Radiology

ORIGINAL RESEARCH • GENITOURINARY IMAGING

Global Variation in Magnetic Resonance Imaging Quality of the Prostate

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Conflicts of interest are listed at the end of this article.

See also the editorial by Almansour and Chernyak in this issue.

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Background: High variability in prostate MRI quality might reduce accuracy in prostate cancer detection.

Purpose: To prospectively evaluate the quality of MRI scanners taking part in the quality control phase of the global PRIME (Prostate Imaging Using MRI ± Contrast Enhancement) trial using the Prostate Imaging Quality (PI-QUAL) standardized scoring system, give recommendations on how to improve the MRI protocols, and establish whether MRI quality could be improved by these recommendations.

Materials and Methods: In the prospective clinical trial (PRIME), for each scanner, centers performing prostate MRI submitted five consecutive studies and the MRI protocols (phase I). Submitted data were evaluated in consensus by two expert genitourinary radiologists using the PI-QUAL scoring system that evaluates MRI diagnostic quality using five points (1 and 2 = nondiagnostic; 3 = sufficient; 4 = adequate, 5 = optimal) between September 2021 and August 2022. Feedback was provided for scanners not achieving a PI-QUAL 5 score, and centers were invited to resubmit new imaging data using the modified protocol (phase II). Descriptive comparison of outcomes was made between the MRI scanners, feedback provided, and overall PI-QUAL scores.

Results: In phase I, 41 centers from 18 countries submitted a total of 355 multiparametric MRI studies from 71 scanners, with nine (13%) scanners achieving a PI-QUAL score of 3, 39 (55%) achieving a score of 4, and 23 (32%) achieving a score of 5. Of the 48 (n = 71 [68%]) scanners that received feedback to improve, the dynamic contrast-enhanced sequences were those that least adhered to the Prostate Imaging Reporting and Data System, version 2.1, criteria (44 of 48 [92%]), followed by diffusion-weighted imaging (20 of 48 [42%]) and T2-weighted imaging (19 of 48 [40%]). In phase II, 36 centers from 17 countries resubmitted revised studies, resulting in a total of 62 (n = 64 [97%]) scanners with a final PI-QUAL score of 5.

Conclusion: Substantial variation in global prostate MRI acquisition parameters as a measure of quality was observed, particularly with DCE sequences. Basic evaluation and modifications to MRI protocols using PI-QUAL can lead to substantial improvements in quality.

Clinical trial registration no. NCT04571840

Supplemental material is available for this article.

Multiparametric MRI of the prostate is now the standard of care in patients with clinical suspicion of prostate cancer and is recommended to take place before biopsies in patients who are biopsy naive (1,2). Level Ia evidence has shown that risk assessment with MRI before biopsy and MRI-targeted biopsy is superior to the previous standard transrectal US-guided biopsy. It enables detection of a greater proportion of clinically significant prostate cancer, a lower proportion of clinically insignificant prostate cancer (1,3–5), and better risk stratification (6).

The introduction of MRI into international guideline recommendations for prostate cancer diagnosis has led to a steep increase in the demand and use of this technique over the past few years (2,7). However, a major concern about more widespread use of this technology is its ability to produce high-quality images with the existing health

Abbreviations

DCE = dynamic contrast enhanced, GLIMPSE = Global Variation in Magnetic Resonance Imaging Quality of the Prostate, PI-QUAL = Prostate Imaging Quality, PI-RADS = Prostate Imaging Reporting and Data System, PRECISION = Prostate Evaluation for Clinically Important Disease: Sampling Using Image Guidance or Not, PRIME = Prostate Imaging Using MRI ± Contrast Enhancement

Summary

There is substantial global variation in prostate MRI quality, particularly in the dynamic contrast-enhanced sequences, when compared with the Prostate Imaging Reporting and Data System standards; however, quality can be optimized with basic modifications to MRI protocols.

Key Results

- In an international, multicenter prospective clinical trial (PRIME [Prostate Imaging Using MRI ± Contrast Enhancement]), assessment of MRI quality showed that nine of 71 (13%) MRI scanners received a Prostate Imaging Quality (PI-QUAL) score of 3 (sufficient image quality), 39 of 71 (55%) received a score of 4 (adequate image quality), and 23 of 71 (32%) received a score of 5 (optimal image quality).
- Basic changes to technical recommendations outlined in Prostate Imaging Reporting and Data System guidelines improved the scores of MRI scanners on requalification, with 97% of scanners obtaining a PI-QUAL score of 5 and 3% obtaining a score of 4.

care infrastructure. Poor MRI quality can influence the ability to diagnose and treat prostate cancer, and concerns have been raised over whether results seen with level I evidence studies are reproducible in typical centers that perform prostate MRI (1,5,8–10), as image quality affects the performance of MRI relative to biopsy outcomes in all settings (initial diagnosis, active surveillance, posttreatment). In addition to this, poorer image quality is associated with increased uncertainty in the MRI decision making (ie, higher call rate of equivocal lesions and lower call rate of negative scans).

