A multicentre assessment of prostate MRI quality and compliance with UK and international standards☆

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AIM: To assess prostate magnetic resonance imaging (MRI) image quality and compliance with technical standards between centres in the South West region of the UK.

MATERIALS AND METHODS: Fifteen imaging sites in the region submitted seven consecutive anonymised MRI studies. These were assessed by two experienced radiologists in consensus. Overall, subjective image quality for T2-weighted imaging (T2W), diffusion weighted imaging (DWI), and dynamic contrast enhancement (DCE) was scored on a five-point Likert scale. Five additional quality parameters were also assessed visually, including image noise, motion, artefact, and distortion. The degree of compliance by each site with 21 published technical standards was also assessed.

RESULTS: Ninety-four MRI examinations were reviewed from across all sites (mean 6.3 scans per site, range 5—7). Mean compliance with technical standards was 63% (range 38—86%). Forty-seven percent of sites did not perform DCE. One site used a 3 T scanner. The percentage of patients with overall quality scores of ≥ 3 (diagnostically acceptable) were 68% for T2W, 81% for DWI, and 60% for both T2W and DWI. Ninety-three percent of the 45 patients who underwent DCE had diagnostically acceptable studies. By scanner age, the percentage of patients with diagnostically acceptable T2W scores was 53% for scanners ≥ 7 years and 80% when <7 years ($p=0.006$). Comparing individual sites, the mean overall quality scores were 2.9 (range 2.2—4.2) for T2W, 3.2 (1.8—4.7) for DWI, and 3.4 (2.5—4.7) for DCE.

CONCLUSION: There is wide variation in compliance with recognised technical standards and image quality across sites. If MRI is to replace biopsy in selected low-risk patients, improvements in image quality may be required.

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Introduction

Prostate cancer is the second leading cause of male cancer mortality worldwide, with incidence expected to double due to the ageing population.[1] Several recent prospective studies have highlighted the ability of pre-biopsy

magnetic resonance imaging (MRI) to both improve the yield of clinically significant cancer and reduce the over-diagnosis of indolent disease.[2–6]

The PROMIS and PRECISION trials were set up as multi-centre "real-world" studies performed predominantly using 1.5 T magnets, with reporters of varying experience, and suggested than biopsy could safely be avoided in 27–28% of men based on a negative MRI.[2,3] More recent studies have suggested that the biopsy avoidance rate could be as high 41–49% in the context of clinical risk stratification, opti-mising the quality of MRI protocols and with experienced radiologists reporting at high-throughput centres.[4,5]

Head-to-head cost analysis suggests an increase cost of multiparametric (mp)MRI-led pathways compared to the traditional transrectal ultrasound (TRUS)-guided systematic biopsy approach[7]; however, the avoidance of biopsy in a subset of patients will mitigate these excess costs. The pathway therefore relies on biopsy avoidance in a per-centage of low-risk patients with negative MRI results, thus necessitating optimal quality. Upfront MRI can also reduce diagnostic times by up to a third,[7] which may help avoid financial penalties in the UK system of timed cancer targets. Positive MRI calls offer the additional advantage of "getting it right first time" with subsequent targeted biopsies, potentially saving additional patient anxiety and healthcare costs. MRI pre-biopsy has therefore become an attractive concept, with up to 73% of trusts in England offering this as part of a prostate diagnostic service, despite this exceeding the recommendations of current national guidelines.[8,9]

It is noteworthy that even in the "real-world" PROMIS study, mpMRI from all sites underwent quality control checks and studies deemed of insufficient quality were repeated prior to biopsy. Furthermore, it has been sug-gested that the quality of MRI acquisition and reporting should be ensured and audited before pre-biopsy MRI initiation, particularly if used as a means of avoiding bi-opsy.[10] This clearly brings into focus the quality of the technique, particularly outside large academic centres and without access to latest-generation high-quality MRI sys-tems and with limited scanner time. The aim of this study was therefore to assess the technical quality of prostate MRI across multiple hospitals in the South West region of the UK and compliance with guideline recommendations.

