



# Strategies for improving image quality in prostate MRI

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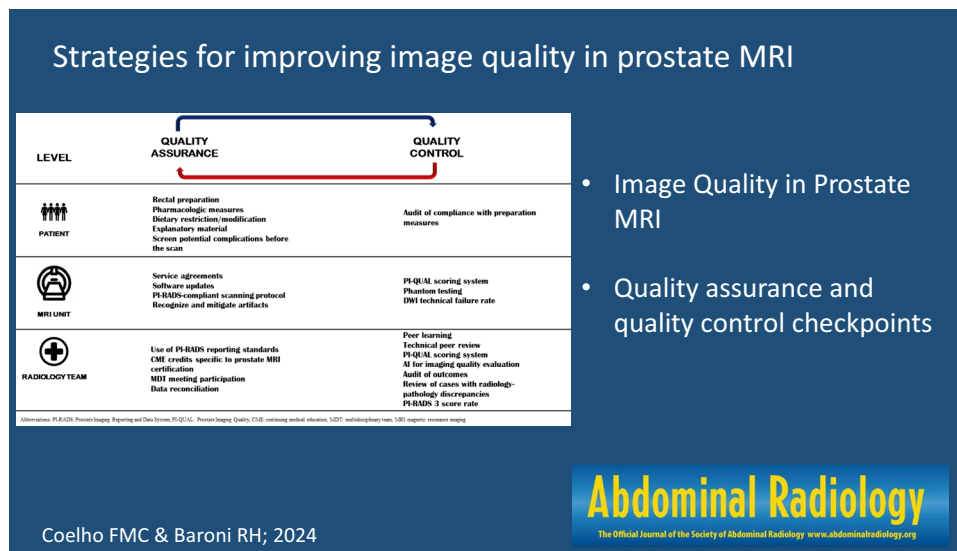
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## Abstract

Prostate magnetic resonance imaging (MRI) stands as the cornerstone in diagnosing prostate cancer (PCa), offering superior detection capabilities while minimizing unnecessary biopsies. Despite its critical role, global disparities in MRI diagnostic performance persist, stemming from variations in image quality and radiologist expertise. This manuscript reviews the challenges and strategies for enhancing image quality in prostate MRI, spanning patient preparation, MRI unit optimization, and radiology team engagement. Quality assurance (QA) and quality control (QC) processes are pivotal, emphasizing standardized protocols, meticulous patient evaluation, MRI unit workflow, and radiology team performance. Additionally, artificial intelligence (AI) advancements offer promising avenues for improving image quality and reducing acquisition times. The Prostate-Imaging Quality (PI-QUAL) scoring system emerges as a valuable tool for assessing MRI image quality. A comprehensive approach addressing technical, procedural, and interpretative aspects is essential to ensure consistent and reliable prostate MRI outcomes.

## Graphical abstract



**Keywords** Magnetic resonance imaging · Prostate cancer · Image quality · Quality assurance · Quality control · PI-QUAL · PI-RADS

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## Introduction

With a high level of evidence, prostate magnetic resonance imaging (MRI) is the first-line examination in the evaluation of patients with suspected prostate cancer (PCa) [1–4].

MRI is a valuable tool due to its ability to detect clinically significant PCa (csPCa), which is defined as a Gleason grade  $\geq 3 + 4$ /International Society of Urological Pathology (ISUP) [5] grade  $\geq 2$ , and/or tumor volume  $> 0.5 \text{ cm}^3$ , and/or the presence of extraprostatic extension [6]. Consequently, there is a reduction in unnecessary biopsies, thereby lowering the diagnosis rate of clinically insignificant PCa [1–4]. It is worth noting that the European Association of Urology (EAU) [7] and American Urological Association (AUA) [8] strongly recommend prostate MRI as the first imaging study for patients with suspected PCa. Hence, the MRI pathway carries notable responsibility for downstream outcomes.

While some studies demonstrate excellent results, there is significant global variation in MRI diagnostic performance [9, 10], primarily due to image quality and radiologist expertise. A multicenter study found that 40% of prostate MRI images in the United Kingdom were of suboptimal quality [11]. Poor image quality increases uncertainty and reduces examination accuracy [11, 12]. In this regard, the Prostate Imaging Reporting and Data System (PI-RADS) was created in 2012 [13] with updates in 2015 [14] and 2019 [6]. It presents the minimum technical standards to reduce examination variability and optimize image quality [6]. However, adhering solely to these recommendations does not guarantee high image quality. There are several factors that the PI-RADS recommendations do not address or are not clear about, such as the age of the scanner, surface coil quality, magnet field and gradient strengths, software updates, and




scanner-specific sequence optimization [15]. Moreover, patient-related issues, such as stool/air in the rectum, may cause artifacts, resulting in poor-quality images [15–17].

In this scenario, the European Society of Urogenital Radiology (ESUR) consensus has emphasized the importance of MRI quality by recommending that image quality be checked and reported [18]. In a recent review, Barrett et al. designed quality checkpoints to help minimize variation in practice and ensure consistency of outcomes through quality assurance (QA) and quality control (QC) processes [16]. These components can be applied to three levels for image quality: patient, MRI unit, and radiology team [15, 16]. Therefore, QA and QC components must be established to improve MRI quality outcomes.

Our article discusses strategies to improve image quality in prostate MRI at the patient, MRI unit, and radiology team levels. We also cover QA and QC concepts to enhance image quality outcomes.

## Quality assurance and quality control

The guarantee of QA and QC is the turning point for obtaining an MRI with optimal image quality. Although the terms are interchangeable and there is some overlap, QA and QC present distinct characteristics [15, 16]. *In QA, procedures are established to uphold high quality, while QC evaluates*

LEVEL	QUALITY ASSURANCE	QUALITY CONTROL
 PATIENT	Rectal preparation Pharmacologic measures Dietary restriction/modification Explanatory material Screen potential complications before the scan	Audit of compliance with preparation measures
 MRI UNIT	Service agreements Software updates PI-RADS-compliant scanning protocol Recognize and mitigate artifacts	PI-QUAL scoring system Phantom testing DWI technical failure rate
 RADIOLOGY TEAM	Use of PI-RADS reporting standards CME credits specific to prostate MRI certification MDT meeting participation Data reconciliation	Peer learning Technical peer review PI-QUAL scoring system AI for imaging quality evaluation Audit of outcomes Review of cases with radiology-pathology discrepancies PI-RADS 3 score rate

Abbreviations: PI-RADS: Prostate Imaging Reporting and Data System, PI-QUAL: Prostate Imaging Quality, CME: continuing medical education, MDT: multidisciplinary team, MRI: magnetic resonance imaging

Fig. 1 Recommended quality assurance and quality control checklist

whether quality standards are being upheld, thereby focusing on quality assessment. Published articles have shown examples of attention points in the QA process and QC checks for patients, MRI units, and radiologists (Fig. 1) [15, 16].

Patient-level issues such as rectal spasms, stool/air in the rectum, and hip metalwork can affect image quality even if the MRI protocol is optimal. Therefore, actions should be taken to mitigate low-quality images related to patient issues [19].

At the MRI unit level, diagnostic imaging facilities must meet local regulatory requirements and conduct regular calibration tests for MRI scans. In this regard, the American College of Radiology (ACR) has a process for centers to become "designated" for prostate MRI if they are already ACR accredited in body MRI [15, 20]. In the United Kingdom, the QA program led to a significant improvement in the quality of prostate MRI [21].

