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Picture Perfect: The Status of Image Quality in Prostate MRI

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Magnetic resonance imaging is the gold standard imaging modality for the diagnosis of prostate cancer (PCa). Image quality is a fundamental prerequisite for the ability to detect clinically significant disease. In this critical review, we separate the issue of image quality into quality improvement and quality assessment. Beginning with the evolution of technical recommendations for scan acquisition, we investigate the role of patient preparation, scanner factors, and more advanced sequences, including those featuring Artificial Intelligence (AI), in determining image quality. As means of quality appraisal, the published literature on scoring systems (including the Prostate Imaging Quality score), is evaluated. Finally, the application of AI and teaching courses as ways to facilitate quality assessment are discussed, encouraging the implementation of future image quality initiatives along the PCa diagnostic and monitoring pathway.
Evidence Level: 3
Technical Efficacy: Stage 3

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Introduction

Magnetic resonance imaging (MRI) of the prostate is now an established modality for the detection of prostate cancer (PCa).[1] In particular, when used as a triage test, multiparametric MRI (mpMRI), which combines T2-weighted imaging (T2-WI), diffusion weighted imaging (DWI), and dynamic contrast enhanced (DCE) sequences, helps patients to avoid unnecessary procedures and clinicians to perform targeted biopsies.[2] This has a twofold benefit: 1) an improved detection of clinically significant prostate cancer (csPCa), commonly defined as either Gleason Grade (GG) ≥ 3 + 4 or International Society of Urological Pathology (ISUP) grade ≥ 2,[3] and 2) reduced detection of clinically insignificant cancer, when compared to transrectal ultrasound-guided biopsy alone.[4]

Adequate image quality is a prerequisite for the detection of csPCa, as an accurate visualization of the prostate gland and its surrounding structures, or lack thereof, is linked to factors related to both the technical parameters set up in the machine and to the patient's preparation and habitus.[5] It must be highlighted that prostate MRI has also been the victim of its own success: due to its widespread adoption, quality across centers is widely variable.[1] A multicenter audit in the United Kingdom showed that 40% of scans were of suboptimal diagnostic quality.[6]

Improving image quality has been a goal across all imaging modalities. For example, guidelines for evaluation of mammogram image quality have existed for a number of years.[7] In prostate MRI, this is still an emerging focus.

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A recent review outlined the dual importance of both quality control (i.e., radiologists assessing scan quality as part of clinical practice) and quality assurance (i.e., the measures introduced to guarantee that scans are of the optimal quality).[8] The need for both initiatives has been recognized in the past and supported by a dedicated European working group[9] as well as a panel of experts in the United Kingdom.[10] Nevertheless, the heterogeneity of scanners and settings worldwide has made it "impossible to provide a tailored mpMRI prostate imaging protocol for every MR system,"[11] rendering quality assurance difficult.

In this review, we separate prostate MRI image quality into quality improvement and quality assessment, encompassing both subjective (anatomical differentiation, presence of artifacts, etc.) and objective (signal-to-noise ratio [SNR], and contrast-to-noise ratio [CNR]) metrics. From early beginnings with the Prostate Imaging and Data Reporting System (PI-RADS) that set out the minimum technical requirements to acquire a good quality MRI scan, we move on to assess the evidence regarding both scanner and patient factors and discuss the recent creation and implementation of scoring systems to assess image quality. In addition, as in many disciplines of Radiology, the growing influence of Artificial Intelligence (AI) in both the reconstruction and assessment of scans also features. Our group stresses the value of dedicated teaching courses and workshops to educate radiologists on the subject, as there are now a variety of mechanisms that could act synergistically to raise the standards of prostate MRI quality worldwide. We note that the issue of image quality has led to two significant milestones so far:

1. a dedicated standardized scoring system to assess prostate MRI image quality: the Prostate Imaging Quality (PI-QUAL) score[12]
2. a pathway to accredit centers for producing high-quality scans: the American College of Radiology Prostate Cancer MRI Center Designation[13]

Quality Improvement

Prostate MRI Standards to Ensure Image Quality

The first major international effort to address image quality in prostate MRI came as a result of a European consensus meeting in 2011,[14] where the suitability of certain quality-related metrics, such as slice thickness and *b*-values, was discussed. However, it was not until the publication of the first PI-RADS document a year later[15] that a set of formal, reproducible criteria for image acquisition was introduced.

As well as providing a framework to assess an area for the likelihood of harboring csPCa, the PI-RADS guidelines reported technical specifications for each sequence (T2-WI, DWI, and DCE) that should be adhered to in order to achieve good quality scans.[16] The evolution of these recommendations is outlined in Table 1. Nevertheless, simple adherence to these does not necessarily translate into high quality images.[17] Minor adjustments to PI-RADS guidelines can be beneficial. In the UK, the introduction of a quality assurance program, where scanners were optimized and standardized in line with PI-RADS requirements (aside from an increased slice thickness on DWI), resulted in significant improvements in the diagnostic quality of the scans.[18]

In this section, we discuss the effect of magnetic field strength, endorectal coil (ERC) use and different rectal preparation strategies on image quality. Following this, we look at how 3D sequences, motion correction and a reduced FOV can be used to improve this further.

It concludes with how AI can be used as a method of reconstructing images.

Scanner Factors

Magnetic Field Strength

At a scanner level, image quality is inherently related to the choice of magnetic field strength—between 1.5 Tesla (T) and 3 T, and the use (or non-use) of ERCs. These must be considered when reporting the results of any study involving quality assurance. This section focuses on the head-to-head comparison between 1.5 T and 3 T as well as the use of ERCs at the same magnetic field strength. Nevertheless, there exists a wealth of evidence on the comparison between 1.5 T + ERC and 3 T, which also warrants discussion.

The benefit of a higher magnetic field strength derives from the greater SNR produced.[19] This does however result in a greater propensity to artifacts and tends not to affect CNR, which is the ability to differentiate between benign and cancerous tissue.[20]

The PI-RADS guidelines provide a clear stance that 3 T is generally preferred, except in cases of metallic implants and devices, as 3 T magnets are more prone to artifacts.[21] To date, there are a few studies which have compared 1.5 T and 3 T scanners, unconfounded. Where no ERCs were used, both Mazaheri et al[22] and Ullrich et al[23] reported a better SNR and subjective image quality on DWI at 3 T. The latter also found a greater CNR for DWI, but both SNR and CNR were deemed comparable for T2-WI and Apparent Diffusion Coefficient (ADC) maps. Importantly, the same group noted better subjective image quality for both T2-WI and DWI at 3 T. In terms of clinical impact, Ryznarova and colleagues[24] reported no significant differences in the ability to stage cancer between the two field strengths. Similarly, a meta-analysis on the subject[25] describes no statistically significant differences in sensitivity, specificity, or odds ratio for the detection of PCa between 1.5 T and 3 T scanners. However, conclusions drawn from this study are largely limited on three counts: the sample size (only four studies), the heterogeneity

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TABLE 1. Evolution of Minimum Technical Requirements for mpMRI Acquisition

		Dickinson et al (European Consensus Meeting)[14]	Barentsz et al (PI-RADS v1)[15]	Weinreb et al (PI-RADS v2)[16]	Turkbey et al (PI-RADS v2.1)[21]
Year		2011	2012	2015	2019
T2-WI	Max slice thickness	≤4 mm at 1.5 T and ≤3 mm at 3 T		≤3 mm	≤3 mm
	Planes of imaging	Axial and at least one other	2–3 planes	Axial and at least one other (sagittal/coronal)	Axial and at least one other (sagittal/coronal)
	Field of view			12–20 cm	12–20 cm
	In-plane resolution	0.5 × 0.5 mm to 0.7 × 0.7 mm			
	In-plane dimension			≤0.7 mm (phase) and ≤0.4 mm (frequency)	≤0.7 mm (phase) and ≤0.4 mm (frequency)
DWI	Max slice thickness	≤5 mm		≤4 mm	≤4 mm
	Planes of imaging	Axial	Axial	Similar to T2-WI and DCE	Similar to T2-WI and DCE
	In-plane resolution	1.5 × 1.5 mm to 2 × 2 mm			
	Field of view			16–22 cm	16–22 cm
	In plane dimension			≤2.5 mm (phase and frequency)	≤2.5 mm (phase and frequency)
	Time to Echo		≤90 msec	≤90 msec	≤90 msec
	Repetition time			≥3000 msec	≥3000 msec
	Fat saturation			Recommended	Recommended
	B value sequences	For ADC calculation, ≤800 sec/mm^2	0, 100, and 800–1000 sec/mm^2 for ADC calculation	0–100 and 800–1000 sec/mm^2 for ADC calculation. Mandatory to have one ≥1400 sec/mm^2	0–100 and 800–1000 sec/mm^2 for ADC calculation. Mandatory to have one ≥1400 sec/mm^2
	Time to echo			<5 msec	<5 msec
	Repetition time			<100 msec	<100 msec

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TABLE 1. Continued

		Dickinson et al (European Consensus Meeting)[14]	Barentsz et al (PI-RADS v1)[15]	Weinreb et al (PI-RADS v2)[16]	Turkbey et al (PI-RADS v2.1)[21]
DCE	Slice thickness	≤4 mm		3 mm	3 mm
	Imaging planes	Axial		Same as for DWI and DCE	Same as for DWI and DCE
	Field of view			Encompass entire prostate gland and SVs	Encompass entire prostate gland and SVs
	In plane resolution	0.7 × 0.7 mm to 1 × 1 mm for 1.5 T and 0.5 × 0.5 mm to 0.7 × 0.7 mm at 3 T			
	In plane dimension			≤3 mm	≤3 mm
	Temporal resolution	10–15 seconds	≤10 seconds	≤10 seconds	≤15 seconds
	Observation rate				≥2 minutes
	Dose			0.1 mmol/kg standard GBCA or equivalent high relativity GBCA	0.1 mmol/kg standard GBCA or equivalent high relativity GBCA
	Injection rate	3 mL/second	2–4 mL/second	2–3 cc/sec starting with continuous image data acquisition	2–3 cc/sec starting with continuous image data acquisition
	Fat suppression/subtractions			Recommended	Recommended

ADC = apparent diffusion coefficient; cc/sec = cubic centimeters per second; DCE = dynamic contrast enhancement; DWI = diffusion weighted imaging; GBCA = Gadolinium-based contrast agents; PI-RADS = prostate imaging and data reporting system; SVs = seminal vesicles; T = Tesla; T2-WI = T2 weighted imaging.

