Taking PI-QUAL beyond the prostate: Towards a standardized radiological image quality score (RI-QUAL)

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ABSTRACT

Purpose: To compare the interreader agreement of a novel quality score, called the Radiological Image Quality Score (RI-QUAL), to a slighly modified version of the existing Prostate Imaging Quality (*m*PI-QUAL) score for magnetic resonance imaging (MRI) of the prostate.

Methods: A total of 43 consecutive scans were evaluated by two subspecialized radiologists who assigned scores using both the RI-QUAL and *m*PI-QUAL methods. The interreader agreement was analyzed using three statistical methods: concordance correlation coefficient (CCC), intraclass correlation coefficient (ICC), and Cohen's kappa. Time needed to arrive at a quality judgment was measured and compared using the Wilcoxon signed rank test.

Results: The interreader agreement for RI-QUAL and *m*PI-QUAL scores was comparable, as evidenced by the high CCC (0.76 vs. 0.77, p = 0.93), ICC (0.86 vs. 0.87, p = 0.93), and moderate Cohen's kappa (0.61 vs. 0.64, p = 0.85) values. Moreover, RI-QUAL assessment was faster than *m*PI-QUAL (19 vs. 40 s, p = 0.001).

Conclusion: RI-QUAL is a new quality score that has comparable interreader agreement to the *m*PI-QUAL score, but with the potential to be applied to different MRI protocols and even different modalities. Like PI-QUAL, RI- QUAL may also facilitate communication about quality to referring physicians, as it provides a standardized and easily interpretable score. Further studies are warranted to validate the usefulness of RI-QUAL in larger patient cohorts and for other imaging modalities.

1. Introduction

Magnetic resonance imaging (MRI) is a widely used imaging mo- dality in clinical practice due to its high soft tissue contrast and lack of ionizing radiation. Like with any other imaging test, the diagnostic ac- curacy of MRI heavily relies on image quality, which can be affected by multiple factors, such as patient motion, scanner hardware and soft- ware, and imaging acquisition protocol. To ensure high-quality MR images, quality control procedures are generally implemented, such as scanner monitoring and protocol and hardware optimization [1]. Moreover, radiologists are encouraged to communicate with referring physicians about image quality to facilitate accurate diagnosis and treatment decisions [2].

Quality assessment in the diagnostic process is an important step to disentangle aleatoric and epistemic uncertainty. Aleatoric uncertainty ("how likely does this combination of findings represent a diagnosis") is captured through various processes, for example the '- reporting and data system' (-RADS) scores [3] and standardized lexica for reporting certainty [4]. Epistemic uncertainty ("how certain are we that our assessment is correct and has not been influenced by specific quality aspects of this particular examination") is typically included as free text in radiology reports. This free text incorporates subjective vocabulary reflecting the visual assessment of images by radiologists or technolo- gists, which can be prone to interobserver variability and lack

of stan- dardization. For example, the same artifact may be described as "motion artifact", "movement artifact", "peristalsis," or "blurring", at different

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locations in the report.
The orchestration of quality control in large healthcare systems

presents unique challenges. Typically, images from a single scanner are distributed among several radiologists, while any given individual radiologist may be tasked with reviewing images from a multitude of scanners. This dispersed workflow makes pattern recognition of tech- nical issues an uphill task. It can be difficult for radiologists to identify scanner-specific or protocol-specific issues when they are viewing a diverse set of images from various scanners and using various protocols in their daily practice. Subtle but systematic artifacts or recurrent quality issues may go unnoticed or unattributed to their root cause because of the wide dispersion of exams among radiologists.

Recent advancements have given rise to the Prostate Imaging Quality (PI-QUAL) score, a measure of prostate MRI quality [5] on a 1-to-5 scale which standardizes evaluation of the quality of multiparametric MRI of the prostate against objective technical recommendations, as per Pros- tate Imaging Reporting and Data System (PI-RADS) guidelines [6], and also against a set of more subjective criteria (i.e., visual assessment) for each sequence. Standardized scores such as PI-QUAL may address the abovementioned quality control issues. By providing a structured lan- guage for radiologists to annotate image quality and technical issues, this information can be systematically extracted from reports. It could then be used to populate interactive dashboards, displaying quality scores, and accompanying issues, organized by scanner, protocol, and over time. This would provide a centralized and objective perspective on scanner performance and offer a robust tool for tracking quality control over time. By transforming the often unstructured and dispersed knowledge about image quality into actionable data, this could revo- lutionize how radiologists, technologists, and physicists monitor and optimize MRI quality in large healthcare systems. It can enable pattern recognition at a system level, thereby promoting proactive maintenance and consistent imaging quality across scanners and protocols. However, PI-QUAL is inherently limited to MRI of the prostate, and currently only in its first iteration [5].