To the authors' knowledge, the Prostate Imaging Quality (PI-QUAL) score from the PRECISION (Prostate Evaluation for Clinically Important Disease: Sampling Using Image Guidance or Not) trial (clinical trial registration no. NCT02380027) is the first standardized scoring system to evaluate image quality of prostate MRI (11). It is a five-point scale that assesses image quality against a set of objective technical parameters (as per Prostate Imaging Reporting and Data System [PI-RADS] minimum technical requirements and standards for prostate multiparametric MRI reporting) together with visual criteria obtained from the image (12,13). In PI-QUAL, each sequence is evaluated according to a checklist that is used to influence an overall judgment on whether that sequence is of diagnostic quality. Each scan is then given an overall PI-QUAL score for its MRI quality considering all the sequences. A PI-QUAL score of 1 or 2 means that the study is nondiagnostic (ie, it is not possible to rule in or rule out all clinically significant lesions), a PI-QUAL score of 3 means that the study is of sufficient diagnostic quality (ie, it is possible to rule in but not rule out all clinically significant lesions), and a PI-QUAL score of 4 (adequate diagnostic quality) and 5 (optimal diagnostic quality) means that it is possible to rule in and rule out all clinically significant lesions. In particular, scanners can only be PI-QUAL 5 if they are fully adherent to the PI-RADS, version 2.1, technical recommendations. Numerous studies using the PI-QUAL evaluation have shown that MRI quality can affect diagnostic performance for cancer detection, staging decisions, and treatment decisions (14–17).

With the increasing need for prostate MRI and the resource limitations in meeting this demand, methods of streamlining multiparametric MRI have been proposed. One such approach would be whether biparametric MRI, in which the dynamic contrast-enhanced (DCE) sequence is omitted, could be an alternative standard of care. This approach would save time and resource use and may enable greater accessibility of prostate MRI to patients who need it. The PRIME (Prostate Imaging Using MRI ± Contrast Enhancement; clinical trial registration no. NCT04571840) trial has been designed to address this issue (18). It is an ongoing prospective, international, within-patient, multicenter, level I evidence clinical trial evaluating whether biparametric MRI (ie, no intravenous contrast material administration) is noninferior to multiparametric MRI in the detection of clinically significant prostate cancer. To truly evaluate the added role of DCE sequences in detecting cancer and compare all MRI sequences, it is crucial that the scan is of optimal diagnostic quality; otherwise, it may be MRI quality rather than the DCE sequence that could explain the differences or lack thereof between biparametric MRI and multiparametric MRI. None of the previous studies reporting biparametric MRI versus multiparametric MRI have evaluated MRI quality.

The aim of this study, called GLIMPSE (Global Variation in Magnetic Resonance Imaging Quality of the Prostate), was to prospectively evaluate the quality of all MRI scanners taking part in the quality control phase of the global PRIME trial using the PI-QUAL scoring system, give recommendations on how to improve the MRI protocols, and establish whether MRI quality could be improved by these recommendations.

Materials and Methods

Ethical approval for the prospective clinical trial, PRIME (clinicaltrials.gov NCT04571840), and the quality control phase was granted by the National Research Ethics Committee (West Midlands, Nottingham, England) (ethics committee approval 21/WM/0091), on May 26, 2021. Participating centers were responsible for obtaining any further local approval to participate in this quality improvement project.

Study Sample

An open invitation was issued to any center in the world that performed prostate MRI and was interested in taking part in the PRIME trial. Centers that expressed an interest in participating in the PRIME trial were then invited to take part in a phase of quality control to establish suitability to participate in the study. Conditions for taking part were that centers needed to perform prostate MRI and MRI-targeted biopsy and needed to be able to provide audit data for their biopsy cancer detection rates. Centers were required to have at least one MRI scanner that was not

Table 1: Technical Requirements for Multiparametric Prostate MRI according to PI-RADS, Version 2.1, Guidelines

Technical Requirements	T2-weighted Imaging	DW Imaging	DCE
Imaging planes	Same used for DW imaging and DCE	Same used for T2-weighted and DCE imaging	Same used for T2-weighted and DW imaging
Section thickness	3 mm, no gap	≤4 mm, no gap	3 mm, no gap
Field of view (cm)	12–20*	16–22	12–20*
In-plane dimension (mm)	≤0.7 × ≤0.4	≤2.5	≤2
Specific recommendation 1	Axial plane: either straight axial to the participant or in an oblique axial plane matching the long axis of the prostate	Low *b* value, 50–100 sec/mm^2	Temporal resolution ≤15 sec
Specific recommendation 2	One or more additional orthogonal plane (sagittal, coronal, or both)	Intermediate *b* value, 800–1000 sec/mm^2	Fat suppression
Specific recommendation 3	3D axial as an adjunct to 2D acquisitions	High *b* value; dedicated (≥1400 sec/mm^2); synthesized (from other *b* values)	GBCA, 0.1 mmol per kilogram of body weight; injection rate, 2–3 mL/sec; observation rate, ≥2 minutes

Note.—DCE = dynamic contrast enhanced, DW = diffusion weighted, GBCA = gadolinium-based contrast agent, PI-RADS = Prostate Imaging Reporting and Data System, 3D = three-dimensional, 2D = two-dimensional.

* To encompass the entire prostate gland and seminal vesicles.

older than 10 years at the time of image submission. No other restrictions were made, including on academic center status, type of MRI scanner, magnet coil strength, use of endorectal coil, or use of bowel relaxant.

For each scanner, centers were required to provide five of the most recent consecutive anonymized prostate multiparametric MRI scans obtained in patients suspected of having prostate cancer who had either histopathologic confirmation of identified lesions from MRI-targeted biopsy or nonsuspicious MRI scans and who did not undergo biopsy. If a center wished to use more than one scanner in the study, five scans were required for each additional MRI scanner. For each patient's scans submitted, the overall PI-RADS score assigned by the local radiologists, the overall pathology result (if the patient underwent biopsy), and a detailed protocol for the scanner were collected. MRI-anonymized Digital Imaging and Communications in Medicine files were uploaded onto a dedicated platform (MIM Symphony Dx, version 7.1.2; MIM Software), and quantitative data were uploaded onto a REDCap form (Vanderbilt University) (19) (Appendixes S1, S2).

Centers submitted images from between one and five MRI scanners for consideration of the PRIME trial.

