diffusion. J Magn Reson Imaging. 2010; 32: 647–653.
20 Laurence Klotz. Active surveillance with selective delayed intervention is the way to manage ‘good-risk’ prostate cancer. Nat Rev Urol 2005; 2: 136–142.
21 Klotz L, Zhang L, Lam A, Nam R, Mamedov A, Loblaw A. Clinical results of long-term follow-up of a large, active surveillance cohort with localized prostate cancer. J Clin Oncol 2010; 28: 126–131.

22 Zakian KL, Shukla-Dave A, Ackerstaff E, Hricak H, Koutcher JA. 1H magnetic resonance spectroscopy of prostate cancer: biomarkers for tumor characterization. Cancer Biomark 2008; 4: 263–276.

23 Shukla-Dave A, Hricak H, Kattan MW, Pucar D, Kuroiwa K, Chen HN et al. The utility of magnetic resonance imaging and spectroscopy for predicting insignificant prostate cancer: an initial analysis. BJU Int 2007; 99: 786–793.

24 Epstein JI, Chan DW, Sokoll LJ, Walsh PC, Cox JL, Rittenhouse H et al. Nonpalpable stage T1C prostate cancer: prediction of insignificant disease using free/total prostate specific antigen levels and needle biopsy findings. J Urol 1998; 160: 2407–2411.

This work is licensed under a Creative Commons Attribution 4.0 International License. The images or other third party material in this article are included in the article’s Creative Commons license, unless indicated otherwise in the credit line; if the material is not included under the Creative Commons license, users will need to obtain permission from the license holder to reproduce the material. To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/