Moreover, prostate MRI protocols should include at least the minimum quality criteria recommended by PI-RADS to achieve a high-quality examination [6]. Factors such as magnet strength, gradient strength, scanner age, and available software updates should be primarily evaluated for this. Scanner age, especially for 1.5 T magnets and at a cut-off time of over seven years, has been shown to correlate with reduced image quality [11]. The utilization of the Prostate Imaging Quality (PI-QUAL) scoring system is a valuable tool for retrospectively measuring the quality of prostate MRI examinations [22–26].

Additionally, QA processes and QC checks should also be implemented for radiologists. The use of PI-RADS in reports, prostate MRI certification, and participation in multidisciplinary team (MDT) meetings are QA actions. QC checkpoints include peer learning, outcome audits, review of discrepant cases, and the PI-RADS 3 score rate [15, 16]. It is well known that experienced radiologists and MRI physicists can substantially improve prostate MRI quality [21]. In this line, the ACR Education Center offers courses for the continuous education of radiologists, who can receive the "ACR Certificate of Proficiency" in prostate MRI [20].

On this line, the ACR designed several initiatives to establish QA and QC programs [20]. An important step of ACR was the creation of the Prostate MR Image Quality Improvement Collaborative as part of the ACR Learning Network. A recent study showed that the collaborative learning network model achieved a 20% increment of PI-QUAL  $\geq 4$  [27]. Moreover, the PRIME trial's quality control phase evaluated MRI scanners' image quality using the PI-QUAL scoring system at baseline (phase I) and after feedback (phase II) [10]. The study found a substantial increment in image quality in phase II assessment. These results highlight the relevance of robustly implementing QA and QC

programs to achieve better image quality and, consequently, clinical outcomes.

The new version of Prostate Cancer Radiological Estimation of Change in Sequential Evaluation (PRECISE) recommendations supports image quality evaluation with a dedicated scoring system (PI-QUAL) [28]. Additionally, the expert panel achieved a high agreement to recommend an optimal MRI scan (PI-QUAL  $\geq 4$ ) to follow patients in active surveillance safely and to repeat exams of suboptimal quality. This PRECISE version 2 provided a new score (PRECISE score X) for cases where the score cannot be applied, such as poor image quality.

In this regard, the discussion on the image quality of prostate MRI through QA and QC measures must have a broad global reach. Hence, the PI-RADS document, which significantly impacts the medical community, should incorporate checkpoints and respective procedures for QA and QC. Standardization of this assessment is crucial for advancing the MRI pathway in PCa.

The QA and QC actions addressing patient-level issues, MRI units, and radiologists are vital for obtaining adequate-quality images. The following sections discuss various approaches to achieving and increasing the image quality of prostate MRI at each level.

## Patient-level issues

One of the initial steps to ensure optimal quality prostate MRI is patient preparation. Patient preparation can occur at two moments: pre-examination and on-site. *The primary objective is to minimize artifacts such as motion, rectal gas, and peristalsis, which are patient-level issues.*

The PI-RADS document does not provide formal guidance on prostate MRI preparation recommendations [6]. A scoping literature review showed favorable results for patient preparation, especially regarding enemas [29]. However, there is not a high level of evidence, and the choice of appropriate and feasible strategies depends on each center's investigation and expertise.

This section discusses the main types of patient preparation (dietary restriction, enema, rectal catheter, and antispasmodics) and some additional items that can increase prostate MRI quality.

## Pre-examination orientation

Pre-examination orientation is the first step towards achieving high-quality prostate MRI. Potential complications, such as metallic prostheses, pacemakers, and claustrophobia, can be screened for when scheduling the exam. In these cases, the MRI department can allocate the patient to a suitable

machine, optimizing the department's time on the exam day and improving image quality due to the procedure being performed on an appropriate scan.

During scheduling, a brief explanatory material about the prostate MRI procedure can be sent to the patient. Prior knowledge of the examination flow helps minimize anxiety and increase patient adherence. Some centers recommend sexual abstinence for three days before the exam to ensure maximum seminal vesicle distension. However, the clinical benefit is controversial [30, 31].

Additionally, although there is no strong evidence, dietary restriction/modification guidance can also be provided. Consuming a liquid diet in the 6 h preceding the exam theoretically helps reduce intestinal peristalsis artifacts. Purysko et al. found an improvement in image quality, reduction in rectal content, and improvement in diffusion-weighted imaging (DWI) distortion artifacts in the dietary restriction and enema groups. However, the enema group showed better performance [32]. Sathiadoss et al. compared five rectal preparation strategies and reported a smaller rectal diameter, improved image quality, and reduced artifacts in the enema + dietary restriction group and the enema + dietary restriction + antispasmodic agent group [33]. On the other hand, Schmidt et al. showed an increase in stool/air in the rectum and geometric distortion of DWI in the dietary restriction without the enema group compared to the dietary restriction with the enema group [34]. *These studies*

*are insufficient to affirm that dietary restriction significantly improves prostate MRI quality.*

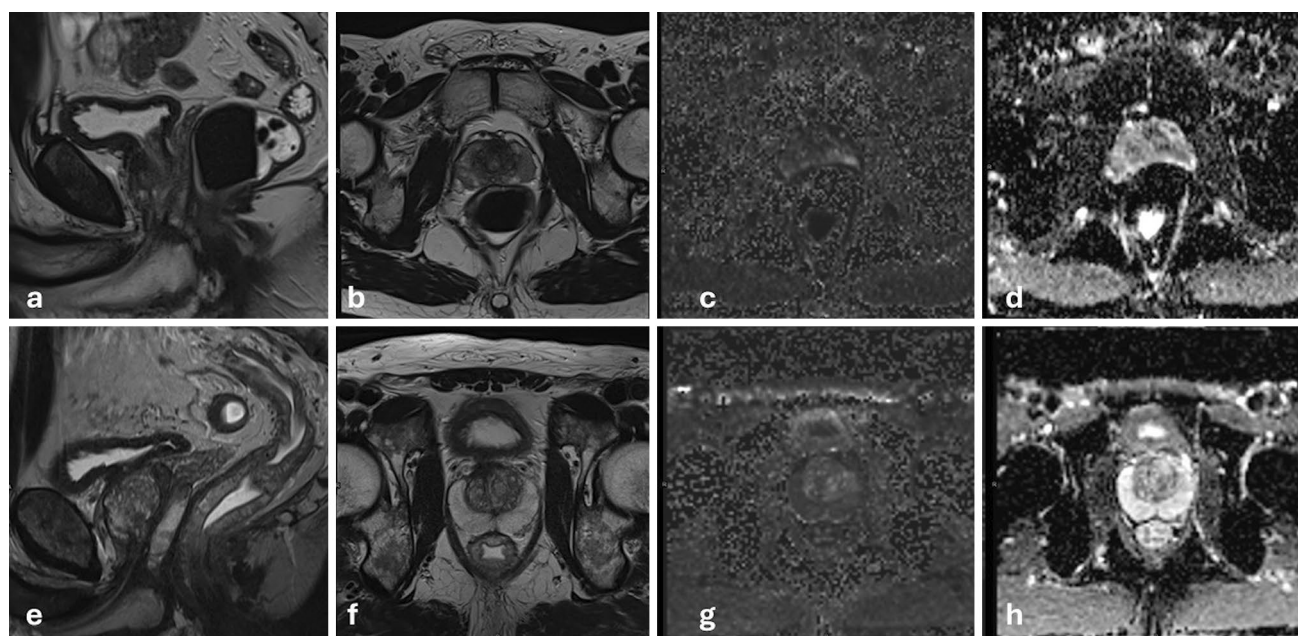
## On-site actions

The MRI team should be kind and receptive to welcome patients and reduce exam anxiety. Technologists and medical staff should be available to answer any questions before the exam starts. *Moreover, several actions, such as enema, rectal catheter, and antispasmodic agents, can enhance image quality at the prostate MRI examination.*