Evaluation of MRI Quality

Image quality of the submitted data was evaluated in consensus at the coordinating center by two expert consultant genitourinary radiologists who actively participate at weekly prostate multidisciplinary meetings (F.G., C.A.; 12 and 23 years of experience, respectively, in prostate multiparametric MRI acquisition and reporting more than 1000 prostate multiparametric MRI scans per year) between September 2021 and August 2022. The radiologists were blinded to the local radiologist's reports of the scans and whether the patient underwent biopsy. They did not have access to any biopsy results until after their assessment.

MRI quality was assessed by means of the PI-QUAL score, including compliance with the PI-RADS technical recommendations (Table 1), and a dedicated semiautomated software program was used (20). The highest PI-QUAL score from the available scans (eg, the one not hampered by participant-related artifacts) was determined for each scanner, and any modifiable technical standards were provided as feedback to each center. Centers scoring PI-QUAL of less than 5 were invited to resubmit a single revised version (ie, one scan) of Digital Imaging and Communications in Medicine images for a re-evaluation if they were willing to adopt the suggestions. Resubmitted images were re-evaluated, and a new PI-QUAL score was assigned.

For the purpose of the PRIME trial, centers scoring PI-QUAL 5 by the second evaluation were permitted to take part.

Statistical Analysis

Descriptive comparison of outcomes (percentages) was made between the MRI scanners, the feedback provided, and their overall PI-QUAL scores.

Results

Demographics and Quality of Prostate MRI Scans in the Study Sample

A total of 66 centers from 22 countries in Asia, Australia, Europe, North America, and South America expressed an interest in taking part in the PRIME trial. Twenty-five centers did not respond. Thus, phase I consisted of 41 centers from 18 countries (71 MRI scanners). Five centers did not respond after phase I, leaving 36 centers from 17 countries in phase II (64 scanners). An overall flowchart of the GLIMPSE study is shown in Figure 1.

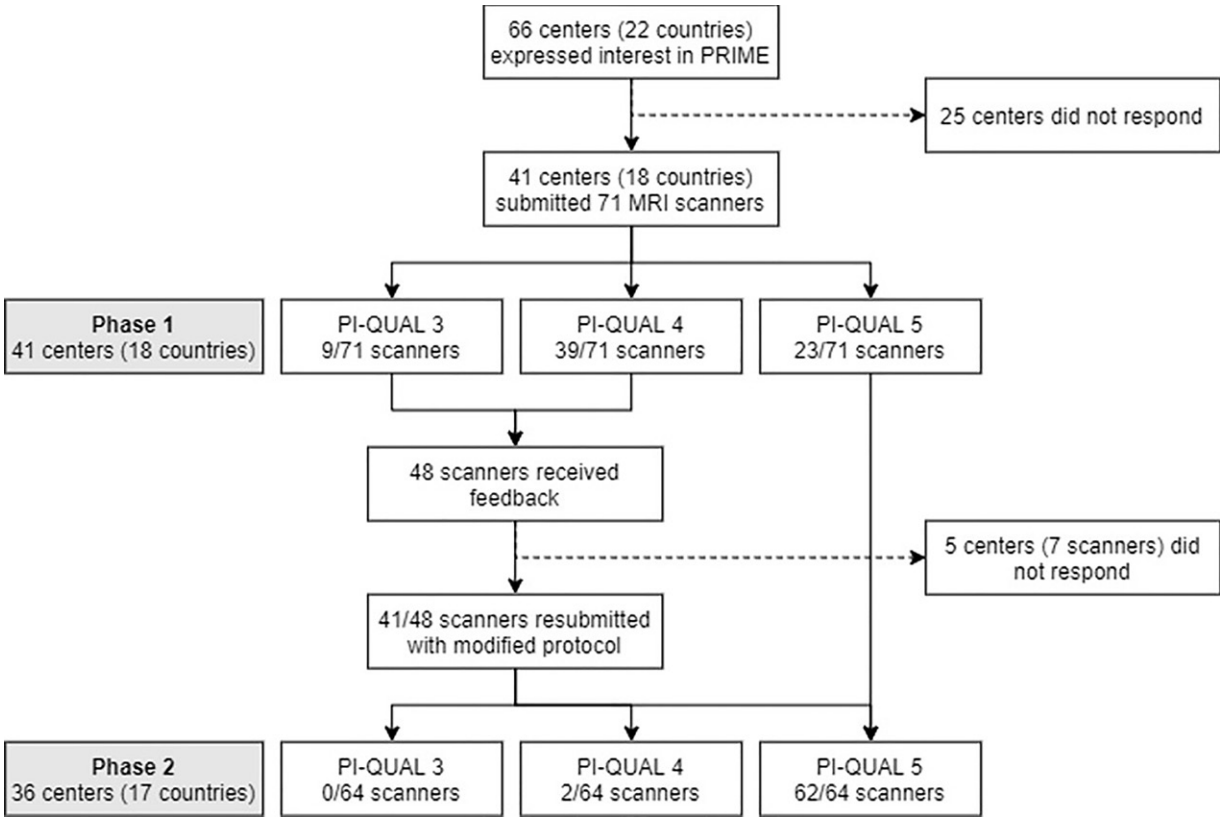

Figure 1: Flowchart of the Global Variation in Magnetic Resonance Imaging Quality of the Prostate (GLIMPSE) study. A Prostate Imaging Quality (PI-QUAL) score of 3 indicates sufficient image quality; 4, adequate image quality; and 5, optimal image quality. PRIME = Prostate Imaging Using MRI ± Contrast Enhancement.

Phase I: Initial Review of Images

In this phase, 41 of 66 (62%) centers and 18 of 22 (82%) countries took part, submitting 355 multiparametric MRI studies for a total of 71 MRI scanners.