Materials and methods

This audit was carried out through the Prostate Cancer Diagnostic Pathway Steering Group, a group consisting of three radiologists and two urologists, set up by the two South West Cancer Alliances (Peninsula and SWAG) to evaluate prostate diagnostic pathways in the region. The audit consisted of two parts, firstly an objective assessment of compliance with recognised technical standards and secondly, a subjective assessment of image quality.

The radiology departments of all 14 hospitals offering prostate services within two cancer alliance regions were contacted: Peninsula (representing Cornwall and Devon) and SWAG (representing Somerset, Wiltshire, Avon, and Gloucestershire). The 14 hospitals comprised three teaching hospitals, eight medium-sized community hospitals, and three smaller community hospitals. One hospital submitted two data sets (representative of their two scanning sites). Each department was asked to provide anonymised ver-sions of their first seven prostate MRI examinations (irre-spective of clinical indication or specific protocol) scanned consecutively from 1 July 2018. Departments were also asked to indicate scanner age.

MRI interpretation

The MRI images were reviewed by two experienced fellowship-trained radiologists (both having reported on >3,000 prostate MRI examinations), one with 10 years' experience in an academic centre, the other with 15 years reading experience in a district general hospital. Studies were read over 2 days with both readers blinded to clinical information, hospital site, and scanner make, model, and magnetic strength. MRI examinations were excluded from the audit in cases of prior prostatectomy, obvious radio-therapy changes, and/or hip replacement(s).

Technical standards

Twenty-one technical standards were determined, derived from two documents: Prostate Imaging-Reporting and Data System (PI-RADS) guidelines, version 2[11] and the UK consensus paper on prostate MRI[10]; where discordant, the standard from the latter more recent document was adopted. Compliance with standards was assessed for each site by either interrogation of DICOM data fields or by visual review of images (in the case of choice of image planes and for measurement of field of view).

Image quality

Image quality was assessed visually and in consensus by allocating a score for each parameter. Three sequences were evaluated: axial high-resolution T2-weighted (T2W), axial diffusion-weighted imaging (DWI), and axial dynamic contrast enhancement (DCE). For each sequence, overall subjective image quality was assessed using a five-point Likert scale (with 1= very poor; 3= just acceptable diag-nostically; 5 = very good). The following additional pa-rameters were assessed using a four-point Likert scale: T2W: noise (1=marked, 4=nil), motion artefact (1=very blurred, 4=sharp), and degree of rectal distension (on sagittal T2W sequence, 1= empty, 4=significantly dis-tended); DWI: distortion (1=significant warping, 4=none) and other artefact (1=marked, 4=nil; see electronic supplementary material). For DCE, the percentage of corrupt data points on a region of interest enhancement curve were recorded (corrupt points were defined as more than 10% difference in value between adjacent data-points, after the initial upstroke of the curve).[12,13]

Statistical analysis

Means are presented based on the Likert scales for the various quality measures, but the comparative analyses are based on dichotomising the scores as described elsewhere. Since data refer to patients within hospital sites, a multi-level model was used, with some variables (e.g., image quality, rectal distension) at the level of the patient, and others at the level of the site (e.g., age of scanner). Mixed-effects logistic regression models were fitted to assess the effect of variables of interest on the various quality measures, including site as a random effect. The results of these models are presented in the form of odds ratios with 95% confidence intervals and associated *p*-values. The effects of scanner age and rectal distension on DCE were not assessed statistically due to the limited number of patients who had this sequence.

Results

One hundred and five MRI examinations were received, 11 were excluded (seven due to prior hip replacement(s), one with obvious radiotherapy change, one prostatectomy, and two with incomplete datasets). Ninety-four MRI examinations were therefore included in the audit. The mean number of MRI examinations assessed per site was 6.3 (range 5—7).