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of acquisition parameters (eg, different coils) and the lack of a reference standard (i.e., presence/absence of csPCa).

In pure comparison, the small volume of studies points toward the superiority of 3 T in terms of image quality. Nevertheless, studies with comparable results indicate that adequate diagnostic quality is still possible for a well optimized 1.5 T scan. Furthermore, even if suspected, the sparse literature does not indicate that these differences between 1.5 T and 3 T translate into improved PCa characterization.

ERC Use

In a study of academic radiology centers in the United States, ERCs were used just shy of 50% of the time at 3 T and almost in all cases at 1.5 T—and for community groups its use was found to be much less frequent.[26] ERCs are used to improve SNR, especially with 1.5 T scanners.[27] Yet, the potential benefits must be balanced against the drawbacks, which include additional time, cost, and discomfort.[28] In terms of image quality, a misplaced ERC can cause artifacts that include ghosting (i.e., multiple representations of the same section) and flare (i.e., drastic increases in signal intensity that can obscure the prostate).[29]

At the same magnetic field strength, it is of no surprise that there are numerous studies that validate the proposed superiority in SNR that results from using an ERC.[30–32] Few studies have evaluated CNR, although Ullrich et al[31] did not observe improved discrimination between benign and cancerous prostate. The expected improvement in image quality, as rated by radiologists on a 1 to 5 Likert scale, has been shown for DWI[32,33] and T2-WI[34] but certain studies have also reported no superiority with either set up.[30,35] Where a 1 to 4 Likert scale was used to assess image quality, no significant difference was found.[31] In terms of localization and staging, one group found that using an ERC improved image quality for visualizing the different zones of the prostate and possible lesions,[36] although they reported no significant difference when combining assessment of the capsule and possible invasion, neurovascular bundle and rectoprostatic angle into an average score. Other groups have demonstrated increased artifacts when using an ERC on T2-WI[30,31,34] and DWI,[33] while Ullrich et al[31] found fewer motion-related artifacts on DWI. These discrepancies could be due to differences in patients' selection and preparation.

The true impact of the ERC can be assessed in localizing and characterizing cancer. In line with trying to avoid overdiagnosis, studies assessing csPCa rates are the most useful, as this is the cancer which is of most clinical concern. Dhatt et al[35] found that images using an ERC detected 31% more cases of csPCa at a cut-off point of GG ≥3 + 4 but had no effect on detection of more aggressive disease. Mirak et al[37] found a lower detection rate of anterior and transition zone tumors, but they used a cut-off point of GG 3 + 3 and ≥1 cm size. For any cancer, both Costa et al[38] and Turkbey et al[39] demonstrated greater sensitivity for cancer detection with ERC although a number of studies[32,34,36,40] have been unable to replicate this improvement. No differences in the ability of radiologists to accurately stage cancer, for example through detecting extraprostatic extension (EPE) and seminal vesicle (SV) invasion has been shown at 1.5 T[41] or 3 T.[42]

Naturally, the majority of research reflects the reality of clinical practice where 1.5 T scanners using an ERC have been pitted against 3 T scanners without, in the aim of identifying which option may be more prone to artifacts and inferior image quality. Mixed results can be seen for subjective image quality assessment with studies reporting superior[43,44] or comparable[45,46] quality for ERC use at the lower magnetic field compared to the higher one. There has been one study on patients with hip replacements that revealed no significant difference in artifact severity between patients scanned at 1.5 T + ERC and those at 3 T.[47] In terms of diagnosis, aside from one study which reported improved detection and staging of PCa,[48] there is concordant evidence pointing to a similar diagnostic ability of 1.5 T + ERC with 3 T.[29,43,44]

The prevalence of ERC use at either 1.5 T or 3 T is not widely reported, yet when used, it is typically with the aim of improving 1.5 T scan quality. Although the evidence favors this approach, caution must be exercised when using an ERC owing to concerns over the presence of supplementary artifacts. Regardless of the chosen acquisition setup, age is a key determinant of the quality produced by a scanner, especially when it has not undergone scheduled maintenance and upgrade. A multicenter analysis of MRI in the United Kingdom revealed a negative correlation between scanner age and image quality on T2-WI sequences, with a more pronounced drop-off occurring at the 7-year mark on 1.5 T scanners.[6] Audits of 3 T scanners would be beneficial as they contribute to an increasing number of scans every year.

Key Point(s):

1. A well optimized 1.5 T scan can still achieve diagnostic quality, even if 3 T scans tend to be preferred (except in case of metallic implants and devices).
2. There can be a benefit to using an ERC with a 1.5 T scanner in boosting SNR.

Recommendation(s):

1. Quality control is useful in determining whether scanner or coil choice is adequate.

Patient Preparation

It is worth considering the sources of additional artifacts that can occur on prostate MRI prior to discussion on how these can be minimized. Most often, these include patient's motion, rectal air and peristalsis, and occasionally metallic implants.[5] Other than prior evacuation of the rectum, the PI-RADS v2.1 guidelines provide no specific recommendations

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on how to prepare patients for prostate MRI.[21] A recent scoping review[49] suggested that there is support for the use of enemas and, to a lesser extent, for dietary restrictions, but Level I evidence on rectal preparation strategies is yet to be published.

Rectal Catheters

One of the strategies aimed at removing rectal air is through the insertion of small catheters in the rectum. Huang et al[50] reported less artifacts from rectal air in patients who had a catheter inserted. Compared to patients who underwent no preparatory measures, a substantial agreement was found among different radiologists that those with catheters had fewer image distortions on DWI and higher image quality on ADC maps. However, no improvements were observed for motion artifacts on T2-WI. Reischauer et al[51] did not use a control group but compared an enema preparation with the use of a small catheter. They found that use of the latter led to more susceptibility artifacts on DWI as well as inferior differentiation of prostate anatomy and overall image quality. Very few studies have investigated rectal catheters and little judgment can be passed on this technique.

Anti-Peristaltic Medications

There has been considerable research into the effects of anti-peristaltic agents on image quality for prostate MRI. Most studies administered doses of either 20 mg or 40 mg of hyoscine butylbromide (also known as butylscopolamine) intravenously, with results displaying varying degrees of success. Certain studies reported no difference in overall image quality with hyoscine butylbromide doses of 20 mg[52,53] and 40 mg.[54] One study found better quality on T2-WI but not on DWI.[55] In terms of motion-related artifacts on T2-WI, Slough et al[55] and Ullrich et al[56] demonstrated fewer artifacts with hyoscine butylbromide administration, although other groups failed to reproduce this.[52,54] In patients scanned with ERCs, Wagner et al[57] revealed no improvements to image quality, motion artifacts and delineation of prostatic structures after intramuscular or intravenous hyoscine butylbromide administration. The use of other medications, such as glucagon, has been investigated by Froelich and colleagues,[58] who observed a more prolonged effect on bowel peristalsis compared to hyoscine butylbromide. A recent publication on the effect of intramuscular glucagon on T2-WI found no significant effect on subjective image quality and csPCa detection between cohorts. The positive predictive value (PPV) for PI-RADS 4 lesions was in fact higher in patients not given glucagon.[59] Although studied fairly extensively, the jury is still out regarding hyoscine butylbromide use in prostate MRI. For glucagon, the only published study at this current moment[59] serves to oppose its use.

Dietary Restrictions

In order to reduce the artifacts related to bowel peristalsis, implementing dietary restrictions, such as the constraint to consume only clear fluids from at least 6 hours before a scan, seems logical. Three studies have evaluated the effect of dietary restrictions on image quality in prostate MRI: two compared patients who underwent dietary restrictions to those with no such limitation[52,60] and one compared dietary restrictions in combination with either: a microenema and anti-spasmodics or anti-spasmodics alone, to those without any instructions.[53] The study by Purysko and colleagues[60] pitted patients who could only drink clear fluids from 6 hours before the scan to those who had no dietary constraints. The majority of readers (75%) reported less stool or air in the rectum, fewer distortions on DWI and better overall image quality following dietary restrictions but no differences in motion-related artifact on T2-WI and no clear impact on peristalsis. Sathadioss and colleagues[52] found no additional improvement of dietary restrictions on rectal air and motion-related artifacts on T2-WI. Nevertheless, when dietary restrictions were combined with an enema, image quality improved for both sequences.[60] On the contrary, Schmidt et al[53] observed that its presence or absence made no difference to image quality in a cohort with a microenema and HBB preparation. At present, it cannot be claimed that dietary restrictions significantly improve image quality of prostate MRI.