Fifty-four of 71 (76%) scanners had a field strength of 3 T, 66 of 71 (93%) did not include an endorectal coil, and 43 of 71 (61%) used a bowel relaxant. On initial review, 71 of 71 (100%) scanners were deemed of sufficient diagnostic quality for T2-weighted imaging and diffusion-weighted imaging, though not necessarily all fully compliant according to the PI-QUAL scoring sheet (Fig S1, Table S1). Initial review of the DCE sequences showed that 57 of 71 (80%) scanners were deemed of sufficient diagnostic quality.

Scanners were assigned overall MRI quality scores of PI-QUAL 3 in nine of 71 (13%), PI-QUAL 4 in 39 of 71 (55%), and PI-QUAL 5 in 23 of 71 (32%).

Feedback was provided for each sequence, if appropriate. Twenty-three of 71 (32%) scanners received no feedback, as they scored PI-QUAL 5 on initial assessment. Of the 48 of 71 (68%) scanners that received feedback, the DCE sequences were those that least adhered to PI-RADS, version 2.1, technical recommendations (44 of 48 [92%]), followed by diffusion-weighted imaging (20 of 48 [42%]) and T2-weighted imaging (19 of 48 [40%]).

The three most-provided recommendations for T2-weighted imaging were *(a)* adjusting the in-plane resolution to meet PI-RADS, version 2.1, guidelines (10 of 48 [21%]); *(b)* acquiring an additional orthogonal separate plane (four of 48 [8%]);

Table 2: Summary of Top Three Most Provided Recommendations for Each Sequence after Feedback

Sequence and Recommendation	No. of MRI Scans*
T2-weighted imaging	
Adjusting the in-plane resolution to meet PI-RADS, version 2.1, guidelines	10/48 (21)
Acquiring additional orthogonal separate planes	4/48 (8)
Decreasing the section thickness to 3 mm	2/48 (4)
Diffusion-weighted imaging	
Including an acquired or calculated high *b* value of >1400 sec/mm^2	19/48 (40)
Decreasing the section thickness to ≤4 mm	2/48 (4)
Reducing the field of view between 16 and 22 cm	2/48 (4)
Dynamic contrast-enhanced imaging	
Adjusting the temporal resolution to a maximum of 15 seconds, as per PI-RADS, version 2.1, guidelines	27/48 (56)
Using fat-suppressed (subtracted) sequences	16/48 (33)
Using a power injector with a pump speed of 3 mL/sec with a saline chaser	7/48 (15)

Note.— Data in parentheses are percentages. PI-RADS = Prostate Imaging Reporting and Data System, T2-WI = T2-weighted imaging.

* Scans scoring Prostate Imaging Quality of 4 or less in phase I.

Table 3: Compliance to Technical Recommendations for the Scanners Included in Phase II of the GLIMPSE Study

Sequence and Technical Parameters	Yes (Baseline)	Yes (after Feedback)	No (Baseline)	No (after Feedback)
T2-weighted imaging				
Axial plane	64 (100)	64 (100)	…	…
Sagittal or coronal plane	61 (95)	64 (100)	3 (5)	…
Adequate field of view	57 (89)	64 (100)	7 (11)	…
Adequate in-plane resolution	43 (67)	62 (97)	21 (33)	2 (2)
Adequate section thickness	63 (98)	64 (100)	1 (2)	…
Z-axis correctly positioned	64 (100)	64 (100)	…	…
Diffusion-weighted imaging				
Axial plane matching T2-weighted imaging	64 (100)	64 (100)	…	…
Adequate field of view	60 (94)	63 (98)	4 (6)	1 (2)
Adequate in-plane resolution	63 (98)	64 (100)	1 (2)	…
Adequate section thickness	61 (95)	64 (100)	3 (5)	…
Multiple (two or more) *b* values acquired	64 (100)	64 (100)	…	…
High *b* value (synthesized or acquired)	51 (80)	64 (100)	13 (20)	…
Dynamic contrast enhanced				
Axial plane matching T2-weighted imaging	64 (100)	64 (100)	…	…
Adequate field of view	53 (83)	63 (98)	11 (17)	1 (2)
Adequate in-plane resolution	63 (98)	64 (100)	1 (2)	…
Adequate section thickness	44 (69)	64 (100)	20 (31)	…
Precontrast T1-weighted imaging available	64 (100)	64 (100)	…	…
Fat suppression or subtraction	58 (91)	63 (98)	6 (9)	1 (2)
Adequate temporal resolution (≤15 seconds)	62 (97)	64 (100)	2 (3)	…
Adequate total observation rate (≥2 minutes)	62 (97)	64 (100)	2 (3)	…

Note.—Data are number of scanners, and data in parentheses are percentages. Technical recommendations were based on Prostate Imaging Reporting and Data System, version 2.1, guidelines. GLIMPSE = Global Variation in Magnetic Resonance Imaging Quality of the Prostate.

and *(c)* decreasing the section thickness to 3 mm (two of 48 [4%]) (Table 2).

For diffusion-weighted imaging, the three most-provided recommendations were *(a)* including an acquired or calculated high *b* value of more than 1400 sec/mm^2 (19 of 48 [40%]), *(b)* decreasing the section thickness to 4 mm or less (two of 48 [4%]), and *(c)* reducing the field of view to between 16 and 22 cm (two of 48 [4%]) (Table 2).

For DCE, the three most-provided recommendations were *(a)* adjusting the temporal resolution to a maximum of 15 seconds, as per PI-RADS, version 2.1, guidelines (27 of 48 [56%]), *(b)* using fat-suppressed (subtracted) sequences (16 of 48 [33%]), and *(c)* using a power injector with a pump speed of 3 mL/sec with a saline chaser (seven of 48 [15%]) (Table 2).