Compliance with technical standards

Two sites had incomplete data. Mean compliance with the 21 standards across the 13 remaining sites was 63% (range 38—86%; Table 1). Seven of the 15 sites (47%) did not include DCE sequences, which significantly affected their overall compliance results, as seven of the standards related directly to DCE. Mean compliance with the 14 standards unrelated to DCE, for the 14 sites with complete data for these standards, was 73% (range 50—93%). Four of the 15 sites (27%) did not scan axial to the patient on T2W, instead scanning approximately axial to the prostatic urethra (Fig 1). Although not a listed standard, it was noted that only one of the 15 sites used a 3 T MRI system.

Image quality

A diagnostically acceptable score of ≥ 3 was seen in 64/94 examinations (68%) for T2W, 76/94 (81%) for DWI, and 42/45 (93%) for DCE. The number of patients with overall quality scores ≥ 3 for both T2W and DWI (diagnostic biparametric [bp]MRI study) was 56/94 (60%) and for T2W, DWI and DCE (diagnostic mpMRI study), 25/45 (56%). Examples of images with high and low overall quality scores are given in Figs 2—4.

The mean scores for all scans from each site were calculated for all nine parameters (Table 2). The mean overall quality score was 2.9 (range 2.2—4.2) for T2W, 3.2 (1.8—4.7) for DWI, and 3.4 (2.5—4.7) for DCE. The highest mean overall quality scores for all three sequences were achieved by one site. Mean overall quality scores per site are shown in Fig 5.

Effect of rectal distension

The effect of rectal distension on image quality was assessed, comparing two groups, less distended (scores

Table 1
Compliance with 21 technical standards across 15 sites (A-O).

Parameter	Standard	Hospital site															Compliance (%)
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
T2W axial plane axial to patient	Axial to patient	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	73
DWI axial to patient	Axial to patient	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	80
DCE axial to patient	Axial to patient	N	Y	N	N	Y	N	Y	Y	Y	Y	Y	N	N	N	N	47
Three planes small FOV T2W	Present	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	87
T2W axial section thickness	3 mm	Y	N	Y	N	Y	Y	Y	N	Y	Y	Y	N	N	Y	N	60
T2W axial section gap	No gap	N	N	N	Y	N	N	N	Y	N	Y	Y	Y	Y	Y	Y	53
T2W axial field of view	12—20 cm	Y	N	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	80
T2W axial in plane resolution	≤ 0.7 mm	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	87
DWI sequence included	Present	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
DWI section thickness	≤ 4 mm	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	87
DWI section gap	No gap	Y	N	N	Y	N	N	N	Y	N	N	N	N	Y	Y	Y	40
DWI field of view	16—22 cm	N	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	Y	Y	47
DWI in plane resolution	≤ 2 mm	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Lowest b-value/s/mm^2	≥ 50	Y	N	N	Y	Y	Y	Y	N	N	N	Y	Y	NA	N	Y	57
Highest b-value/s/mm^2	$\geq 1,400$ for 1.5 T, $\geq 2,000$ for 3 T	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	NA	Y	Y	79
DCE sequence included	Present	N	Y	Y	N	Y	N	Y	Y	Y	Y	Y	N	N	N	N	53
DCE section thickness	3 mm	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	7
DCE section gap	No gap	N	Y	Y	N	Y	N	Y	Y	Y	Y	Y	N	N	N	N	53
DCE in plane resolution size	≤ 2 mm	N	Y	Y	N	Y	N	Y	Y	Y	Y	Y	N	N	N	N	53
DCE temporal resolution	≤ 15 s	N	N	Y	N	N	N	Y	Y	Y	Y	NA	Y	N	N	N	36
DCE duration	≥ 2 min	N	Y	Y	N	N	N	Y	Y	Y	Y	NA	Y	N	N	N	43
% Compliance		43	57	67	57	62	48	81	81	86	NA	86	38	NA	62	52	