## Enema

Enema can be helpful to improve prostate MRI quality by reducing stool/air in the rectal ampulla (Fig. 2). Seven studies demonstrate a reduction in rectal ampulla diameter [29]. Plodeck et al. reported improved DWI sequence quality due to artifact reduction [35]. This result is in line with the studies by Purysko et al. and Smith et al. [32, 34]. On the other hand, another study reported improved DWI quality only in the enema + dietary restriction group [33].

Arnoldner et al. reported a significant improvement in image quality through PI-QUAL and lesion visualization for T2W and DWI sequences in the enema group [36]. In



**Fig. 2** Prostate MRI at 1.5T scan without bowel preparation showing air at the rectal ampulla on T2W images on sagittal (a) and axial (b) planes. Note distortion artifacts on diffusion-weighted imaging with a b value of 1500 sec/mm<sup>2</sup> (c) and ADC map (d). These artifacts

reduce the accuracy of ruling out clinically significant prostate cancer. Another exam in the same scan and protocol with bowel preparation demonstrating an empty rectal ampulla on T2W imaging (e,f) and high-quality DWI (g) and ADC map (h)

contrast, other publications found no significant reduction in T2-weighted (T2W) sequence artifacts [32, 34]. Lim et al. did not demonstrate a statistically significant difference between the groups without preparation and enema for DWI and T2WI sequences [37].

Nonetheless, only one study evaluated the enema's clinical impact on csPCa detection and reported no reduction in the Gleason  $\geq 7$  false-negative rates [38].

### Rectal catheter

The rectal catheter aims to reduce air in the rectal ampulla. However, there is a lack of publications evaluating the impact of rectal catheter use on prostate MRI quality.

Huang et al. reported a reduction in rectal ampulla diameter, an improvement in T2W and DWI sequences, and a reduction in DWI artifacts [39]. Another article compared the group with catheter use to the group without catheter+enema and found a significant decrease in image quality, artifacts, and rectal content in the catheter group [40].

### Antispasmodic agents

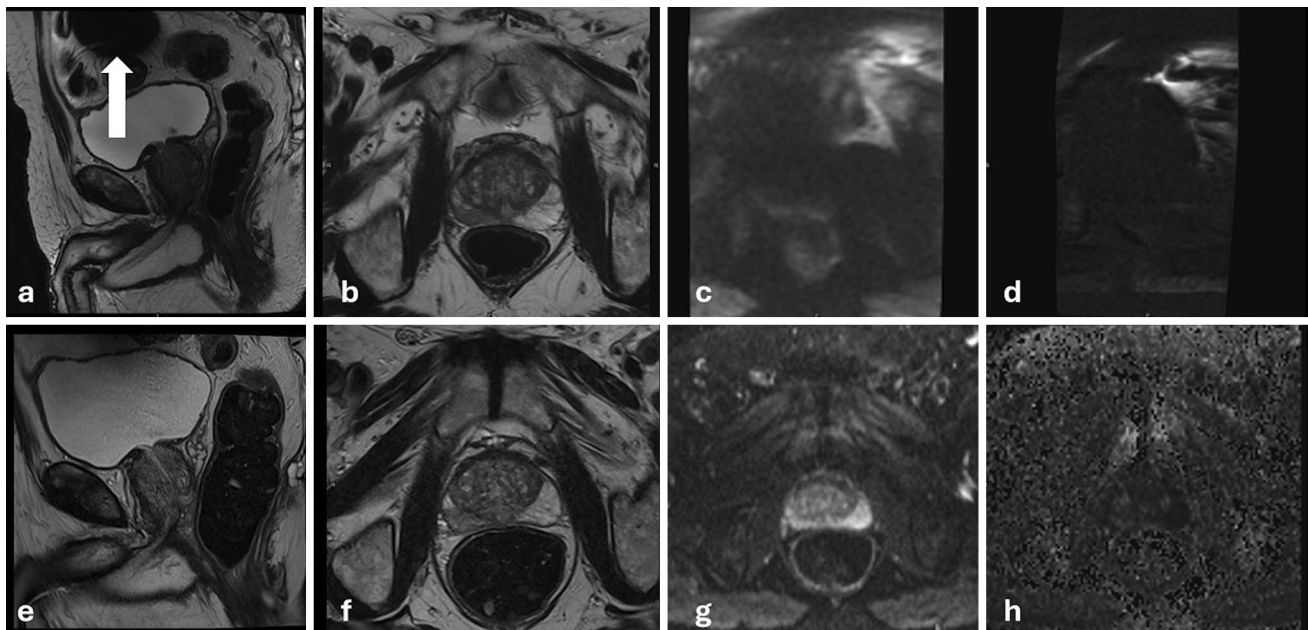
Antispasmodics reduce intestinal peristalsis. The most used antispasmodic is hyoscine butylbromide (HBB), administered intravenously at 20 or 40 mg. Although many studies

have evaluated its utilization, there is still no consensus on the real impact of HBB on prostate MRI quality.

Ullrich et al. evaluated the effect of antispasmodic on anatomical detail visualization and motion artifacts in high-resolution T2W sequences. The authors reported improved image quality and reduced motion artifacts with antispasmodic use [41]. Another publication evaluated the impact of antispasmodic on anatomical and functional image quality through T2W and DWI sequences with the apparent diffusion coefficient (ADC) map. The study showed a significant improvement in T2W image quality with antispasmodic use; however, there was no substantial upgrade in the DWI or ADC map [42]. On the other hand, some studies did not show an overall enhancement in MRI image quality [33, 34, 43].

### Mri unit level

Two variables widely discussed in achieving high-quality prostate MRI are magnetic field strength and coil selection. The main questions often asked are: 1) *Can prostate MRI be performed on a 1.5 T scanner, or is a 3 T scanner necessary?* 2) *Does an MRI exam without an endorectal coil (ERC) have image quality comparable to an ERC?*



**Fig. 3** A 77-year-old man with elevated serum prostate-specific antigen (PSA) levels with a previous history of aortoiliac endoprostheses. The 3T prostate MRI scan images show metalwork artifacts (arrow) on T2W imaging on the sagittal plane (a) and good quality on T2W imaging on the axial plane (b). Note metalworks artifacts on diffusion-weighted images at 50 sec/mm<sup>2</sup> (c) and 1500 sec/mm<sup>2</sup> (d)

b-values, determining poor imaging quality. The patient was recalled to be examined in a 1.5T scan. The imaging quality on T2W images on sagittal (e) and axial planes (f) and diffusion-weighted images at 50 sec/mm<sup>2</sup> (g) and 1500 sec/mm<sup>2</sup> (h) b-values. The MRI was classified as PI-RADS 2 with a high confidence level

This section covers points related to image quality at the MRI unit level, such as MRI magnets (1.5 T vs. 3 T), MRI coils (surface coil vs. ERC), MRI protocols, and artifacts.