In this paper, we present a novel radiological image quality scoring system (RI-QUAL), which offers both standardization and potential flexibility to be extended to other body parts and modalities. We aimed to assess its interreader agreement and time efficiency for assessment, in comparison to a slightly modified version of the established PI-QUAL score within the context of prostate MRI.

2. Methods

2.1. Study population

The study population consisted of 43 consecutive prostate MR scans performed at a single institution in April 2023. As a quality assurance (QA) initiative, the analysis was exempt from institutional review board approval.

2.2. Quality rating

The RI-QUAL was defined as a subjective 4-point scale from A - D (Fig. 1):

1. (A) Diagnostic - No artifacts or limitations. Excellent quality.
2. (B) Diagnostic – Mild/slight artifacts or limitations, unlikely (~10%)

    to have a negative effect on diagnostic confidence.

3. (C) Diagnostic - Moderate artifacts or limitations, possible (~50%)

    negative effect on diagnostic confidence.

4. (D) Non-diagnostic - Marked/Severe artifacts or limitations; probable

    (~75%) negative effect = non-diagnostic exam. In the clinical routine, this score *must* be accompanied by an explanation and, if applicable, a recommendation for further management (imaging or non-imaging).

Letters were chosen instead of numbers to avoid confusion with existing scoring systems. There were no other fixed criteria, but several examples for various modalities were provided in the clinical standard operating procedure document (see attached *Supplement 1*).

2.3. Modified PI-QUAL assessment

We also evaluated interreader agreement of PI-QUAL scoring in prostate MRI. PI-QUAL is a previously proposed and validated measure of Prostate MRI quality that ranges from 1 to 5, with higher scores (i.e., PI-QUAL 4 and 5) indicating diagnostic image quality. The PI-QUAL score is based on assessment of artifacts and technical acquisition pa- rameters, such as slice thickness, field-of-view, and in-plane resolution, as per PI-RADS technical recommendations and as explained in detail in [5]. We allowed for several modifications to the published PI-QUAL criteria: 1. We allowed for assessment of biparametric MRI, i.e., without contrast enhanced sequences. This results in 4 being the maximum PI-QUAL score. 2. We allowed for a slice thickness of 4 mm in T2w imaging (as opposed to 3 mm) without deduction from the final score. 3. Rather than systematic completion of the whole checklist, we

Radiological Imaging Quality Score (RI-QUAL)	Artifacts / Limitations	Effect on diagnostic confidence	Diagnostic
RI-QUAL A	None	None	Yes
RI-QUAL B	Mild	Unlikely (~10%)	Yes
RI-QUAL C	Moderate	Possible (~50%)	Yes
RI-QUAL D *	Severe	Probable (~75%)	No

* This must be accompanied by an explanation along with a recommendation for further management (if applicable)

Fig. 1. RI-QUAL Scoring Card. 2

performed stepwise assessment with omission of time-consuming steps (e.g. looking up scan parameters and checking slice angulation) if a previous step already showed limited quality. For example, if one series already has significant motion artifacts, the

need to look up its detailed scan parameters becomes redundant for scoring purposes. To distinguish this scoring approach from the officially recommended PI-QUAL scoring, we will henceforth refer to it as *m*PI-QUAL.

2.4. Image analysis

Two subspecialized genitourinary radiologists (AB and SW), with more than 4 and 8 years of experience in body imaging since board- certification, respectively, and > 400 clinically reported prostate MRIs annually, independently evaluated the 43 prostate MRI exams using both the RI-QUAL and *m*PI-QUAL scores. The readers were blinded to each other's scores and the clinical information of the patients. The readers also manually measured the readout time, i.e., the time it took them to arrive at a judgment in each case using a stopwatch (time when images finished loading in PACS to time when score was decided).