T2W, T2-weighted imaging; DWI, diffusion-weighted imaging; DCE, dynamic contrast enhancement; FOV, field of view; Y, compliant; N, not compliant; NA, data not available.
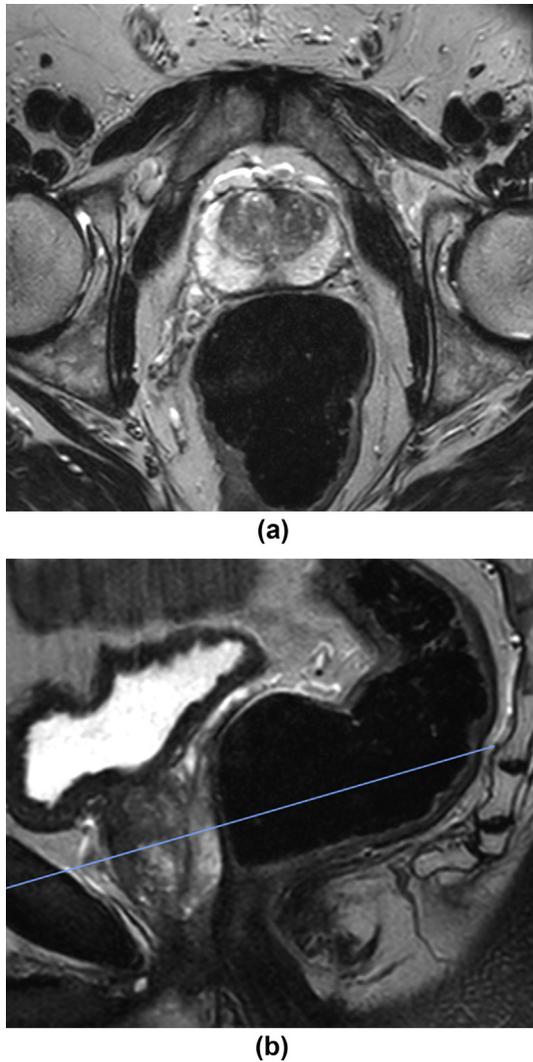
(a)

(b)

Figure 1 Example of non-compliance with technical standards. **(a)** axial T2W sequence is not aligned perpendicular to long axis of patient, as demonstrated on sagittal T2W sequence **(b)**.

1−2, 52 patients) and more distended (scores 3−4, 42 patients) and dichotomising image quality into diagnostic (image quality score ≥3) or non-diagnostic (image quality score ≤2). For T2W in the less distended group, 67% were diagnostic versus 69% in the more distended group; (odds ratio=1.1, range 0.4−2.8, $p = 0.8$). For DWI for the less distended group, 92% were diagnostic versus 67% in the more distended group (odds ratio=0.08, range 0.02−0.43, $p=0.003$).

Effect of scanner age

The influence of scanner age on image quality was assessed by comparing the two groups: MRI performed on scanners <7 years old (54 patients) and MRIs performed on scanners ≥7 years old (40 patients) and dichotomising image quality into diagnostic (image quality score ≥3) and non-diagnostic (score ≤2). For T2W, 80% were diagnostic in the newer scanner group, compared to 53% in the older scanner group (odds ratio 3.5, range 1.4−8.8, $p=0.006$). For DWI for


(a)