### Scanner magnet field strength

There is an important debate regarding the clinical impact of magnetic field strength on prostate MRI exams: 1.5 T vs. 3 T. The primary effect of higher magnetic field strength is a linear increase in signal intensity with the static magnetic field. However, the signal-to-noise ratio (SNR) remains stable. Consequently, higher spatial resolution and reduced scanning time are possible. On the other hand, there is a higher propensity for artifacts in 3 T scanners (Fig. 3) [44].

Rouvière et al. published a review article on this topic in 2005, posing a relevant question: "Prostate MR imaging at high-field strength: evolution or revolution?" [45]. The authors questioned whether we should expect a significant improvement with 3 T MRI over 1.5 T. The PI-RADS v2.1 guideline recommends using 3 T MRI, except in cases involving implants and devices due to the propensity for artifacts [6].

Few studies in the field have been published to date. A prospective article evaluated the influence of imaging and histological factors on PCa detection and found that factors related to cancer detection rate were Gleason score, histological volume, histological architecture, and location. However, neither magnetic field strength nor coil type were cancer detection-related [46].

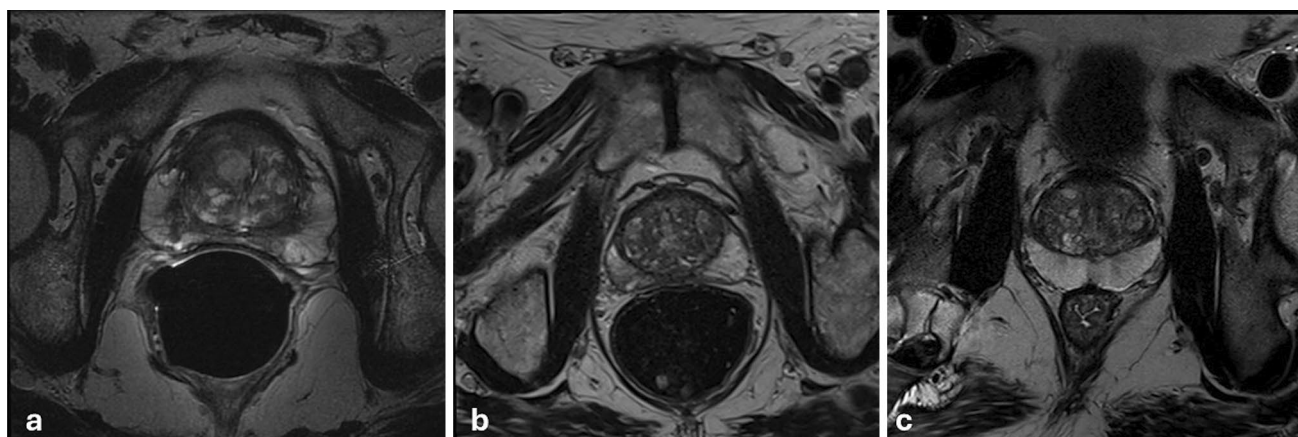
A non-inferiority trial compared image quality between 1.5 T and 3 T MRI with body coils and found similar SNR

and contrast-to-noise ratio (CNR) in objective analysis [47]. Furthermore, the authors found that the PI-RADS scores were comparable. However, subjective evaluation (based on the Likert scale) was significantly higher for 3 T scans in T2W sequences and a high b-value DWI and ADC map.

A retrospective study compared performance between 1.5 T MRI with an ECR and 3 T MRI without an ECR, showing comparable image quality and diagnostic performance between the scans [48]. Another retrospective cohort compared diagnostic performance between 1.5 T and 3 T MRI in PCa staging and localization, demonstrating the better performance of the 3 T scanner in staging (including dynamic contrast-enhanced [DCE] sequence) [49]. For lesion localization, there was no statistically significant difference.

A meta-analysis evaluated diagnostic performance in PCa staging between 1.5 T and 3 T MRI and found no statistically significant difference between magnetic fields [50].

*Therefore, we support that optimized protocols on 1.5 T and 3 T MRI scanners can perform prostate exams with sufficient image quality. However, aligned with the PI-RADS v2.1 recommendation, we suggest performing exams on 3 T scanners whenever possible.* Despite the increasing availability of 3 T scanners, 1.5 T are still much more prevalent worldwide, especially in developing countries and public healthcare systems. Thus, both magnetic fields are safe for prostate evaluation, ensuring greater access to prostate MRI for the population.



**Fig. 4** 1.5T MRI scans with ERC (a) and surface coil (b) and a 3T with surface coil (c). All T2W sequences on the axial plane demonstrate good contrast resolution and adequate evaluation of the prostate

and adjacent structures, with excellent quality. However, the 3T imaging (c) shows better SNR and CNR than 1.5T (a,b)

## MRI coils

Historically, the type of coil has been a significant point of discussion regarding prostate MRI image quality. For a long time, the central premise for using ERC was to enhance image quality, especially on 1.5 T scanners.

Baur et al., using 3 T MRI, demonstrated a better-quality rate for T2W and DWI sequences with ERC use; however, there was no clinically significant difference in index PCa identification and evaluation [51]. Additionally, patients preferred MRI without ERC. Another study on 3 T MRI comparing MRI with and without ERC showed comparable image quality in T2W sequences and better image quality in DWI with ERC for one of the two readers. Additionally, patients reported mild to moderate discomfort and pain [52].

Conversely, a study with a sample of twenty-three patients found no statistically significant difference in image quality but demonstrated higher diagnostic accuracy in detecting Gleason score 7 (3 + 4) PCa using ERC [53]. Another publication on 3 T MRI comparing ERC and wearable pelvic coils (WPC) found similar image quality, reduced artifacts in T2W imaging, and inferior zonal anatomy distinction in DWI with WPC [54]. Additionally, SNR was lower with ERC than with WPC.

Overall, SNR is higher in exams with ERC. However, studies are divergent regarding the clinical impact of MRI with ERC. Therefore, the central question is whether ERC is better to the extent that it must be used in all exams. The main counterpoints widely known are patient discomfort, increased cost, reduced workflow efficiency, coil-related artifacts, and longer exam time for coil positioning [52, 55]. These variables carry significant weight in the decision to use ERC or not. *Despite several factors that should be considered for this decision, the exams can be adequately and safely performed without ERC.*

Due to the satisfactory results of using 1.5 T and 3 T MRI without ERC (Fig. 4), the PI-RADS guideline recommends performing exams with optimized protocols to achieve better and more consistent image quality with the MRI equipment [6].

## MRI protocol

The parameters for prostate MRI recommended by the PI-RADS Steering Committee are shown in Table 1.

The preferred patient positioning for prostate MRI is supine. In addition to being more comfortable, it reduces breathing artifacts and prostate motion compared to the prone position [56].