Phase II: Evaluation after Feedback

Of the 41 centers (18 countries, 71 MRI scanners) that entered phase I, 23 scanners had already scored PI-QUAL 5 and were not required to resubmit any images. Of the remaining 48 scanners that received feedback, MRI studies from 41 scanners (85%) were resubmitted with a modified protocol. A total of 64 scanners (41 resubmitted and 23 PI-QUAL 5 carried forward from phase I) were included in phase II. Forty-eight of 64 (75%) had a field strength of 3 T, 59 of 64 (92%) did not include an endorectal coil, and 38 of 64 (59%) used a bowel relaxant.

Compliance to technical recommendations (as per PI-RADS, version 2.1, guidelines) and visual assessment (as per PI-QUAL scoring sheet) for the 64 scanners included in phase II of the study are presented in Tables 3 and 4. Data for all scanners are presented in Table S1.

Further information on each scanner included in phase II is reported in Table S2.

After recommended changes were made to the MRI protocol, 62 of 64 (97%) scans scored PI-QUAL 5 and two of 64 (3%) scored PI-QUAL 4.

Different examples of images from phase I and phase II are shown in Figures 2–5.

Figure 6 shows the map of countries that took part in phase II of the GLIMPSE study, including the number of centers and scanners for each country.

Discussion

Multiparametric MRI is now routinely recommended by international guidelines. However, with an increasing demand and resource limitation, a shorter biparametric MRI, in which the dynamic contrast-enhanced (DCE) sequences are omitted, has been proposed as an alternative. Previous studies comparing biparametric MRI with multiparametric MRI have not evaluated image quality; therefore, accurate conclusions on the role of DCE in detecting cancer cannot be accurately made. In an

Table 4: Compliance to Visual Assessment for the Scanners Included in Phase II of the GLIMPSE Study

Visual Assessment	Yes (Baseline)	Yes (after Feedback)	No (Baseline)	No (after Feedback)
T2-weighted imaging				
Capsule clearly delineated	64 (100)	64 (100)	…	…
Seminal vesicles clearly delineated	64 (100)	64 (100)	…	…
Ejaculatory ducts clearly delineated	52 (81)	63 (98)	12 (19)	1 (2)
Neurovascular bundles clearly delineated	64 (100)	64 (100)	…	…
Sphincter muscle clearly delineated	63 (98)	64 (100)	1 (2)	…
Absence of artifacts (eg, movement)	62 (97)	64 (100)	2 (3)	…
Diffusion-weighted imaging				
Adequate apparent diffusion coefficient map	64 (100)	64 (100)	…	…
Absence of artifacts (eg, rectal air)	61 (95)	64 (100)	3 (5)	…
Dynamic contrast enhanced				
Capsular vessels clearly delineated	53 (83)	63 (98)	11 (17)	1 (2)
Vessels in the Alcock canal clearly delineated	53 (83)	63 (98)	11 (17)	1 (2)
Absence of artifacts (eg, movement)	56 (88)	63 (98)	8 (13)	1 (2)

Note.—Data are number of scanners, and data in parentheses are percentages. GLIMPSE = Global Variation in Magnetic Resonance Imaging Quality of the Prostate.

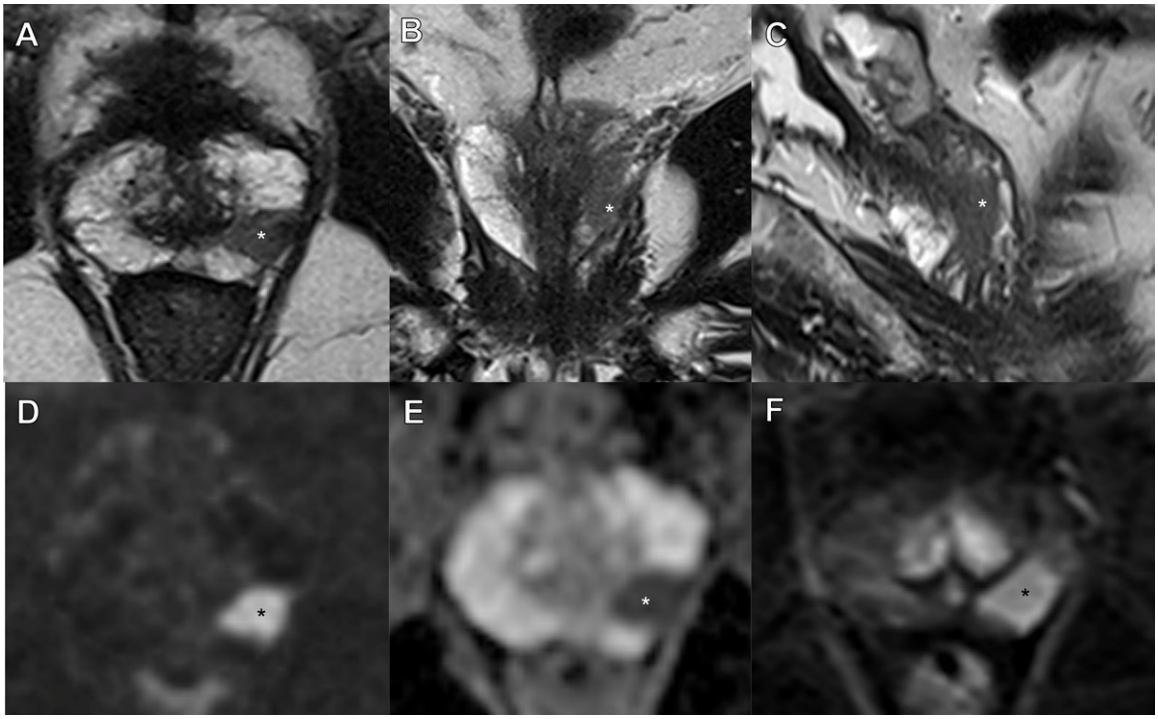

Figure 2: A case of multiparametric MRI of the prostate scoring Prostate Imaging Quality 5 (optimal diagnostic quality) in phase I. The lesion (*) in the left peripheral zone at midgland is clearly visible on axial **(A)**, coronal **(B)**, and sagittal **(C)** T2-weighted images as well as on a high-*b*-value image **(D)**, an apparent diffusion coefficient map **(E)** , and a dynamic contrast-enhanced image **(F)**. The scan was fully compliant with the technical parameters described in Prostate Imaging Reporting and Data System, version 2.1, guidelines and the Prostate Imaging Quality visual assessment criteria for each sequence.