(b)
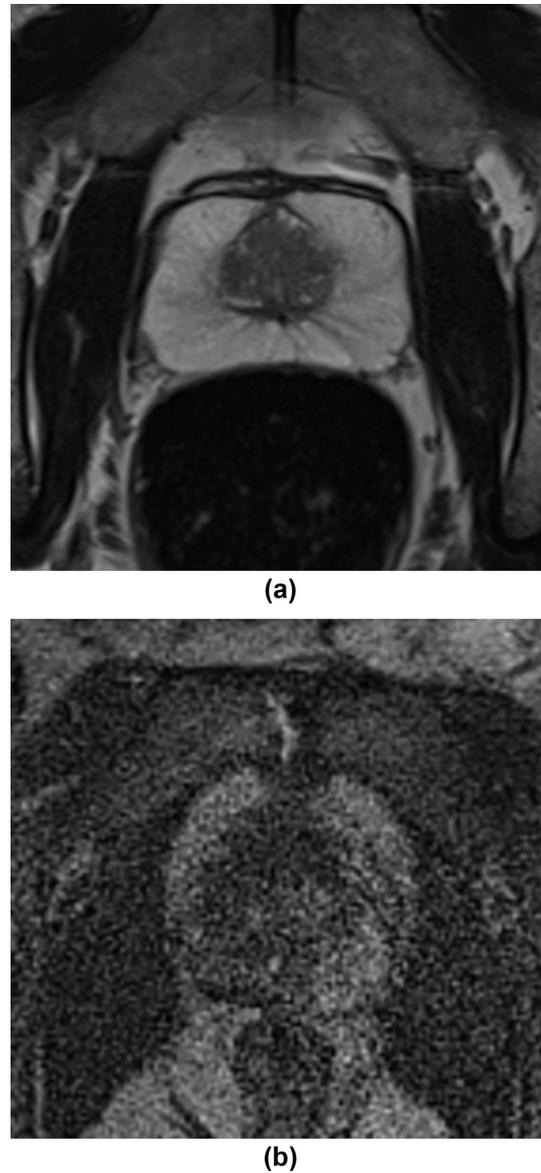
Figure 2 T2W image quality. **(a)** quality score 5 with low noise, no blurring, and good resolution and **(b)** quality score 1 with high noise level.

the newer scanner group, 81% were diagnostic and in the older scanner group, 80% were diagnostic (odds ratio=1.2, range 0.3−5.9, $p=0.8$). The relationship between scanner age for each site and mean T2W overall quality score is shown in Fig 6, demonstrating an inverse correlation.

Comparing mpMRI to bpMRI sites

Two further groups were compared—those who had DCE (mpMRI: 45 patients) and those who did not (bpMRI: 49 patients)—to determine if sites that administered contrast medium also had better overall quality scores for T2W and DWI. Again, image quality was dichotomised into diagnostic (image quality score ≥3) and non-diagnostic (score ≤2). For T2W in the DCE group, 64% were diagnostic and for the non-DCE group, 71% were diagnostic (odds ratio=0.73, range 0.27−1.94, $p=0.52$). For DWI in the DCE group, 76% were
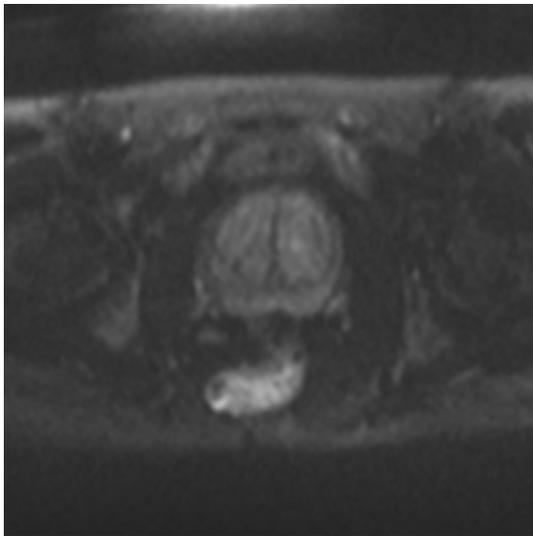
(a)
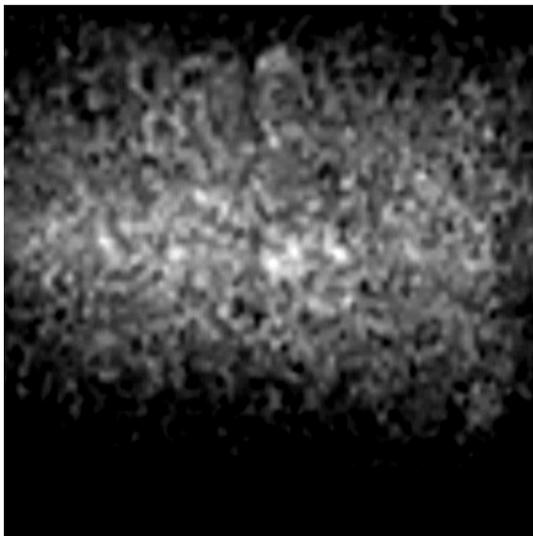