**Table 1** MRI technical parameters for T2W, DWI, and DCE from PI-RADS steering committee

	T2W	DWI	DCE
TE (msec)		≤90	<5
TR (msec)		≥3000	<100
Slice Thickness (mm)	≤3	≤4	3
Gap	No gap	No gap	No gap
FOV (cm)	12–20	16–22	encompass the entire prostate gland and seminal vesicles
In-plane dimension	≤0.7 mm phase and ≤0.4 mm frequency	≤2.5 mm phase and frequency	≤2 mm x ≤2 mm
In-plane resolution			
Fat saturation		Recommended	Recommended (also perform subtraction)
b-value		At least two b-values (0–100 s/mm <sup>2</sup> and 800–1000 s/mm <sup>2</sup> ) to calculate ADC map High b-value ≥ 1400 s/mm <sup>2</sup>	
Temporal resolution (sec)			≤15
Total observation rate (min)			≥2
Dose and injection rate			0.1 mmol/Kg standard GBCA 2–3 cc/sec starting with continuous image data acquisition

MRI magnetic resonance imaging, T2W T2-weighted, DWI diffusion-weighted imaging, DCE dynamic contrast-enhanced, PI-RADS Prostate Imaging Reporting and Data System, TE Time of echo, TR time of repetition, FOV field of view, GBCA gadolinium-based contrast agents

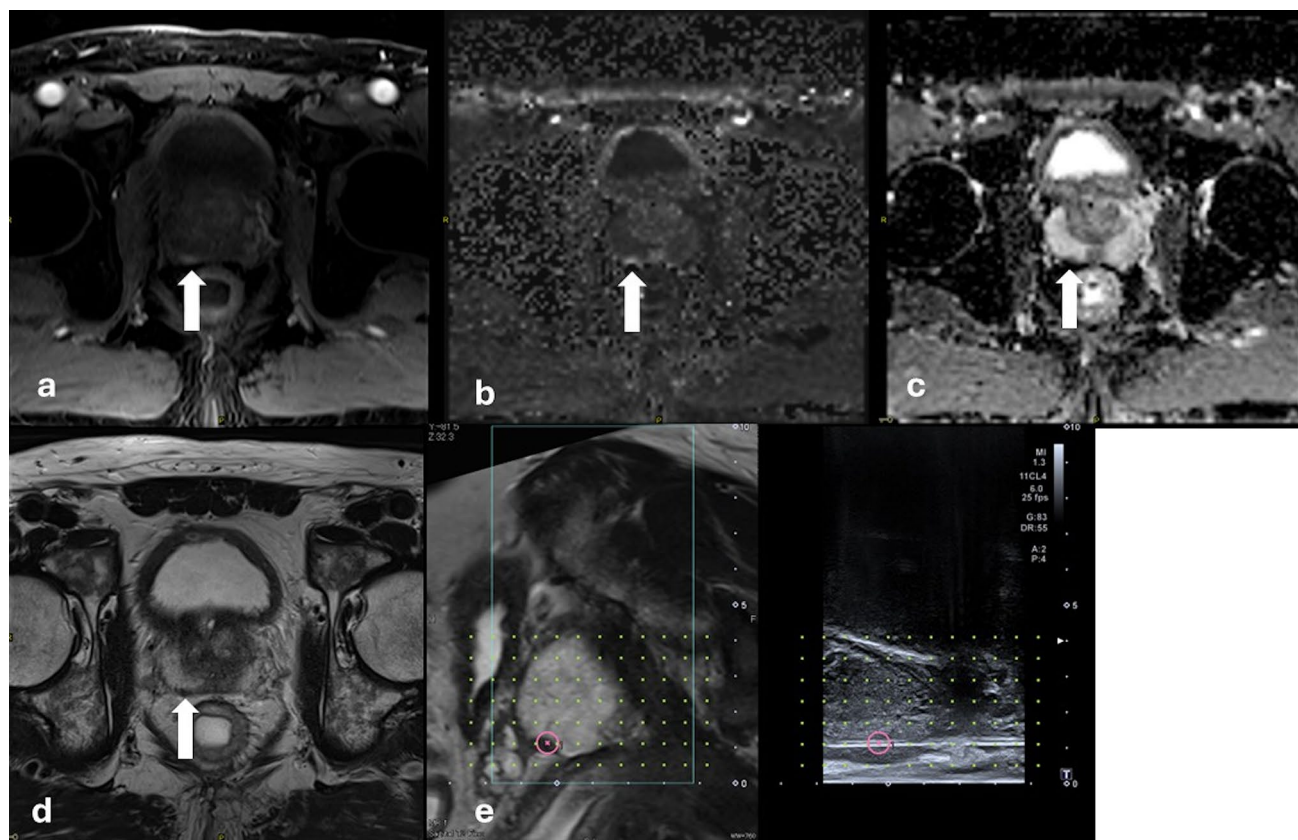
Although MRI examination protocols may vary among different centers, four sequences are of utmost importance and recommended by the PI-RADS guideline: T1-weighted (T1W), T2W, DWI, and DCE [6]. Each sequence has specific characteristics and allows the evaluation of different parameters comprising the multiparametric MRI protocol.

T1W sequences are important for detecting hemorrhagic foci in the prostate, which may occasionally be seen months after biopsy [57]. T1W sequences are commonly fast spin echo (FSE) or gradient echo (GRE) and can be acquired with or without fat suppression. To facilitate correlation with other sequences, it is advisable to keep some parameters, such as gap and slice thickness, similar to other sequences [6]. Some authors suggest performing these sequences with a wide field of view (FOV) to investigate suspicious lymph nodes and bone metastases [58].

The dedicated two-dimensional (2D) T2W sequence provides the highest soft tissue contrast and resolution for prostate imaging. Commonly acquired planes include axial, coronal, and sagittal. Some centers prefer to perform oblique axial and coronal T2 sequences oriented by the peripheral zone. *The PI-RADS guideline recommends a*

*slice thickness of 3 mm, no gap, and a FOV of 12–20 cm covering the entire prostate and seminal vesicles [6]. Tri-dimensional (3D) T2 sequences using isotropic voxels can be obtained to evaluate the anatomy in greater detail. Although studies have not shown a significant difference in tumor detection and glandular delineation [59–62], it should not replace 2D acquisitions by the PI-RADS Steering Committee [6].*

DWI is one of the main sequences in multiparametric MRI, commonly acquired in the axial plane, matching with T2W and DCE sequences. *DWI should be obtained with a slice thickness of  $\leq 4$  mm, no gap, and a FOV of 16–22 cm [6]. We recommend using a slice thickness of 3 mm whenever possible to match the parameters of the T2 sequence.* DWI sequences can be acquired with different b-values, but at least two b-values should be obtained [6, 63, 64]. The PI-RADS recommends acquiring high b-values of at least 1000 s/mm<sup>2</sup>, with a value higher than 1400 s/mm<sup>2</sup> for interpretation. *Additionally, high b-values can be extrapolated from low b-values using computational techniques, reducing acquisition time and potential distortion and ghosting [65, 66]. The extrapolated high b-value also presents better*



**Fig 5.** A 67-year-old man with altered digital rectal examination. Note the safety net role of the DCE sequence (a). The lesion in the right base of the peripheral zone is clear on DCE (a). There is less

conspicuity on DWI with high b-value (b), ADC map (c), and T2W imaging (d) (arrow). The transperineal MRI-ultrasound fusion targeted biopsy (e) confirmed a Gleason 7 (3+4) adenocarcinoma



image quality and SNR than acquired values, with similar tumor detection rates for PCa [65].