international, multicenter prospective clinical trial (PRIME [Prostate Imaging Using MRI ± Contrast Enhancement]), assessment of multiparametric MRI quality showed that nine of 71 (13%) MRI scanners initially received a Prostate Imaging Quality (PI-QUAL) score of 3 (sufficient image quality), 39 of 71 (55%) received a score of 4 (adequate image quality), and 23 of 71 (32%) received a score of 5 (optimal image quality). Basic changes to technical recommendations outlined in the Prostate Imaging Reporting and Data System guidelines markedly improved the quality of scanners, with 97% of scanners obtaining a PI-QUAL score of 5 and 3% obtaining a score of 4.

At baseline, 13% of the submitted scans received an initial PI-QUAL score of 3 (ie, it is possible to rule in but not to rule out all clinically significant lesions), and only 32% of scanners

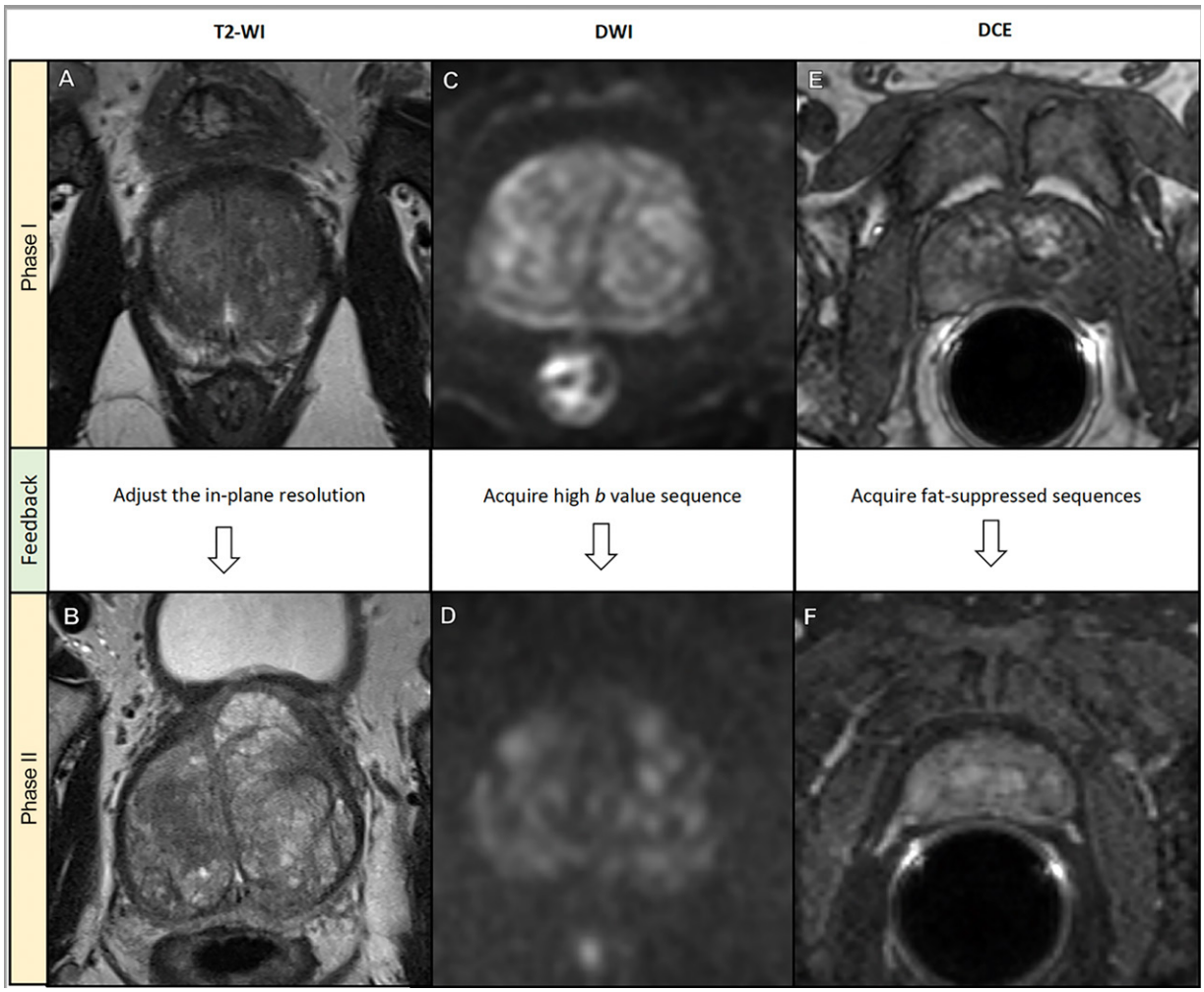

Figure 3: Three examples (from different centers and scanners) of improved image quality before **(A, C, E)** and after **(B, D, F)** feedback. For T2-weighted imaging (T2-WI), the in-plane resolution was changed from 0.56 mm (phase) × 0.56 mm (frequency) **(A)** to 0.40 mm (phase) × 0.38 mm (frequency) **(B)**. For diffusion-weighted imaging (DWI), the original highest available *b* value was 1000 sec/mm^2 **(C)**, but after feedback, a dedicated high *b* value of 1600 sec/mm^2 was acquired **(D)**. For the dynamic contrast-enhanced (DCE) sequences, fat suppression was not performed in phase I **(E)** but was performed in phase II **(F)**.