Enemas

As far as enemas are concerned, some studies showed that the use of enema either outperformed[60] or remained comparable[53] to a control group. As mentioned above, Sathiadoss and colleagues[52] reported improved quality on T2-WI and fewer artifacts when combined with dietary restrictions, in line with the results by Purysko et al.[60] On DWI, one study found that images were of higher quality after enema,[60] while another could only replicate this when enema use was combined with dietary restrictions.[52] This improvement on DWI is also supported by Plodeck and colleagues,[61] who reported less severe artifacts after enema. A study by Coskun et al[62] comparing the ability of radiologists and urologists to evaluate image quality yielded conflicting results, as the radiologist reported less distortion on DWI with use of enema, but this was not the case for the urologist. Conversely, Lim et al[63] noticed no changes to image quality on any sequence for their enema group. Interestingly, one study also combined an enema with ultrasound gel and reported improved quality on DWI and for one of their readers on T2-WI.[64] Ultimately, the only study to assess clinical benefit of enemas found no difference in the rate of detection for csPCa (ISUP Group ≥2).[65]

Key Point(s):

1. The most studied technique for minimizing artifacts is enema use but more convincing evidence is needed to

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support any of the four strategies (rectal catheters, antiperistaltic medications, dietary restrictions, enemas).
2. The impact of different preparations on PCa staging is yet to be explored in considerable detail.

Recommendation(s):
1. Patient preparation tends to be very anecdotal and thus centers should investigate the feasibility and success of different methods.

Additional Sequences

Three-Dimensional Sequences

PI-RADS v2.1 guidelines state that two-dimensional (2D) T2-WI should be acquired in the axial as well as either coronal or sagittal planes.[21] There have been numerous attempts to introduce an mpMRI sequence that can be produced more quickly while retaining the same quality. Among these attempts is the use of three-dimensional (3D) acquisition for T2-WI. Overall, a number of studies point toward non-inferiority of these sequences in terms of image quality as compared to 2D sequences, yet assessment of image quality has been rather heterogeneous. For quantitative measures of quality, studies on 3D sequences have shown similar[66–68] and even greater CNR for tumors.[69] On the contrary, the SNR in the peripheral zone has been reported to be lower in two studies[66,69] and similar in one.[67] For subjective measures, no significant difference in overall quality has been reported on a 1 to 5 scale[69,70] and 1 to 4 scale,[66] while both Vidya Shankar and colleagues[67] and Tanaka and colleagues[68] found it to be inferior for the 3D sequence.

Specific indicators of image quality have been relatively conflicting with no clear pattern observed: 3D has outperformed 2D sequences when assessing artifacts (excluding motion)[71] or for visualizing the genitourinary diaphragm.[66] Conversely, 2D sequences have displayed superiority for sharpness,[71] and for visualizing SVs,[66] as well as the external capsule.[72] There has been agreement on there being similar conspicuousness of lesions,[68,70,71] general anatomical visualization[71] image sharpness and artifacts.[67,72] Interestingly, no study has reported significant differences in terms of either diagnostic ability[68–70] or staging ability[68,69] of either sequence. Tanaka and colleagues[68] also used a modified 3D sequence in their study which is enhanced by variable refocusing flip angle. They found improved contrast and visualization of internal prostate anatomy when compared to traditional 2D sequences. However, this benefit again did not translate to detection and staging of cancer. Overall, these studies point in an encouraging direction but larger studies on rates of csPCa using prostatectomy as a reference standard are needed to validate this sequence.

Motion/Magnetic Correction Strategies

One of the attempts to try and reduce the unwanted effects of motion or magnetic field inhomogeneity has been by combination of k-space radial sampling and fast spin echo, of which the most notable effort has been PROPELLER.[73] This suggested effect has been exemplified by Czyzewska and colleagues[74] and Meier-Schroers and colleagues,[75] who used an updated version of the software (MultiVane XD). The first group did not observe a corresponding effect on subjective image quality while the second did, and this may have been related to a difference in Likert scale used to assess this (1 to 5 vs. 1 to 4). In using BLADE, a near-identical sequence, Rosenkrantz and colleagues[76] did not observe the same reduction in artifacts. Looking at clinical impact, no group has been able to demonstrate superior cancer detection (of any Gleason grade)[74] or EPE recognition.[76] There are also potential negatives to these modified T2-weighted sequences; notably lower CNR[75,76] and more blurring.[74]

In addition to T2-WI, there have been three studies that have investigated the use of this sampling technique in DWI, all in patients with metallic implants—as they are a cohort vulnerable to artifacts. Improvements for overall image quality on a 1 to 5 scale have been observed.[77–79] In a very small sample size (N = 5), use of PROPELLER-DWI resulted in reduced distortion but no difference to artifacts.[78] It would be of interest to see if the positive findings of PROPELLER for DWI (or equivalent) translate to a standard cohort of patients (i.e., those without metallic implants or devices) and what clinical impact (if any) there might be.

Selective Excitation Reduced Field of View Sequences

Inequalities in magnetic field distribution, owing to rectal air for example, lead to artifact production on DWI sequences.[80] One method to combat this has been through the development of a reduced field of view (FOV) of the prostate scan.

There are numerous ways of achieving a reduced FOV, with the approach most commonly studied involving selective excitation of a smaller mass, done with the aim of reducing image distortion and improving resolution.[81] This is potentially useful in patients with metallic implants.[82] Known commercially under various names (ZOOMit, FOCUS, iZOOM), this technique is now well established.

In studies opposing this form of reduced FOV DWI to conventional DWI, authors have investigated a variety of metrics for image quality. In subjective Likert scales, reduced FOV led to significant quality improvement for some[80,83–85] but not others.[86–89] This is similar for distortion, where there have been groups reporting a reduction[83–85,87,90] but others have not been able to replicate this.[86,89,91] Except for Stocker et al[86] and Rosenkrantz et al,[89] most other groups who looked at artifacts reported improvements with the reduced FOV sequence.[80,83,85,91,92] Confounding factors may include

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the type of outcome measured as well as differences in the scanner set-up (eg, *b*-value used). In terms of cancer detection, only Ma and colleagues[85] have demonstrated improvement using a reduced FOV, however this was not stratified by clinical significance and was not conclusive in the transition zone. Other studies found that alterations to the FOV made no statistically significant difference to the sensitivity and specificity for both lesion[83] and cancer[88] detection. This could be due to the fact that when both the pixel size is small and SNR high, the FOV has a limited role in determining image quality.[93]

There have been other attempts to improve DWI quality related to reducing the FOV. In taking the aforementioned selective excitation technique but tilting pulse trajectories with the aim of lessening artifacts, Lee and colleagues[92] found that this modification outperformed the original in all studied outcomes for image quality. Where a traditional small FOV sequence has been used, one group found this resulted in worse quality, increased distortion, and increased production of artifacts.[89]

There are also many other additional modalities, not covered here, such as computed DWI or readout segmented DWI.[94] MR fingerprinting or luminal water imaging have also been trialed to improve prostate MRI quality[95] and it remains to be seen as to whether these will begin to be implemented.

Key Point(s):
1. Optimization of time without sacrificing image quality is a future goal due to the increasing number of prostate MRI scans performed globally.
2. These sequences may be differentiated from the conventional prostate MRI but future research is needed

Recommendation(s):
1. At this point, these sequences are only available to specialist centers but their evolution should be closely monitored.

AI for Image Acquisition

As an imaging-based specialty, Radiology is at the forefront of research into AI. In prostate MRI, there is a range of targets for AI application, including PCa detection, lesion contouring, prostate segmentation, and image quality.[96]

Most research into AI and image quality has centered around trying to improve image quality. Deep learning reconstruction (DLR), where a convolutional neural network (CNN) is trained to reduce noise and Gibbs ringing[97] has been tested on different parameters of mpMRI, featuring multiple measures of assessing scan quality. For T2-WI, there is some support for the benefit of DLR. Studies have shown that implementing DLR leads to higher perceived image quality.[98–100] Superior SNR and CNR for DLR-based acquisition have also been reported,[100] however some studies have been unable to replicate this quantitative improvement, and found that T2-WI quality was compromised according to qualitative assessment.[97,101]

For DWI, discordant results have been published. While DLR use led to superior SNR and CNR,[100,102] only Ueda and colleagues[102] have shown superior subjective image quality in contrary to other groups.[100,103,104] Two studies have found no difference in detection of lesions[103] or EPE[102] as opposed to conventional MRI. Multicenter studies with 1) larger sample sizes, 2) standardized methods of assessing image quality, and 3) correlation to cancer and EPE detection would be needed to garner support for this type of reconstruction.