The ADC map should be generated from at least two b-values to quantify diffusion restriction (in  $\text{mm}^2/\text{s}$ ) and avoid T2 shine-through effects. The quality of the ADC map, and consequently PCa detection, is related to the proper selection of b-values [67, 68]. There is debate regarding b-value selection [68, 69], with a consensus that using more b-values increases the accuracy of estimated ADC values [70]. The highest b-value recommended by PI-RADS for ADC map is  $1000 \text{ s}/\text{mm}^2$  [6].

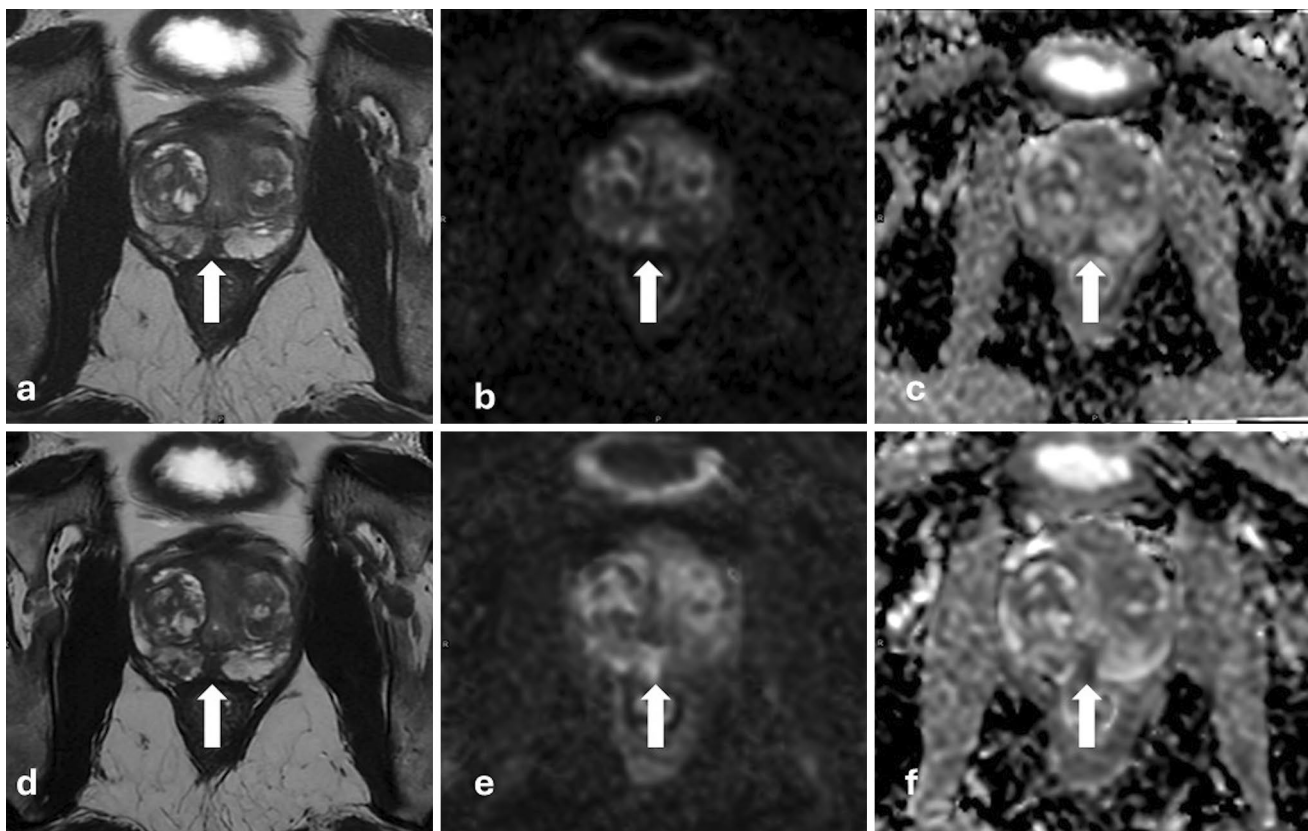
As the PI-RADS guideline recommends, DCE should be obtained with a slice thickness of 3 mm, FOV encompassing the entire prostate gland and seminal vesicles, and a temporal resolution of less than 15 s for at least 2 min [6]. 3D T1W GRE is generally available using modern systems and is preferred over 2D T1W [6]. Gadolinium-based contrast agent (GBCA) should be injected as a bolus, typically at 2–3 cc/sec, and the acquisition plane should match T2W and DWI. The use of contrast in prostate MRI is subject to

ongoing debate, with the injection of GBCA questioned in various studies [71–74]. The main disadvantages listed are the high cost, increased examination time, risk of adverse reactions, potential gadolinium deposition in tissues, and the risk of nephrogenic systemic fibrosis in patients with renal insufficiency. *Although multicenter trials can provide further clarification [75], it should be emphasized that the DCE sequence is essential as a safety net (Fig. 5) in cases where DWI did not achieve satisfactory quality [76].*

Our prostate MRI protocol with optimized parameters is demonstrated in Supplementary Table S1.

## Artifacts

Artifacts can arise during prostate MRI examinations, and the workgroup must be able to recognize and mitigate them. One of the most common artifacts is motion, manifested as blurring or ghosting in the phase encoding direction. One



**Fig. 6** A 3T MRI exam comparing imaging acquisition with and without deep learning reconstruction (DLR). T2W imaging (a), extrapolated high b-value DWI (b), and ADC map (c) without DLR show a midline posterior lesion in the peripheral zone (arrow). Note the excellent imaging quality of these sequences, which were obtained in approximately 4 (T2W imaging) and 6 (DWI) minutes.

The images acquired with DLR (d-f) also demonstrate a lesion with great conspicuity (arrow). The acquisition time was around 2 minutes for T2W imaging and 3 minutes for DWI. The images with DLR maintained the capability to rule in and rule out clinically significant prostate cancer but at half time of acquisition time for T2W imaging and DWI

way to reduce or eliminate motion artifacts is by reducing the speed and magnitude of motion during image acquisition [77]. *This can be achieved, for example, by fasting for at least 4 h and using antispasmodics before exams to reduce intestinal peristalsis [77] or using breath-hold sequences [77].*

Another common artifact is magnetic susceptibility, appearing as a signal loss at the interface between structures with different magnetic susceptibilities, such as air and soft tissue [77–79], causing blurring, stretching, and geometric distortions of the image [77]. Although it cannot be eliminated entirely during the exam, some strategies can be employed to reduce it, such as selecting single-shot sequences, avoiding fat suppression, using thinner slices, increasing the receiver bandwidth, or shifting the artifact by changing the phase and frequency encoding directions [77, 80].

Aliasing artifact occurs when choosing a smaller FOV than the structure being assessed. Some ways to eliminate or reduce aliasing are to exchange the readout direction with the phase-encoding direction, increase the phase FOV, or apply spatial saturation pulses outside the FOV [81].

Most radiology centers use the echo-planar DWI technique, which is more susceptible to eddy currents. These currents can cause anatomical distortion of the prostate in high b-value acquisitions. This distortion can be amplified by an inhomogeneous magnetic field and mitigated by applying parallel imaging techniques, reducing receiver bandwidth, echo spacing, echo-train length, and echo time [82]. Parallel imaging strategies employ linear combinations of individual coil sensitivities to generate spatial harmonics, which can replace phase encoding data, improving spatial or temporal resolutions. However, background noise inhomogeneity increases with the acceleration factor [81]. Techniques such as DWI with periodically rotated parallel lines with

enhanced reconstruction (PROPELLER™) can also minimize artifacts [83], and using left-to-right phase-encoding can avoid artifact projection onto the prostate gland [82].