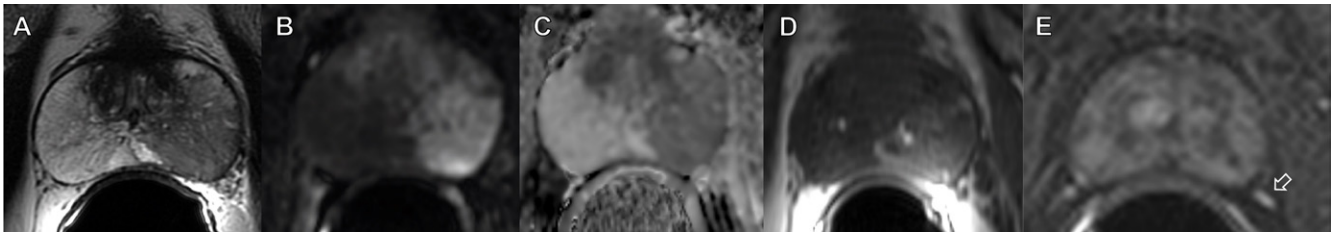

Figure 4: Example of a scanner with an endorectal coil whose image quality was improved after feedback. Images from phase I **(A–D)** show axial T2-weighted imaging **(A)**, high *b* value (*b* = 1400 sec/mm^2) **(B)**, and apparent diffusion coefficient map **(C)** of optimal diagnostic quality, but dynamic contrast-enhanced sequences **(D)** are not fat suppressed and show artifacts. Feedback for these sequences was provided, and the resubmitted dynamic contrast-enhanced images from phase II **(E)** show adequate fat suppression and clearly visible capsular vessels (arrow).

received a score of 5 (ie, optimal diagnostic quality, where it is possible to rule in and rule out clinically significant cancer), which highlights some room for improvement in MRI quality across centers. The highest variation in the quality of individual sequences was for DCE, with there being a particular need for optimization of temporal resolution and acquisition of fat-suppressed sequences. Centers performed T2-weighted imaging and diffusion-weighted imaging to a higher standard, though there was still room for improvement. After centers received feedback and modified their MRI sequences, we observed a clear improvement in the overall quality of scans across the majority of centers in the study, with 97% of the scans at the end of phase

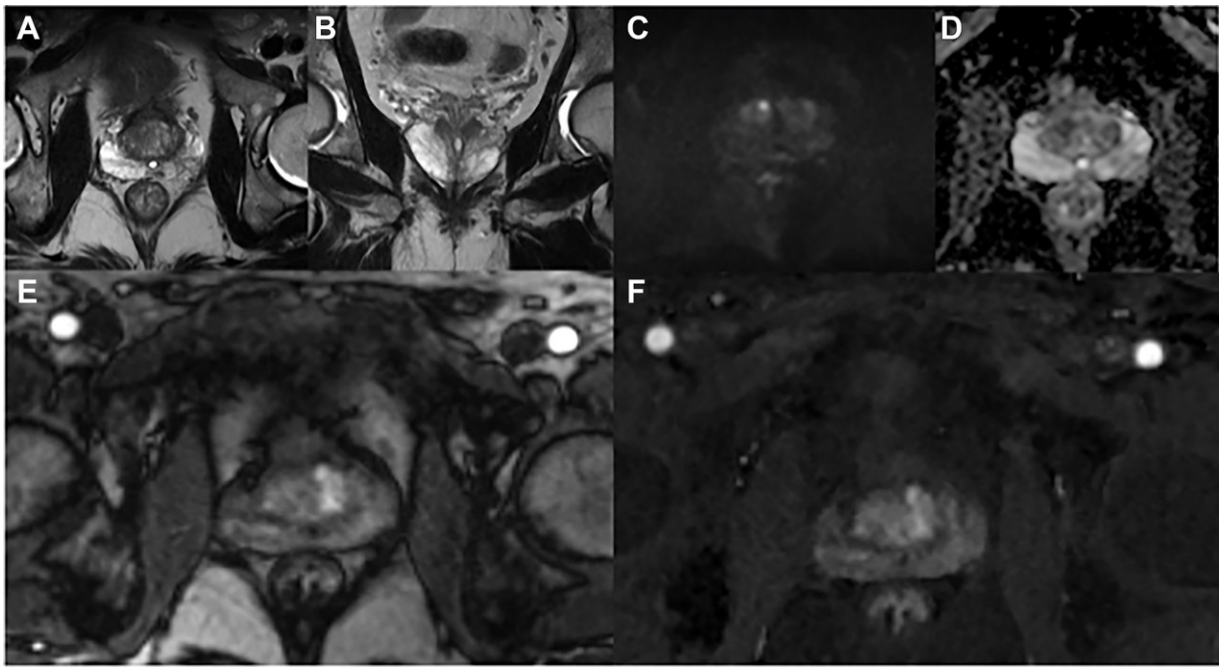

Figure 5: A case of multiparametric MRI of the prostate showing the difference between a prostate imaging quality (PI-QUAL) score of 4 and 5 in the same participant. Axial **(A)** and coronal **(B)** T2-weighted sequences are unremarkable as is the high-*b*-value sequence **(C)** and the apparent diffusion coefficient map **(D)**. The dynamic contrast-enhanced sequences are shown before **(E)** and after **(F)** fat suppression, which makes the difference between PI-QUAL 4 and PI-QUAL 5 (ie, the vessels are clearly seen only after fat suppression). A PI-QUAL score of 4 indicates adequate image quality, and a score of 5 indicates optimal image quality.