Deep learning has also been used in the emerging field of synthetic MRI, where generative adversial models create images based on acquired data.[105] Hu and colleagues[106] compared acquired DWI images to those modified by their model and found improved image quality with reduced distortion and artifacts. In addition, they also found that for younger radiologists, this resulted in an improved ability to detect PCa. However, Xu and colleagues[105] found that a blinded radiologist did not find the quality of their synthetic images to be inferior to those non-processed.

Whether it be for reconstruction or synthetic MRI, AI is yet to display superiority as compared to established methods in terms of boosting image quality. However, given the time that may be saved in performing fast acquisitions, DLR use as a way of achieving non-inferiority may be the target.

Key Point(s):
1. Using AI may help save time through reconstruction or generation of images but more research should be conducted.

Recommendation(s):
1. Further investigation into evaluation of image quality using AI algorithms should be conducted.

Quality Assessment

The following section outlines the PI-QUAL score and Prostate Signal Homogeneity Score (PSHS) used to assess the quality of prostate MRI, and how the first AI models are being trained in basic quality control. Subsequently, this review stresses how educational interventions can be involved in the expansion of quality control.

The PI-QUAL Score

Born from the PRECISION trial,[107] The PI-QUAL score is the first standardized scoring system to evaluate the quality of prostate mpMRI.[12] Combining the aforementioned PI-RADS technical recommendations (Table 1)[21] with a set of more subjective criteria which assess the ability to both clearly

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visualize specific anatomical landmarks and assess the absence/presence of artifacts on all sequences, PI-QUAL evaluates the diagnostic quality of all three sequences (T2-WI, DWI, and DCE). As shown in Fig. 1, PI-QUAL provides an overall score that ranges from 1 to 5 using a combination of this data. Figures 2–6 provide examples of PI-QUAL 1–5 mpMRI images. A PI-QUAL score of 1 means that no sequences are of adequate diagnostic quality (i.e., it is not possible to rule in and rule out all clinically significant visible lesions) while a PI-QUAL score of 5 entails that all sequences are of optimal diagnostic quality (i.e., it is possible to rule in and rule out all clinically significant visible lesions). Of note, for visible lesions a PI-QUAL score of 3 means that it is possible to rule in but not to rule out all csPCa, while a score of 4 and above means that csPCa can be both ruled in and out.[12]

As can be seen in Table 2, there are now a number of studies that have incorporated this scoring system. Many have assessed its reproducibility, and results for agreement, as assessed by Cohen's kappa (κ), have ranged from slight[88] to moderate[64,108–112] to substantial[112,113] and even excellent.[114] Care must be taken when looking at such values as it is difficult to calculate true agreement among readers owing to the differing levels of expertise and prior exposure to the PI-QUAL, which has varied across these studies.

The use of the PI-QUAL score to assess image quality has potential for clinical benefit in terms of better lesion detection and characterization. Brembilla and colleagues[115] found that for PI-RADS 3 scans, those of suboptimal quality (PI-QUAL ≤ 3) were more likely to undergo a biopsy and less likely to harbor csPCa (GG ≥ 3 + 4/ISUP GG ≥ 2). This is in line with the results by Karanasios and colleagues,[110] who found that for both negative (PI-RADS 1 and 2) and indeterminate (PI-RADS 3) scans, those of suboptimal quality were more likely to proceed to biopsy and had a reduced ability to rule in or rule out csPCa. When stratifying scans by quality using the same criteria (PI-QUAL ≥ 4 and PI-QUAL ≤ 3), Brembilla's group also reported superior PPVs for detecting csPCa in the higher quality scans[115]—a finding replicated by Pötsch and colleagues who divided the prostate into six zones as opposed to per-patient assessment.[109] This suggests that a higher number of biopsy procedures may be performed when image quality is suboptimal than is strictly necessary, although neither study provides information on the prevalence of cancer that would be missed.

Four studies have investigated the PI-QUAL score using cohorts who underwent prostatectomy. Windisch et al[116] reported a higher rate of EPE detection and thereafter a lower rate of upstaging for scans of higher quality (PI-QUAL ≥ 4). Interestingly, this difference was non-significant when comparing PI-QUAL 3 scans and PI-QUAL ≥ 4 scans. Only a minority (12%) of scans were scored PI-QUAL < 3 here, a prevalence similar to other cohorts in other studies[64,108,110,113,114]—hence grouping from 1 to 3 may be potentially misleading. Conducting research in non-academic, non-tertiary centers, where image quality is likely to be suboptimal, could determine how applicable this data is to less experienced institutions. The relationship between PI-QUAL and staging is also supported by Dinneen et al.[117] Here, PI-QUAL scores ≥4 had a greater sensitivity and specificity for detecting EPE than scans scoring PI-QUAL ≤ 3, although the sample size was smaller. In contrast, recent studies have reported no significant difference between PI-QUAL ≥ 4 and PI-QUAL ≤ 3 scans in the ability to stage PCa[112] or detect EPE.[118]

Overall, even though there are only a small number of studies on PI-QUAL and diagnostic ability (both detection and staging) at present, the idea that better scan quality leads to a more accurate characterization of PCa has been partially supported by the implementation of this standardized method of assessing image quality. However, the power of such studies has been limited by the small sample size of scans of non-diagnostic quality.

One of the main limitations of the PI-QUAL score is that it cannot be applied to biparametric MRI (bpMRI). A growing number of centers are using such an approach; for example, as of 2018, bpMRI was the pre-biopsy modality of choice for approximately 35% of areas in the UK.[119] It is expected that the future version of PI-QUAL (i.e., PI-QUAL v2) will address this limitation and thus will ensure the score is also applicable to bpMRI. Furthermore, it should be stressed that T2-WI is the main sequence utilized for the detection of EPE[118] and therefore adequate image quality of only this sequence is the crucial factor for staging purposes. It has been correctly pointed out that a scan with sub-optimal image quality could still be acceptable for detection, especially in large PI-RADS 5 lesions.[120]

Future iterations of PI-QUAL could, for example, group the scoring system into a three-point scale, as simplification of the current version (i.e., PI-QUAL 1–2 vs. PI-QUAL 3 vs. PI-QUAL 4–5) has shown promising results.[108,114] More validation on PI-QUAL as a true indicator of image quality in prostate MRI is needed. This will involve adaptation of the score and efforts to disseminate it by means of educational interventions and AI, both discussed in the next sections.

Key Point(s):

1. PI-QUAL is now an established scoring system for assessing image quality that has been validated in multiple contexts.
2. Further modifications to ensure greater interreader agreement are expected.

Recommendation(s):

1. A metric for image quality (eg, PI-QUAL or other dedicated scoring systems) should be included in a prostate MRI report.

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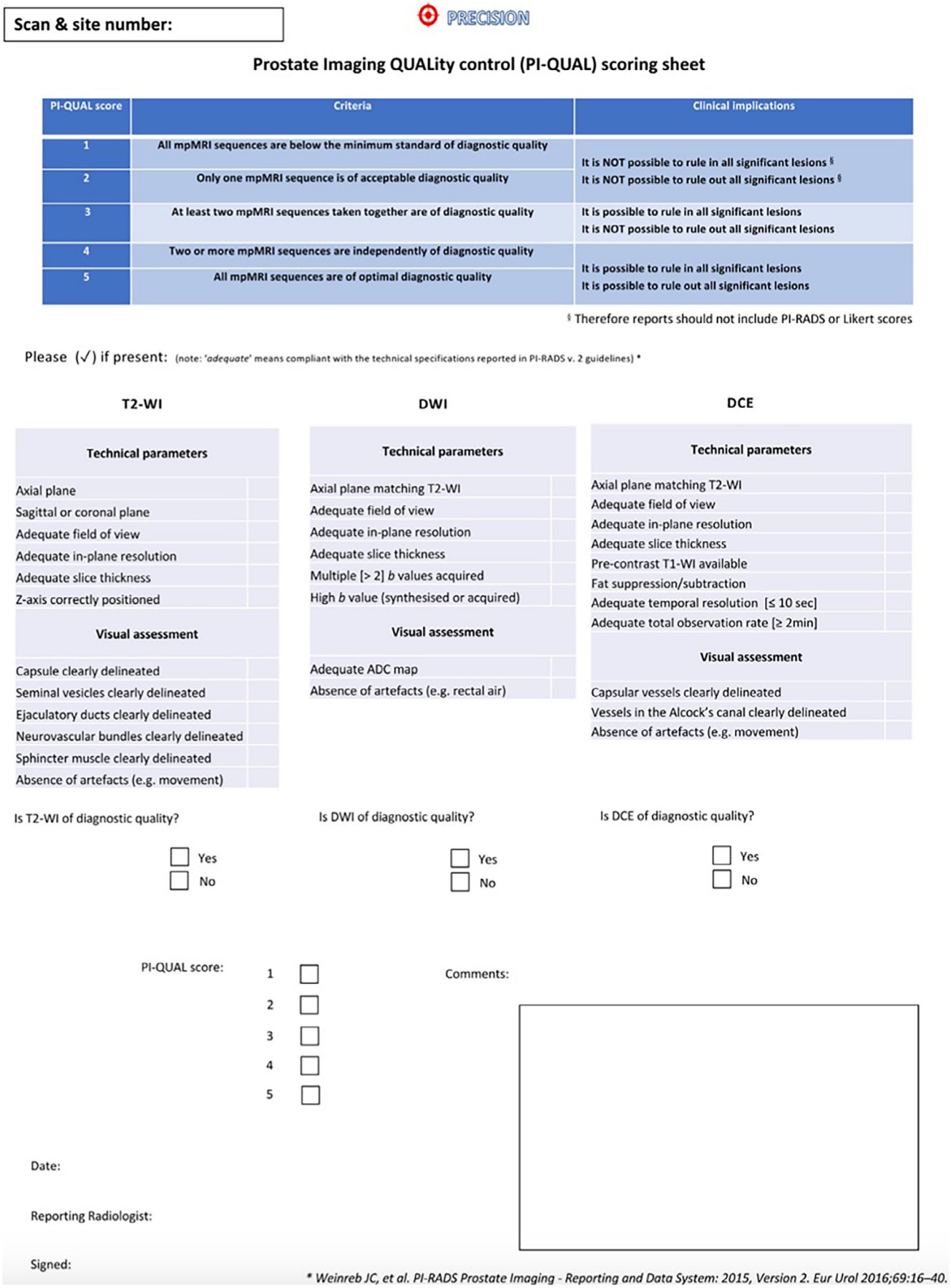