## Artificial intelligence and deep learning reconstruction

Artificial intelligence (AI) has recently emerged as a valuable tool to improve imaging quality and reduce the time taken for MRI acquisition (Fig. 6). This is done by applying reconstruction algorithms to raw data using deep learning (DL) techniques, which help to improve noise and Gibbs ringing [84, 85]. These algorithms can provide faster image acquisition times, reducing motion artifacts. Additionally, they can enhance SNR and image sharpness, resulting in better-quality images [86].

Some recent studies have shown mixed results regarding the improvement of image quality. Ueda et al. investigated whether DL reconstruction (DLR) could increment the image quality of DWI with b values ranging from 1000 s/mm<sup>2</sup> to 5000 s/mm<sup>2</sup> [87]. The authors found significantly higher SNRs and CNRs in DWI with DLR than those without DLR and demonstrated better image quality in qualitative assessment. Additionally, the ADCs derived from acquisitions with and without DLR showed no relevant difference. Another study assessed the impact of DLR on quantitative (SNR and CNR) and qualitative parameters of image quality, PI-RADS score, and examination time [88]. They demonstrated a significant increase in quantitative image quality parameters, a reduction in examination time (33% for T2W and 49% for DWI), and higher image quality for T2 sequence in qualitative assessment (with no substantial difference for DWI). Other studies did not significantly improve image quality through qualitative

**Table 2** Prostate imaging quality (PI-QUAL) scoring system classification

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

\* Reports should not include Prostate Imaging- Reporting and Data System or Likert scores

assessment for DWI [88–90] or quantitative assessment for T2W [84, 91].

So far, the most impactful clinical application is reducing the acquisition time of prostate MRI, which may improve imaging quality. The rapid advancement of AI and the conduct of studies with a higher level of evidence promise to enhance image quality more robustly.

## Radiology team level

As mentioned above, the processes to obtain high-quality prostate MRI images should be taken in several stages. This section discusses ways to ensure and improve the imaging quality at the radiology team level.

## Multidisciplinary radiology team

Experienced technologists, nurses, MRI physicists, and radiologists are vital in obtaining adequate-quality images and ensuring QA and QC [21, 92]. Hence, adequate training is crucial to ensuring a cohesive team experience.

Technologists and nurses frequently interface with the patient, so this group of MDTs needs to know all the steps of MRI prostate flow. Moreover, these professionals should recognize gaps that may impact the examination and try to mitigate them by following preset institutional protocols. *For radiology departments with few experienced technologists, a virtual command center can be an interesting solution.* MRI physicists play a vital role in ensuring that the image data generated from MRI scans are of high quality and provide reliable diagnostic information for patient management. One of the primary objectives is to work with equipment manufacturers to address image quality concerns, standardize examination procedures across multiple scanner models, and customize examination parameters based on their practice's needs.

Radiologists should actively participate in prostate MRI examinations. Due to the high demand for exams and pressure to generate a high volume of reports, it is challenging for radiologists to be present on-site for tailored examinations. Therefore, the creation of clear protocols for technologists to follow is crucial. On the other hand, radiologists need to be available to discuss and evaluate exams if any doubts arise within the rest of the MDT. In addition, *expert radiologists in prostate MRI should supervise various quality indicators, such as auditing outcomes, reviewing cases of discrepancy, and checking the PI-RADS 3 rate and PI-QUAL scores [15, 16, 18].*

*Experienced radiologists in prostate imaging are essential for improving the quality of MRI scans.* Until now (February 2024), there has been no agreement on the minimum number of MRI readings required to become proficient [18, 93–95]. The ESUR/ESUI consensus deems a minimum of 400 exams as ‘beginner’ and over 1,000 as ‘expert’ [18]. The panelists recommend using self-performance tests with histopathologic feedback to determine individual reporting accuracy, preferably compared to expert readings and external performance assessments. Additionally, expert centers exhibit lower PI-RADS 3 cases in biopsy-naïve men than non-expert centers.

*Certification in prostate MRI is a promising QC tool.* It should include requirements such as minimum reporting numbers and mandatory feedback for MRI reports, such as auditing biopsy results or attending multidisciplinary team meetings. It should also require obtaining prostate-specific continuing professional development credits and potentially an examination [15, 16].

Participation in *workshops* of accredited entities is an additional tool that assists in radiologists' continuous education and aids in their acquisition of experience in prostate imaging. Furthermore, participation in *tumor boards* with various specialties is vital as a QA measure, enabling the review of cases with radiology-pathology discrepancies (QC measure).

## Prostate imaging quality (PI-QUAL) scoring system and beyond

Imaging quality is one of the main factors impacting the entire pathway of MRI PCa assessment. Low-quality examinations can negatively influence all downstream events. In this regard, ESUR, the EAU Section of Urologic Imaging (ESUI), and the UK consensus reinforce the necessity of quality criteria for technical prostate MRI acquisition [18, 94].

The PI-QUAL scoring system, derived from the PRECISION trial [1], was the first classification addressed to this issue [25]. *This scoring system is based on a 1–5 Likert scale that assesses the imaging quality of MRI sequences, such as T2W, DWI, and DCE (Table 2) [24–26].* The MRI sequences should be evaluated using minimal technical parameters from PI-RADS recommendations [6] and considering the visual assessment as anatomical landmarks and artifacts (Supplementary Table S2). PI-QUAL  $\geq 4$  means that clinically significant PCa may be ruled in and ruled out. In PI-QUAL 3, the csPCa could be ruled in but not ruled out. On the other hand, the clinical implication of PI-QUAL  $\leq 2$  is that it is not possible to rule in all clinically significant PCa lesions [25, 26].

Some studies have assessed the usefulness of the PI-QUAL score in clinical settings. A retrospective study found that when prostate MRI had a PI-RADS  $\leq 3$  and suboptimal image quality, it was more likely to require a biopsy [96]. Furthermore, it had a lower ability to diagnose csPCa accurately. Another study found that suboptimal quality scans had a higher proportion of PI-RADS 3 scores referred for biopsy [97]. Moreover, the authors showed that the positive predictive value was lower for PI-QUAL  $< 4$ . On the other hand, Pötsch et al. did not demonstrate a significant difference in diagnostic performance between studies PI-QUAL  $> 3$  compared to PI-QUAL  $\leq 3$  [98].

Few publications were evaluating the impact of the PI-QUAL score in staging PCa after radical prostatectomy. A multicenter retrospective cohort found a higher rate of upstaging from organ-confined PCa on MRI to locally advanced disease on pathology for PI-QUAL  $< 3$  [23]. These results aligned with the study of Dinneen et al., which demonstrated a higher diagnostic performance for MRI with optimal quality [99]. However, another study did not find an impact on image quality to assess extraprostatic extension [100]. Woernle et al. recently reviewed reproducibility, which showed agreement ranging from slight to excellent through Cohen's Kappa for the PI-QUAL scoring system [17].