(b)

Figure 3 DWI image quality. (**a**) quality score 5 with reasonable resolution, low artefact and distortion and (**b**) quality score 1 with high noise level and no anatomical detail seen.

diagnostic, and for the non-DCE group, 86% were diagnostic (odds ratio=0.52, range 0.14–1.97, *p*=0.33).

Discussion

In our study, 40% of patients did not have diagnostic quality biparametric prostate MRI. To the authors' knowledge, this is the first published comprehensive audit of prostate MRI image quality. Although lesion detection and pathological outcomes were not assessed as part of the present study, it is likely that good image quality is equally, if not more, important for confidently excluding disease, as for detecting tumours. These findings may, therefore, have implications for the development of policies centred around biopsy avoidance in low-risk patients with a negative MRI.

There was wide inter-site variation in compliance with recognised standards (38–86%). It is noteworthy that only
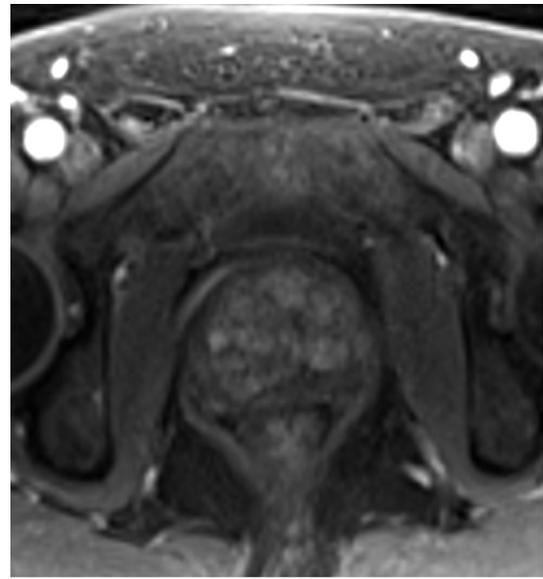
(a)
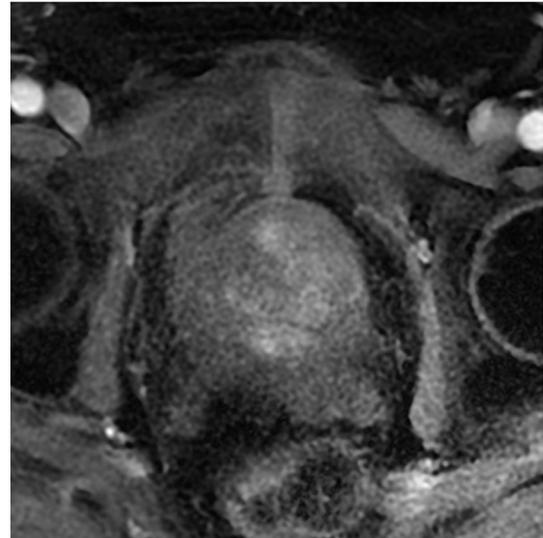
(b)

Figure 4 DCE image quality. (**a**) quality score 5 with low noise and good resolution and (**b**) quality score 1 with blurring artefact right side of gland.