Scan & site number:

PRECISION

Prostate Imaging QUALity control (PI-QUAL) scoring sheet

PI-QUAL score	Criteria	Clinical implications
1	All mpMRI sequences are below the minimum standard of diagnostic quality	It is NOT possible to rule in all significant lesions § It is NOT possible to rule out all significant lesions §
2	Only one mpMRI sequence is of acceptable diagnostic quality	
3	At least two mpMRI sequences taken together are of diagnostic quality	It is possible to rule in all significant lesions It is NOT possible to rule out all significant lesions
4	Two or more mpMRI sequences are independently of diagnostic quality	It is possible to rule in all significant lesions It is possible to rule out all significant lesions
5	All mpMRI sequences are of optimal diagnostic quality	

§ Therefore reports should not include PI-RADS or Likert scores

Please (✓) if present: (note: '*adequate*' means compliant with the technical specifications reported in PI-RADS v. 2 guidelines) *

T2-WI

Technical parameters	
Axial plane	
Sagittal or coronal plane	
Adequate field of view	
Adequate in-plane resolution	
Adequate slice thickness	
Z-axis correctly positioned	
Visual assessment	
Capsule clearly delineated	
Seminal vesicles clearly delineated	
Ejaculatory ducts clearly delineated	
Neurovascular bundles clearly delineated	
Sphincter muscle clearly delineated	
Absence of artefacts (e.g. movement)	

DWI

Technical parameters	
Axial plane matching T2-WI	
Adequate field of view	
Adequate in-plane resolution	
Adequate slice thickness	
Multiple [> 2] *b* values acquired	
High *b* value (synthesised or acquired)	
Visual assessment	
Adequate ADC map	
Absence of artefacts (e.g. rectal air)	

DCE

Technical parameters	
Axial plane matching T2-WI	
Adequate field of view	
Adequate in-plane resolution	
Adequate slice thickness	
Pre-contrast T1-WI available	
Fat suppression/subtraction	
Adequate temporal resolution [≤ 10 sec]	
Adequate total observation rate [≥ 2min]	
Visual assessment	
Capsular vessels clearly delineated	
Vessels in the Alcock's canal clearly delineated	
Absence of artefacts (e.g. movement)	

Is T2-WI of diagnostic quality? ☐ Yes ☐ No

Is DWI of diagnostic quality? ☐ Yes ☐ No

Is DCE of diagnostic quality? ☐ Yes ☐ No

PI-QUAL score: 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Comments:

Date:

Reporting Radiologist:

Signed:

* Weinreb JC, et al. PI-RADS Prostate Imaging - Reporting and Data System: 2015, Version 2. Eur Urol 2016;69:16–40.

FIGURE 1: PI-QUAL scoring sheet[12] (reprinted with permission from European Urology Oncology).

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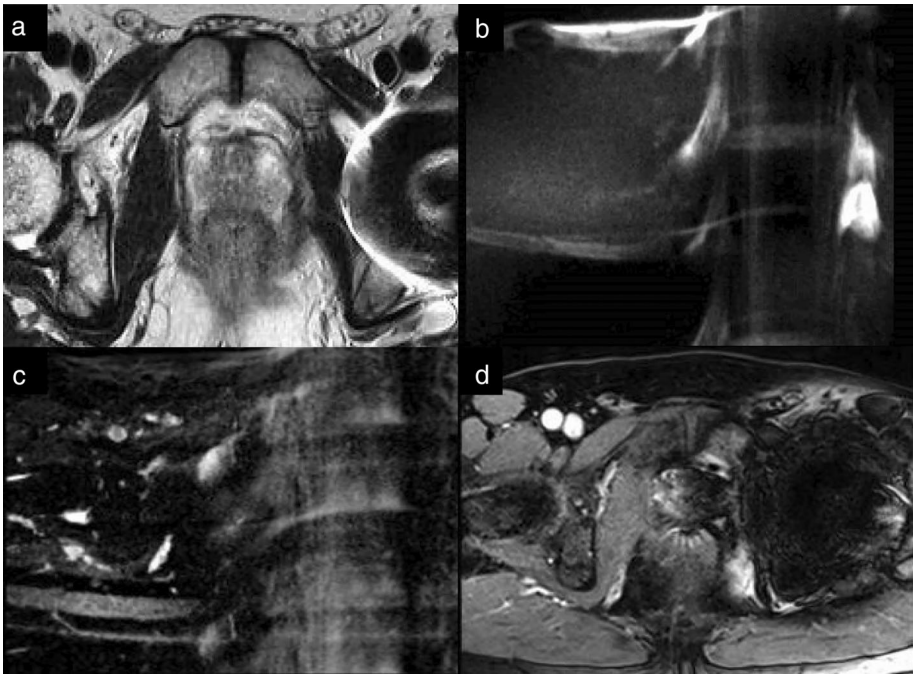

FIGURE 2: Axial T2-weighted imaging (a), high *b* value (1400 seconds/mm^2) (b), ADC map (c), and DCE acquisition (d) of a study that was given a PI-QUAL score of 1. All MR sequences are non-diagnostic due to the presence of severe artifacts from left hip replacement and inadequate in-plane resolution on axial T2-WI.

The PSHS Score

The PSHS provides another method of assessing prostate MR image quality. It focuses on the homogeneity of the peripheral zone in line with the uniformity of signal intensity of T2-WI.[121] The more significant the heterogeneity and hypointensity, the greater the difficulty in viewing focal lesions and thus the lower the score. This score, contrary to PI-QUAL, is purely subjective and does not assess DWI or DCE, or the transition zone.

Two studies have tested the PSHS and notably one of them involved a comparison to the PI-QUAL score. Interobserver agreement for PSHS has been substantial ($\kappa = 0.65$[111] and $\kappa = 0.78$[121]), and greater for more experienced readers,[111] although it must be acknowledged that the PSHS has only been tested on a couple of cohorts and thus requires further validation. As a scoring system which assesses only one aspect of one sequence compared to PI-QUAL, which encompasses multiple factors across three sequences, it is unsurprising that the authors reported higher interobserver agreement when using PSHS ($\kappa = 0.65$ vs. 0.58).[111] For PI-RADS ≥ 3 and PI-RADS ≥ 4 scans, higher PSHS scores were associated with a greater prevalence of csPCa, while this was only significant for PI-RADS ≥ 4 scans using PI-QUAL. This is in line with the original pilot study on PSHS that found a greater sensitivity for the detection of csPCa in higher PSHS scoring scans,[121] although a trend toward lower specificity was also reported.

At this point in time, neither scoring system provides an absolute marker of optimal image quality. Nevertheless, even at this stage, a calculation of both scores (i.e., PI-QUAL and PSHS), which assess different aspects of image quality, could be a useful adjunct to help radiologists to decide how much confidence can be placed in a prostate MRI scan.

Key Point(s):

1. The PSHS is a simple yet effective system of assessing image quality and initial results are promising.

Recommendation(s):

1. The PSHS scoring system requires further validation.

AI for Evaluating Image Quality

There have been a few attempts to assess prostate MRI quality using AI thus far. For example, Cipollari et al,[122] trained a CNN to stratify scans into those of low and high quality. This achieved near-perfect accuracy as compared to the radiologist's assessment, although the assessment was binary and based on no strict criteria. Alis and colleagues[123] employed a similar method but utilized a 3-point Likert system. In return, their model—much like the less experienced radiologists in their study—exhibited moderate to good agreement on bpMRI when compared to expert readers.