Another system for assessing image quality is the Prostate Signal Intensity Homogeneity Score (PSHS) scoring system. The classification is based on a 1–5 Likert scale regarding T2 hypointense changes and the grade of homogeneity in the peripheral zone [101]. A low score indicates significant changes in the peripheral zone, hindering the assessment of focal prostatic lesions. In contrast, a score of 5 indicates a homogeneous, T2-hyperintense peripheral zone that does not hinder lesion assessment. The study of Hötker et al. showed a substantial inter-reader agreement and a high sensitivity of csPCa detection in higher PSHS scores [101]. Another publication regarding the multi-reader assessment of image quality scoring systems showed a good agreement (Kappa value of 0.65 for PSHS and 0.58 for PI-QUAL) [102]. Additionally, the sensitivity of csPCa detection was incremented in exams with high image quality using PI-QUAL and PSHS scoring systems. A cohort focusing on image quality scoring systems assessed the predictors of PCa and csPCa in false-negative MRI and found that PI-QUAL scores were lower in patients with missing csPCa ( $p < 0.005$ ) [103]. The PSHS also was correlated with a higher rate of missing csPCa ( $p < 0.1$ ). The only independent predictor of missed csPCa was the lower PI-QUAL scores.

The successful case of the PI-QUAL scoring system may be extrapolated to evaluate the image quality in other body parts and modalities. The novel model is called RI-QUAL (Radiological Image Quality) and was evaluated regarding the inter-reader agreement [104]. The study found a

moderate Kappa value (0.61), a high concordance correlation coefficient (0.76), and a high interclass correlation coefficient (0.86).

The PI-QUAL scoring system is a promising and viable tool for assessing prostate MR image quality. PSHS is a complementary tool for evaluating image quality that assesses other parameters. Future updates, automated/semi-automated methods, and continuing education can further increase these quality scales. We recommend using the PI-QUAL scoring system in MRI reports as an image quality metric and recommend more studies in the promising PSHS.

An open-source solution can aid in implementing PI-QUAL assessment as a quality control tool. The MRI Analyzer Quality Control (MA-QC) is a free online software that evaluates several parameters of DICOM data to calculate the PI-QUAL score [105].

### PI-RADS 3 score rate

The PI-RADS 3 score rate is a relevant indicator of MRI quality. A high rate of PI-RADS 3 interpretations suggests poor performance due to image quality or reporting experience. It is a quality measure independent of biopsy considerations, similar to the recall rate in screening mammography [15]. Establishing an optimal PI-RADS 3 interpretation range could aid QA efforts, mirroring mammography based on large screening datasets [15]. Some prospective trials have shown the percentage of PI-RADS 3, which can serve as a reference in establishing the optimal value for this parameter, ranging from 6 to 29% [1–4].

Radiology reports that show a rate of PI-RADS 3 higher than 30% could indicate poor image quality and/or a lack of experience on the part of the radiologist. If there is an unusually high rate of PI-RADS 3, it is recommended to investigate the quality of the scanner images and review the processes of the radiology team. This may involve examining patient preparation, coil positioning, and the MRI protocol selection. Additionally, radiologists could consider retraining through courses or continuing education. To ensure proper procedures are followed, an expert radiologist could also re-review the prostate exam. This action alone can reduce the interpretation of equivocal findings by about 10% [106, 107].

### Peer review

Peer review and peer learning are essential for improving and enhancing the quality of radiology departments [108, 109]. These processes significantly impact medical outcomes but do not directly assess technical imaging quality. In addition to conducting peer review and peer learning, we

suggest implementing a technical peer review process for MRI technologists as a QC checkpoint. This process primarily assesses factors associated with the peri-examination execution.

Like classic peer review and peer learning, the primary goal of technical peer review is to promote and maintain a culture of feedback, process improvement, and continuous education for the entire MDT [108, 109]. The ACR created a peer-review scoring system (RADPPER) for radiologic reports [110]. In technical peer review, radiologists evaluate the technical parameters of each exam, focusing on the imaging quality. *The scoring system is based on a 1–5 points Likert scale where 1—severe failure and/or exam at the limit for or need recall; 2—several minor failures or one major failure; 3—one minor failure; 4—exam of good quality; 5—exam of excellent quality and/or with some particular intervention by the technologist.* The radiologist should assign a technical peer review during the exam assessment in the radiologic workstation. After reviewing the data, senior radiologists and technologists analyze negative (peer review scores 1–3) and positive (peer review scores 4–5) evaluations to identify areas for improvement, maintain a feedback culture, and provide education opportunities. A similar idea of the technical peer review was published in nuclear medicine, which found a positive outcome impact due to the capability to measure the rates and types of errors [111].

## Artificial intelligence for imaging quality evaluation

AI has the potential to assist in the QC process by using convolutional neural networks (CNNs) to automate the evaluation of image quality. AI aims to identify and flag suboptimal-quality images. In a retrospective study on 3 T MRI, CNNs were developed and found to have high accuracy in per-slice analysis for T2W (89.95%), DWI (79.83%), ADC (76.64%), and DCE (96.62%) [112]. In per-sequence evaluation, the CNNs showed 100% accuracy for T2W, DWI, and DCE.

An exciting application area for automation processes is the evaluation of the PI-QUAL score, which aims to reduce the time required for radiologists to assess image quality. In this regard, Giganti et al. published a retrospective study comparing the time taken for image quality assessment using the PI-QUAL score between radiologists and a dedicated semi-automated software [113]. Semi-automated software substantially reduced assessment time (5'54'' vs. 7'59'').

*A realistic target is using automated processes to assess image quality during the examination. This would result in increased efficiency in procedure execution and the ability to detect suboptimal-quality images in real-time, indicating whether a sequence should be repeated. However,*

*automated AI systems still lack training and extensive external validation.*

## Data reconciliation

Data reconciliation is a process that aims to identify and correct errors in the MRI pathway using root-cause analysis. This process also generates proactive actions to avoid future mistakes. It is crucial to use audited and curated data in this stage. To ensure this, we recommend periodic MDT meetings that are customized according to the needs of each service to discuss improvement points. The cornerstone of this process is continuous education, which has a direct and indirect impact on the image quality of prostate MRI. It is worth noting that well-designed processes should generate the statistics used in data reconciliation.

## Conclusion

Prostate MRI plays a crucial role in detecting csPCa while reducing the need for unnecessary biopsies. However, the diagnostic accuracy of MRI varies globally due to differences in image quality and radiologist expertise. Although the PI-RADS recommendations aim to standardize protocols and enhance image quality, challenges persist, including scanner-specific issues and patient-related factors.

QA and QC processes are essential at the patient, MRI unit, and radiology team levels to ensure optimal MRI quality. Patient preparation, both before and during the examination, can improve exam flow, alleviate patient anxiety, and minimize image artifacts. At the MRI unit, selecting appropriate protocols, utilizing the correct coil, ensuring magnetic field compatibility, and implementing measures to mitigate image artifacts are essential for obtaining high-quality images. Active engagement from the radiology team through continuous education, feedback via peer review, MDT meetings, and outcome audits is also crucial for improving scan quality. Each aspect contributes significantly to achieving high-quality prostate MRI images, from patient preparation to MRI protocol optimization and integrating emerging technologies such as AI. Furthermore, using tools like the PI-QUAL scoring system can further enhance MRI quality assessment and ensure consistency in clinical outcomes.

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## Declarations

**Conflict of interest** None.

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