53% of sites performed DCE, despite this being clearly recommended within both sets of assessed guidelines[10,11]; however, the guidelines do downplay the role of DCE and somewhat undermine its value with statements such as "the added value is modest"[11] and DCE should be used as a "safety net" or a "back-up sequence".[10] It may be that with limited resources, sites have made a cost–benefit judgement and decided against contrast medium administration. Nevertheless, in the present audit, DCE was the sequence with the highest overall quality score (93% of patients score ≥3) and therefore DCE might be a useful adjunct sequence for departments struggling with ageing scanners. It is also noteworthy that DCE use was not associated with higher T2W or DWI scores, suggesting its use is not simply a reflection of practice in high-quality

Table 2
Mean scores of scans for each site (A–O) for each parameter (range in parentheses).

| Parameter	Hospital Site														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
T2W overall quality score	3 (2–4)	2.5 (2–3)	3.4 (2–4)	3 (2–4)	4.2 (4–5)	2.8 (2–4)	2.2 (1–4)	2.2 (1–3)	3.3 (2–5)	2.6 (2–4)	2.2 (1–3)	3.8 (3–4)	3.3 (3–4)	2.7 (2–4)	3 (2–4)
DWI overall quality score	3.5 (1–5)	3.1 (2–4)	2.8 (2–4)	3.8 (3–4)	4.7 (4–5)	3 (2–4)	2.5 (1–4)	2.8 (2–4)	3.3 (3–4)	3.3 (3–4)	1.8 (1–3)	2.8 (1–4)	4 (4–4)	3.1 (3–4)	3.7 (2–5)
DCE overall quality score	NA	2.5 (1–3)	4.1 (3–5)	NA	4.7 (4–5)	NA	3 (3–4)	3.2 (3–4)	3.6 (3–4)	3 (3–3)	3 (3–3)	NA	NA	NA	NA
T2W noise	2.7	2.8	2.8	2.4	3.1	3.2	1.8	2.2	3.1	2.1	2	3.2	3	2.4	3
T2W motion	2.4	2.3	2.4	2.4	3.2	2.2	2.7	2.2	2.6	2.3	1.7	3	2.8	2.4	2.7
DWI distortion	2.5	3	2.5	2.6	3.7	3.2	3.2	2.8	2.8	3.1	2.5	2.6	3.3	3.4	2.8
DWI artefact	2.8	3	2.1	3.2	3.2	2.6	2.5	2.4	2.5	2.5	2.1	2.6	3	3.4	3.5
Corrupt data points	NA	12%	10%	NA	6%	NA	28%	15%	14%	36%	20%	NA	NA	NA	NA
Rectal distension	2.7	2.1	3.1	2.6	1.5	2.2	2.2	2.1	2.5	3.1	2.2	3	1.6	2.2	2.7
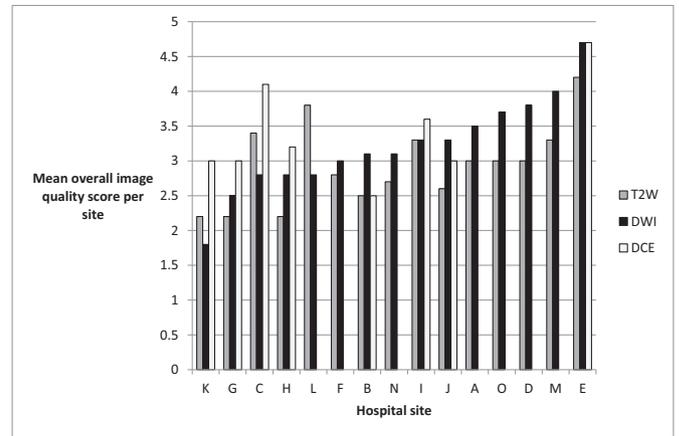
Figure 5 Mean overall quality scores for T2W, DWI and DCE for each site, ordered by ascending DWI score.

centres with up-to-date scanners and more comprehensive imaging protocols. In fact, centres using DCE showed a non-significant trend towards lower T2W and DWI scores, suggesting that its use is likely to provide added benefit. Furthermore, the present audit excluded patients with hip replacements and post-treatment cases, in whom DCE may be of most benefit.