Country	Center(s)	Scanner(s)
Argentina	1	1
Australia	1	1
Belgium	1	1
Brazil	1	2
Canada	1	1
Denmark	1	1
Finland	1	3
France	3	7
Germany	4	4
Hong Kong	1	1
Israel	1	2
Italy	6	8
Netherlands	1	1
Singapore	1	1
Spain	2	3
UK	4	8
USA	6	19
Total	36	64

Figure 6: Global map of countries ($n = 17$) and the number of scanners ($n = 64$) that took part in phase II of the Global Variation in Magnetic Resonance Imaging Qualtiy of the Prostate (GLIMPSE) study. UK = United Kingdom, USA = United States of America.

II reaching a PI-QUAL score of 5. This quality improvement project further allowed standardization of all sequences across all scanners to ensure that DCE sequences in particular, which had the greatest variation, were being performed in accordance with the PI-RADS, version 2.1, standards.

The PI-RADS, version 2.1, guidelines (13) established the minimum technical requirements for the performance of the individual MRI sequences with the goal of standardizing imaging protocols and reducing variability in image quality. Our experience during GLIMPSE was that abiding by these technical parameters alone does not necessarily translate into acquiring high-quality scans. The PI-QUAL scoring system is a method of evaluating MRI quality that combines assessment of image quality with respect to technical parameters specified in the PI-RADS, version 2.1, guidelines with qualitative visual assessment of a number of MRI features that allow the radiologist to make a judgment on the diagnostic quality of the individual sequences and derive an overall

PI-QUAL image quality score. The combined assessment allowed optimization of images for most centers in the study.

The PI-QUAL scoring system was derived from the PRECISION trial (1). This was a landmark multicenter randomized trial recruiting between 2016 and 2017 that provided level I evidence for the use of multiparametric MRI before biopsy in patients suspected of having prostate cancer. It contributed to changes in international guidelines supporting the widespread use of multiparametric MRI. The study also demonstrated that there were limitations in the DCE sequence conduct, though with only 61% of scanners having adequate or optimal imaging quality (ie, PI-QUAL 4 or 5, respectively), it appears MRI quality has improved somewhat in the past 5 years, with 87% of scanners in GLIMPSE having good image quality at baseline. As a similar group of institutions comprising a mix of academic and nonacademic centers took part in both studies, this could reflect ongoing improvement of global MRI conduct. Additionally, a strength of the PI-QUAL scoring system is that the reference for optimal quality was not simply determined subjectively by two expert radiologists, but rather principally, according to adherence to the PI-RADS technical recommendations.

The first requisite for successful delivery of the MRI-influenced prostate cancer pathway is high-quality imaging, as suboptimal quality will negatively impact each component of the downstream MRI pathway. Good image quality has been shown to improve the ability to detect prostate cancer, the accuracy of staging decisions, upstaging after radical prostatectomy, and decision-making for nerve sparing during radical prostatectomy (14–17). Specifically, it has been demonstrated that poorer MRI quality as measured by PI-QUAL leads to a lower detection of clinically significant cancer (21). Thus, the clinical implications of this study are that centers with diagnostic or treatment services for prostate cancer should take part in quality improvement projects with the aid of quality evaluation systems such as PI-QUAL to optimize their MRI quality and produce clinically useful images for their patients. We believe these findings are generalizable, as the recommendations made to sites were relatively simple and reproducible, resulting in an improvement of optimal quality scans from 32% at baseline to 97% after feedback. Dedicated courses on the importance of image quality to train the radiologic community (including radiographers and physicians) should be promoted with some resources already available (22,23), and we would encourage national prostate cancer stakeholders to take action to support the improvement of MRI quality in their countries.

As DCE imaging showed the most room for improvement, this has important research implications for interpreting studies evaluating whether contrast material has an additive role in prostate cancer detection and management. It follows that it is difficult to conclude from prior studies that showed similar performance of biparametric MRI and multiparametric MRI (24) whether this was related to poorly conducted DCE, since MRI quality has never been evaluated in any of these studies. Thus, the results of the PRIME study will help elucidate with more confidence the overall role of the DCE sequence (18). On a broader level, one could argue whether all multicenter practice-defining studies involving prostate MRI should routinely report study-wide MRI quality so that its generalizability can be evaluated.

This study had limitations. First, PI-QUAL is currently only applicable to multiparametric MRI; however, should biparametric MRI become the standard of care, modifications would be required. Future modifications and refinement of the system (ie, PI-QUAL, version 2) are to be expected. Second, although the invitation for involvement in the study was open to any center and although there was representation by academic and nonacademic centers, it is likely that those who chose to be involved would be inclined to be more academic and thus may represent a higher-than-average level of MRI quality at baseline than in routine clinical practice. Although, if in fact MRI quality at baseline is worse than demonstrated here, we would argue that this more strongly supports our recommendation on the need for quality improvement projects. Third, it is recognized that application of the PI-QUAL evaluation requires time and resources, though centers with limited resources could be recommended to collaborate with more experienced centers to pool experience and help improve quality across a network of sites. Finally, MRI quality was reviewed in consensus by two expert genitourinary radiologists, and this represents a limitation when compared with independent reads.

In conclusion, the Global Variation in Magnetic Resonance Imaging Quality of the Prostate, or GLIMPSE, study offers a global overview into the variation of prostate MRI quality in different centers across the world. Despite initial MRI quality being fair, there was room for improvement, particularly with dynamic contrast-enhanced imaging. With basic changes in line with the Prostate Imaging Reporting and Data System technical recommendations and by using a standardized scoring system such as Prostate Imaging Quality (and its future iterations), global MRI quality can be easily improved.

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