In the future, to ensure standardization, automation of image quality scoring could be the end goal. This has already been successful for assessing technical parameters of scans[124,125] and AI-based tools to segment the prostate already exist.[96,126] There is belief that training a program to segment the prostate would allow the visual assessment

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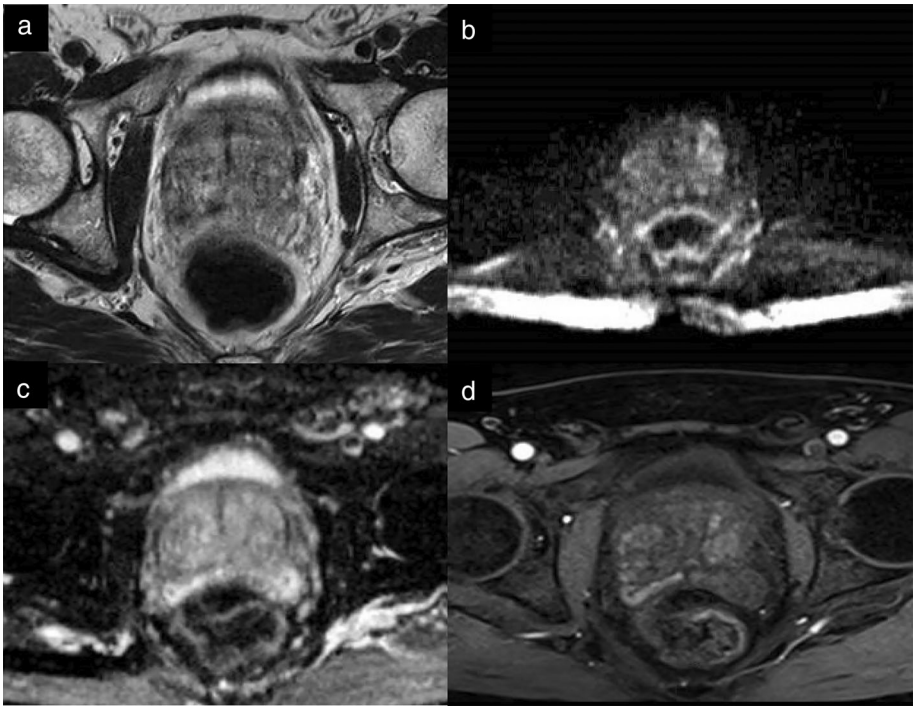

FIGURE 3: Axial T2-weighted imaging (a), high *b* value (1400 seconds/mm^2) (b), ADC map (c), and DCE acquisition (d) of a study that was given a PI-QUAL score of 2, as only DCE sequences are of adequate diagnostic quality (artifacts from motion and rectal air hamper T2-WI and DWI).

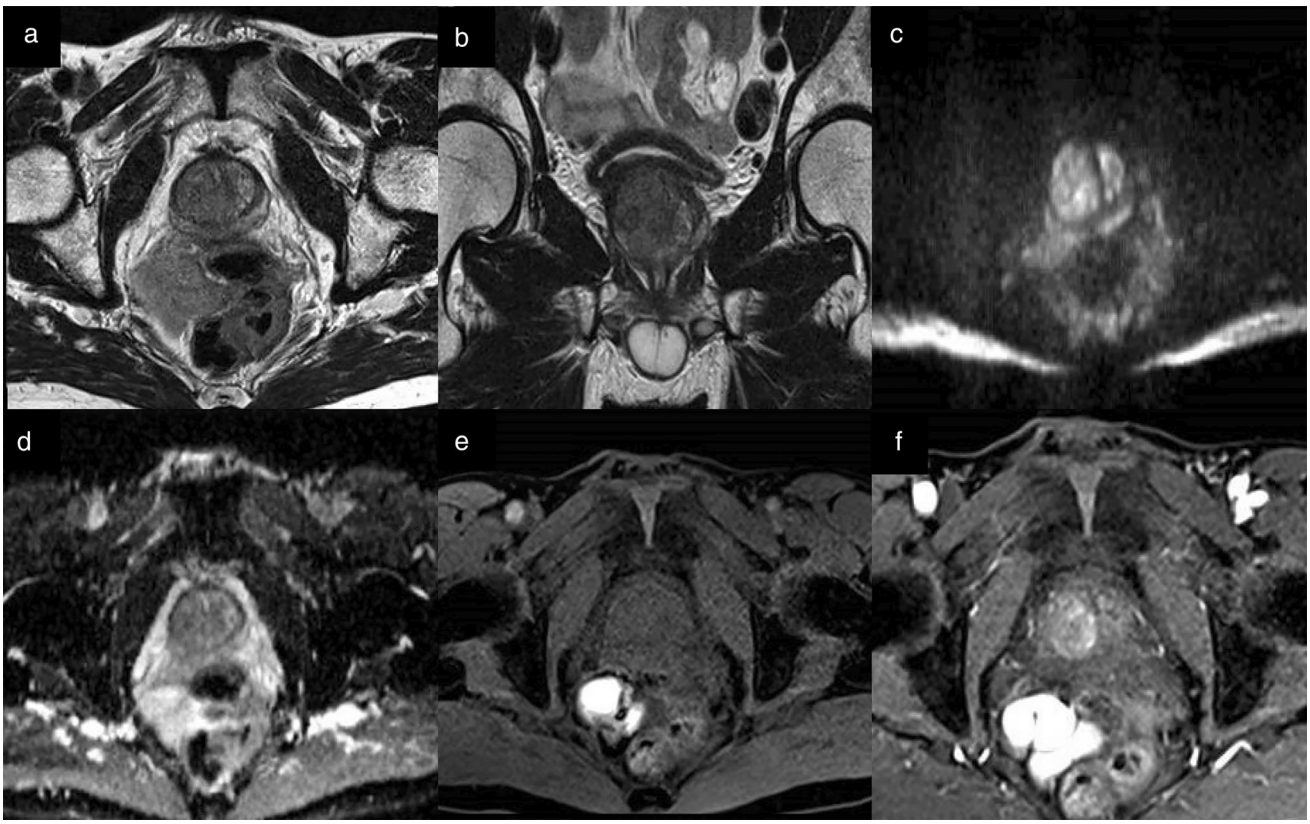

FIGURE 4: Axial (a) and coronal (b) T2-weighted imaging, high *b* value (1400 seconds/mm^2) (c), ADC map (d) and pre-contrast (e) and DCE acquisitions (f) of a study that was given a PI-QUAL score of 3. At least two MR sequences taken together are of diagnostic quality, as there are motion artifacts on T2-WI and artifacts from rectal distension on DWI.

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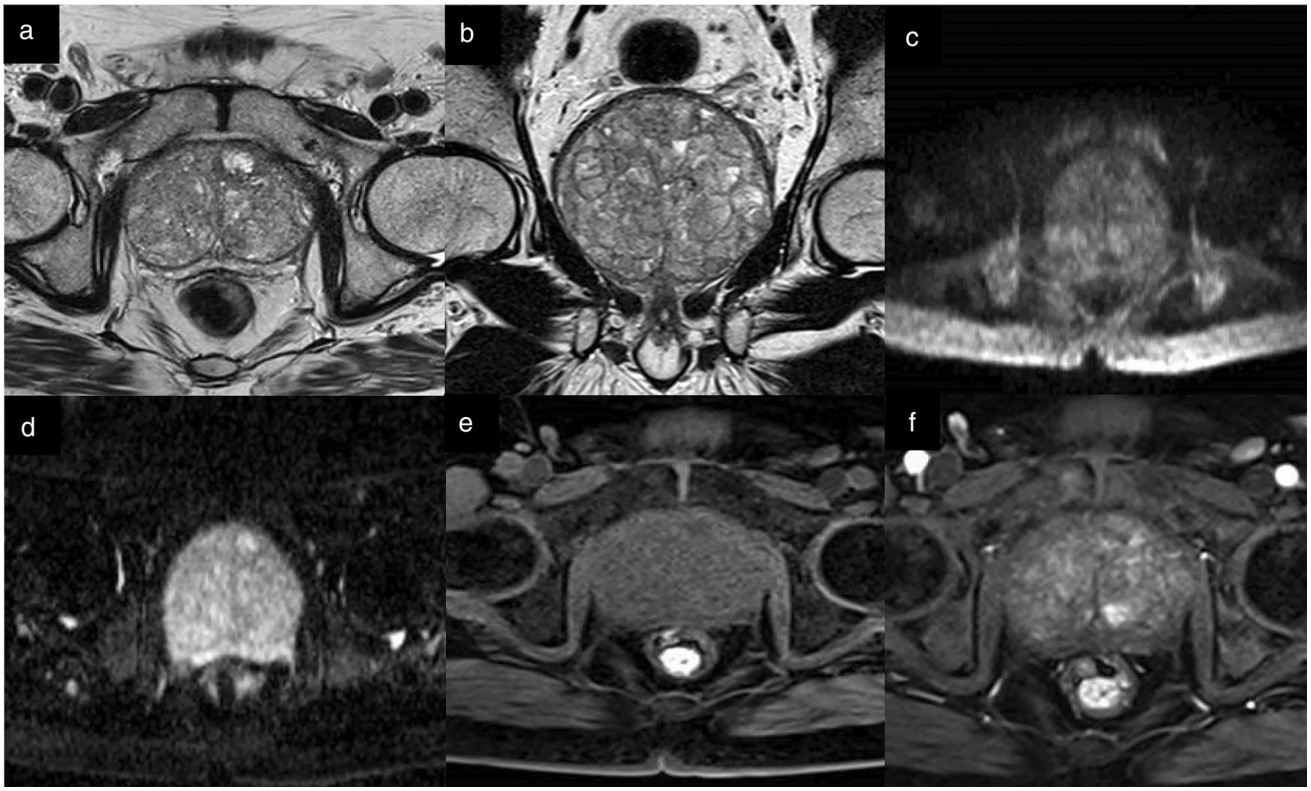

FIGURE 5: Axial (a) and coronal (b) T2w imaging, high *b* value (1400 seconds/mm^2) (c), ADC map (d) and pre-contrast (e) and DCE acquisitions (f) of a study that was given a PI-QUAL score of 4 for the presence of minor artifacts on the high *b* value sequence.