A standard specific to the UK consensus paper,[10] is a requirement to scan axial sequences in a plane axial to the patient, which did not take place in 27% of sites (for the T2W sequence). This standard allows both improved anatomical correlation between sequences and consistency between multiple MRIs in the same patient; in addition, alternative planes chosen tended to transect the rectum more obliquely, and it is speculated that this might predispose to increased gas/motion artefact due to increased rectal coverage present on each image (Fig 1b).

The present audit found wide variation in overall image quality scores across sites. For T2W, there were three sites with a low mean score of 2.2, compared to the highest mean score in the audit of 4.2. Review of sequence protocols and support from MRI physicists and manufacturers'
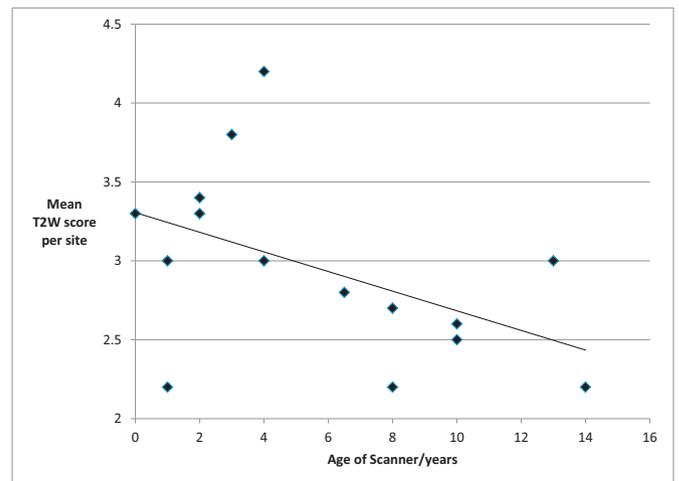

Figure 6 Mean overall T2W image quality per site versus scanner age.

applications specialists may be considered appropriate at some sites to facilitate improvements in image quality.

Scanner age was a significant factor influencing T2W image quality and 40% of scanners were >7 years of age. This was used as a cut-off for defining "older" scanners, as this is in line with regional guidelines that recommend use of a scanner <7 years of age. Lack of investment in new scanners may prove a major obstacle to improving the quality of prostate MRI, with significant funding challenges likely to be encountered nationally. In addition, only one site used a 3 T scanner; although this is not a PIRADS 2 recommendation, it is clearly the committee's strong preference.

The effect of rectal distension on image quality was investigated, and an inverse relationship with overall DWI quality was found, in concordance with the findings of Caglic *et al.* (performed on a 3 T unit).[12] There was no significant relationship with T2W image quality, which is less prone than DWI to air-induced susceptibility artefact. Interestingly, the site with the overall lowest mean rectal distension score (1.5 compared to group mean of 2.4) administered oral senna laxative on the evening prior to scanning and also had the highest overall image quality scores across all three parameters; however, the bowel preparation policy of the other sites is unknown.

The present audit is limited by a relatively small sample size. Patient motion, size, or rectal distension may influence image quality, additionally other extraneous factors such as radiographer experience or technical issues may affect results; however, it is hoped these factors will average out, given a minimum of five cases per site were assessed. Interpretation of image quality is largely a subjective exercise, and the results may not be directly comparable to other audits.

In summary, significant challenges were found across the region in delivering diagnostic prostate MRI, with wide variation across sites in both compliance with technical standards and image quality. This is of particular importance given proposals for widespread adoption of MRI as a first-line investigation for people with suspected clinically localised prostate cancer. It is hoped that this audit will help inform the development of a more standardised national audit process for prostate MRI.

Acknowledgements

Conflict of interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crad.2019.03.026.

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