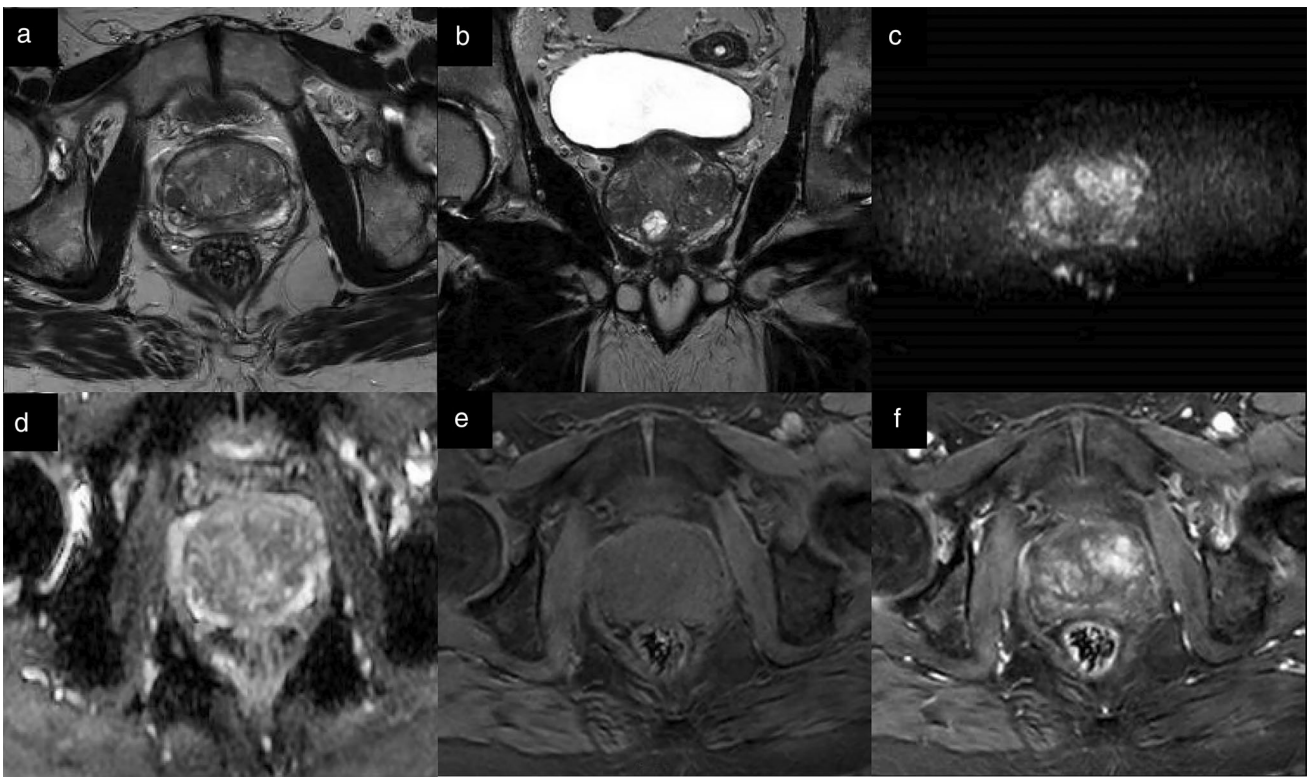

FIGURE 6: Axial (a) and coronal (b) T2w imaging, high *b* value (2000 seconds/mm^2) (c), ADC map (d) and pre-contrast (e) and DCE acquisitions (f) of a study that was given a PI-QUAL score of 5. All MR sequences are of optimal diagnostic quality and fully compliant with PI-RADS v. 2.1 technical recommendations.

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TABLE 2. List of Studies Utilizing the PI-QUAL Score

Author	Year	Country	MR system	ERC	Design	Aim	Interobserver agreement	Key Findings	Limitations
Giganti et al[114]	2021	United Kingdom	1.5 T and 3 T	No	Retrospective	To assess interobserver agreement of the PI-QUAL score	$\kappa = 0.85$	• $\kappa = 0.82$ when grouped into PI-QUAL 1-2, PI-QUAL 3, and PI-QUAL 4-5 • Highest agreement for T2-WI scans	• One radiologist trained the other • Population was for RALP hence may be biased towards more visible lesions
Boschheidgen et al[47]	2021	Germany	1.5 T and 3 T	No	Retrospective	To assess image quality and diagnostic ability of scans in patients with total hip arthroplasty at both 1.5 T and 3 T	N/A	• No difference in artefact severity between 1.5 T and 3 T	• Did not assess cancer prevalence • No interobserver agreement reported
Giganti et al[124]	2021	United Kingdom	1.5 T and 3 T	No	Retrospective	To compare the time taken to score PI-QUAL manually and when using a semi-automated software	N/A	• Significant reduction in time taken to score PI-QUAL using semi-automated software	• Sample size was small • Manual score was done by two radiologists together—no report of interobserver agreement
Arnoldner et al[64]	2022	Austria	3 T	No	Prospective	To assess the effects of endorectal gel and enema on image quality and visibility of lesions	$\kappa = 0.42$	• Significant improvement in subjective image quality in DWI and lesion visibility on both DWI and T2-WI • Higher PI-QUAL scores in the intervention group	• No assessment of confounding factors • Lack of blinding to gel administration • No separation to assess effect of either association
Karanasios et al[110]	2022	United Kingdom	3 T	No	Retrospective	To assess interobserver agreement and clinical impact of PI-QUAL scoring	$\kappa = 0.47$	• For indeterminate and negative scans, those of suboptimal quality (PI-QUAL 1-3) were more likely to undergo biopsy • Scans of suboptimal quality showed inferior ability to rule in and rule out csPCa	• Rate of true negatives could not be established as not all men went for biopsy

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TABLE 2. Continued

Author	Year	Country	MR system	ERC	Design	Aim	Interobserver agreement	Key Findings	Limitations
Girometti et al[108]	2022	Italy	1.5 T	No	Retrospective	To assess interobserver agreement for the PI-QUAL score	$\kappa = 0.55$	• Moderate interobserver agreement on both a 1–3 and 1–5 PI-QUAL scale. • Best agreement for diagnostic assessment of T2-WI, then DCE then DWI	• Relatively small sample size • PI-QUAL may be influenced by high proportion of PI-RADS 4 and above scans
Dinneen et al[117]	2022	United Kingdom	1.5 T and 3 T	No	Retrospective	To assess ability of mpMRI to detect EPE using a Likert scale and scan quality on diagnostic accuracy	N/A	• MpMRI scored using a Likert scale is an accurate method of detecting EPE • Higher scan quality (scored using PI-QUAL) correlates with improved EPE detection	• Radiologists were highly experienced—may not be generalisable • Relatively small sample size • No interobserver agreement reported
Giganti et al[131]	2022	United States of America	1.5 T and 3 T	No	Retrospective	To assess whether a specific training course on PI-QUAL could improve ability to use the score accurately	N/A	• A combination of a lecture and workshop on PI-QUAL improves accuracy in scoring for users with a range of experience in prostate MRI	• Only one reference standard • Small number of participants and cases
Pötsch et al[109]	2022	Austria	1.5 T and 3 T	No	Retrospective	To assess interobserver agreement for PI-QUAL and investigate its relationship to csPCa detection	$\kappa = 0.51$	• PI-QUAL interobserver agreement was moderate • Higher cancer prevalence in PI-QUAL ≥4 scans	• No investigation of cancer missed as scans of low suspicion were not biopsied
Windisch et al[116]	2022	France, Belgium, Italy, Switzerland	1.5 T and 3 T	Both	Retrospective	To assess the relationship between PI-QUAL and staging differences between MRI and pathology	N/A	• Scans of suboptimal quality were associated with higher rates of upstaging and lower rates of EPE detection	• Only one reader assessed PI-QUAL
Hötker et al[111]	2023	Switzerland	3T	No	Retrospective	To assess interobserver agreement for prostate	$\kappa = 0.58$	• Interobserver agreement was substantial for PSHS	• The different scoring systems assess different

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TABLE 2. Continued

Author	Year	Country	MR system	ERC	Design	Aim	Interobserver agreement	Key Findings	Limitations
						image quality scoring systems and relationship to cancer detection		and moderate for PI-QUAL • Improved sensitivity for detecting csPCa was seen for both scores at different thresholds	aspects of image quality, so comparison is limited • Cancer missed was not assessed
Forookhi et al[126]	2023	Italy	3 T	No	Prospective	To assess the effect of using a semi-automated program (Quantib®) for PI-RADS agreement, and PI-RADS agreement in relation to PI-QUAL scoring	$\kappa = 0.09–0.59$	• Quantib® is a useful tool for improving PI-RADS agreement for less experienced readers • For 2/4 (50%) readers, Quantib® improved agreement at all PI-QUAL scores	• One reader was used as a reference standard • No correlation to histology was made
Brembilla et al[115]	2023	Italy	1.5 T	Yes	Retrospective	To assess the relationship between PI-QUAL score and diagnostic ability of MRI	N/A	• Lower quality scans (PIQUAL 2 and 3) were more likely to be called equivocal (PI-RADS 3) • For equivocal scans, scans of lower quality were more likely to undergo biopsy and a lower PPV for detecting csPCa	• A single PI-QUAL score was given by two radiologists together—no possibility to calculate interobserver agreement • Few scans were PI-QUAL <4 (17%) meaning sample size was small for suboptimal quality scans
Wang et al[132]	2023	United States of America	3 T	No	Retrospective	To assess whether a specific lecture on the PI-QUAL score could improve ability to use the score accurately	N/A	• Separating scans into inadequate (PI-QUAL 1–3) and adequate quality (PI-QUAL 4–5) was significantly improved following the intervention for all readers, except for	• One reader was used as a reference standard • Small sample size of readers and scans

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TABLE 2. Continued

Author	Year	Country	MR system	ERC	Design	Aim	Interobserver agreement	Key Findings	Limitations
								abdominal imaging fellows	
Coelho et al[112]	2023	Brazil	3 T	No	Retrospective	To assess interobserver agreement and effect on staging of PCa of PI-QUAL	$\kappa = 0.52–0.69$	• Interobserver agreement was moderate to substantial for expert readers • Between scans of suboptimal and optimal diagnostic quality, no statistically significant difference in detecting EPE was observed	• Small sample size of scans of suboptimal quality
Basar et al[113]	2023	Turkey	1.5 T and 3 T	Both	Retrospective	To assess interobserver agreement among basic prostate MRI readers, following online teaching	$\kappa = 0.66–0.79$	• Interobserver agreement was substantial between all 5 readers. T2-WI and DCE imaging showed the highest level of interobserver agreement	• Pre-teaching interobserver agreement was not assessed • Small sample size of PI-QUAL <3 scans
Robertson et al[135]	2023	United States of America	3 T	No	Retrospective	To validate the PI-QUAL score to assess a quality improvement project	N/A	• PI-QUAL scores significantly improved following the project • Percentage agreement ranged from 67% to 77%	• Time consuming modification of shimming the magnetic field • Kappa values not used to assess interobserver agreement, limiting possibility for comparison
Sabbah et al[125]	2023	France	1.5 T and 3 T	N/A	Retrospective	To test a semi-automated software for PI-QUAL scoring on a data set of prostate bpMRI scans	N/A	• Assessment took 96 seconds on average	• The export of datasets is required which takes up storage and time

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TABLE 2. Continued

Author	Year	Country	MR system	ERC	Design	Aim	Interobserver agreement	Key Findings	Limitations
Ponsiglione et al[118]	2023	Italy	1.5 T and 3 T	No	Retrospective	To assess the effect of image quality on EPE detection	N/A	• The clinical nomogram outperformed EPE grade in lower quality scans • EPE grade was more accurate in higher PI-QUAL scans	• A single PI-QUAL score was given by 2–3 radiologists together—no possibility to calculate interobserver agreement • Radiologists were experts hence this may not be generalisable

csPCa = clinically significant prostate cancer; DCE = dynamic contrast enhancement; DWI = diffusion weighted imaging; EPE = extraprostatic extension; ERC = endorectal coil; mpMRI = multiparametric MRI; MRI = magnetic resonance imaging; PCa = prostate cancer; PI-QUAL = prostate image quality; PI-RADS = prostate imaging reporting and data system; PPV = positive predictive value; PSHS = prostate signal-intensity homogeneity score; N/A = not available; T = Tesla; T2-WI = T2-weighted imaging; *K* = Cohen's Kappa.

aspects of PI-QUAL to be automated. Nevertheless, the ultimate objective is to design a system capable of assessing image quality at the point of capture, but this would require integration of highly functional AI networks into scanner technology[5]—a particularly ambitious goal.

Key Point(s):

1. The first quality control efforts using AI have been introduced with encouraging results.

Recommendation(s):

1. Once reliable quality control methods have been introduced, the goal should be to train AI to execute this task.

Teaching Courses and Feedback Driven Learning

Teaching courses are an established method of conveying information and have been used before to benefit detection of csPCa for both urologists[127] and radiologists,[128,129] as well as for the detection of EPE.[128] In spite of this, not all attempts have been completely successful: in one study additional case-based discussion provided no additional benefit compared to interactive lectures alone for csPCa detection[128] and in another comparing two cohorts (those tasked with self-study and those with additional feedback-based learning), feedback only improved detection of tumors in the transition zone.[130] It has been suggested that radiologists should be taught via a combination of courses and supervision to improve experience with prostate MRI.[9]

With respect to image quality, there have been two examples of educational interventions which have aimed to facilitate effective use of the PI-QUAL score. The first comprised of a series of lectures and interactive workshops.[131] The second was simply a comparison before and after a single lecture on PI-QUAL that included detailed breakdown of the score and discussion of cases.[132] Both strategies resulted in a post-intervention improvement in accuracy for differentiating scans as suboptimal (PI-QUAL ≤ 3) and optimal (PI-QUAL ≥ 4). Interestingly, a greater improvement was seen for more experienced readers in the longer study,[131] while in the shorter one, the improvement got smaller as the reader experience increased.[132] However, in both of these studies it must be noted that there was only one (yet highly experienced) radiologist as a reference standard. Longer term follow-up would be beneficial to assess the longevity of such improvements and need for repeat interventions.

Key Point(s):

1. Results from PI-QUAL educational studies have shown that the field of prostate MR image quality can benefit from this approach,

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Recommendation(s):

1. The creation and attendance of teaching courses is needed to help promote quality control efforts worldwide.

The Future: Working Together for a Global Improvement of Image Quality

Image quality is a fundamental consideration in prostate MRI, which itself is key for the detection, diagnosis, and follow-up of PCa. Without ensuring that scans are of optimal diagnostic quality, investment into radiological training may not yield its full potential.

There are a variety of proxy measures for assessing image quality, and many of these are subjective. This, combined with the fact that individual studies use a variety of preparations, coil setups, field strengths, scoring systems and even cohorts, means that efforts should be made on both a quality assurance and a quality control front to design large, multicenter trials which can lead to Level I evidence for or against a particular strategy.

There exists an ongoing debate regarding the use of bpMRI vs. mpMRI for detection of csPCa and the results of the first multicenter trials, including PRIME,[133] are eagerly awaited. However, regardless of the outcome, one should not underestimate the utility of DCE as a safety net in cases where DWI is hampered by artifact.[134]

It is still likely that there will be always minor differences in how each center conducts prostate MRI, therefore a reliable method of ascertaining whether a scan meets diagnostic quality or not is essential. Scoring systems to assess image quality, in particular PI-QUAL, are now starting to be implemented, associated with specific teaching courses and case-based learning. Various studies have reported positive results and PI-QUAL (and its future iterations) is deserving of confidence.

Achieving optimal scan quality may result from a combination of AI or use of sequences outside the traditional mpMRI. These could be useful on an ad hoc basis when image quality is compromised by artifacts. In the future, in order to standardize quality worldwide, it may be possible to accredit centers, as is being trialed with the ACR Prostate Cancer MRI Center Designation.[13] This will involve certification at both a scanner but also center level, using central submission as a tool for ensuring standardization.

As centers continue to perform prostate MRI, a focus on image quality is imperative. The momentum of recent research must be translated into practical recommendations at national level. Non-academic centers could benefit from submitting scans for central review and participating in training on how they can internally assess scan quality. Standardized quality control may be in fact be more realistic than standardized quality assurance, as there may never be comprehensive guidance on how to scan the prostate from start to finish.

TABLE 3. Questions for Centers Conducting Prostate MRI

Is the MRI scanner calibrated and checked regularly?
Is the prostate MRI protocol compliant with the PI-RADS technical recommendations?
Is image quality evaluated for each scan routinely?
Do you perform any patient preparation?
Do you formally score prostate MRI quality (eg, using PI-QUAL)?
Does the radiographer have license to repeat/interrupt sequences if artifacts from movement or rectal air are noticed?
Do you formally review external MRI scans to check image quality?
Do you repeat a scan before biopsy if the image quality is low?

MRI = magnetic resonance imaging; PI-RADS = prostate imaging reporting and data system; PI-QUAL = prostate image quality.

Finally, as shown in both this review and by Barrett and colleagues,[8] we have outlined some important questions for prostate MRI which centers could reflect on in order to ensure quality along the PCa diagnostic pathway (Table 3).

In conclusion, the field of image quality in prostate MRI is rapidly evolving, with opportunities for improvement across a variety of processes including patient preparation, scanner setup, additional sequences, teaching courses and AI. The recent standardized assessment of prostate MRI is expected to facilitate these developments, which will inevitably result in the refinement of future recommendations.

Conflict of Interest

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