2.5. Statistical analysis

Descriptive statistics were used to summarize the patient charac- teristics and MRI data. The interreader agreement of RI-QUAL and *m*PI- QUAL was assessed using intraclass correlation coefficient (ICC), Lin's concordance correlation coefficient (CCC), and weighted Cohen's kappa. While ICC represents is a more general form of Pearson's corre- lation testing, CCC not only considers the correlation but also the agreement between the two variables and is thus more robust. Lastly Cohen's kappa measures the degree of agreement in classification over what would be expected by chance. The three measures were chosen because they measure slightly different aspects of agreement and are widely used in the radiological literature. The resulting agreement scores were interpreted as follows: slight agreement ($\kappa < 0.20$), fair ($\kappa = 0.20$–0.39), moderate ($\kappa = 0.40$–0.59), substantial ($\kappa = 0.60$–0.79), or excellent ($\kappa > 0.80$) agreement [7]. Student's *t*-test was performed on Fisher's z-transformed estimates to calculate p-values (two-sided). Readout times were compared using a Wilcoxon-signed rank test. A $p < 0.05$ was considered indicative of statistical significance. The statistical analyses were performed using R version 4.3.0 (R Foundation for Sta- tistical Computing, Vienna, Austria).

3. Results

Both RI-QUAL and *m*PI-QUAL exhibited substantial to excellent interreader agreement between Reader 1 and Reader 2. The CCC values were 0.76 (95% CI, 0.59–0.86) for RI-QUAL and 0.77 (95% CI, 0.61–0.86) for *m*PI-QUAL. The ICC values were 0.86 (95% CI, 0.75–0.93) for RI-QUAL and 0.87 (95% CI, 0.76–0.93) for *m*PI-QUAL, indicating equally excellent agreement (both p = 0.93). Cohen's kappa values were 0.61 (95% CI, 0.43–0.80) for RI-QUAL and 0.64 (95% CI, 0.45–0.83) for *m*PI-QUAL, indicating substantial and comparable (p = 0.85) agreement.

The confusion matrices for RI-QUAL and *m*PI-QUAL scores of both readers are shown in Tables 1 and 2.

Median readout times for RI-QUAL were 8 s (IQR: 7–10 s) for Reader 1 and 19 s for reader 2 (IQR: 15–23 s), both readers were significantly

Table 1

Confusion matrix of RI-QUAL scores of Reader 1 vs. Reader 2.

RI-QUAL	D	C	B	A
D	10	0	0	
C	1	7	1	0
B	0	1	9	6
A	0	0	6	11

Table 2

Confusion matrix of *m*PI-QUAL scores of Reader 1 vs. Reader 2. Note the maximum score of 4, since the majority of our scans (n = 33, 77%) were biparametric MRI (bpMRI; i.e., without IV contrast), and none of the mpMRI scans reached a perfect score.

slower when performing a *m*PI-QUAL assessment with 33 s (IQR: 27–42 s) for Reader 1 and 40 s (IQR: 36–44) for Reader 2 (both p < 0.001).

4. Discussion

In this study, we evaluated the interreader agreement of our newly developed RI-QUAL and compared it to a variation of the established PI- QUAL for prostate MRI [5]. The results showed that both methods had high interreader agreement between the two subspecialized radiolo- gists, with similar CCC, ICC, and Cohen's kappa values. These findings suggest that the proposed RI-QUAL could be a valuable tool to identify quality issues in large radiology practices, and for standardizing communication about quality to referring physicians.

The choice of rating scale is an important consideration in the development of any assessment tool. In our study, we used a 4-point rating scale for RI-QUAL. The main advantage of using a 4-point scale, as opposed to a 5 or 3-point scale, is that it forces the rater to make a clear decision, rather than relying on the midpoint as an uncertain choice [8]. Another advantage of using fewer points on a

scale is the reduction of interrater variability, as the number of response options is limited, and therefore, it is easier to reach consensus between raters [9]. This can also be performed *post-hoc* during statistical analysis by collapsing several categories, for example PI-QUAL 4/5 and 1/2 [9]. Whether the distinction between A and B in our scale is necessary or useful, or whether it would be advantageous to further collapse the scale leaving one relatively broad category in the middle should be subject to further investigation, and the answer may well vary between different clinical contexts. For example, for assessment of the prostate after focal treatment, a three-point-scale has recently been proposed which ties in with clinical management recommendations [10]. Furthermore, the quality rating in ultrasound for HCC screening has an officially recom- mended 3-point scale, roughly translating to the lesion size that may be obscured [11]. Lastly, our interreader agreement values are in line with the published literature: Hötker et al. recently reported a Kappa of 0.58 for both subjective assessment (5-point scale) and PI-QUAL score [12]. For PI-QUAL alone, both Pötsch et al. [13] and Karanasios et al. [14] reported a Kappa of 0.51, while Girometti et al. reported a slightly higher Kappa of 0.55 [15]. Overall, our study suggests that a 4-point scale may be a suitable alternative choice to the popular 5-point Likert-like scale for rating system development in quality assessment tools for medical imaging.

Our results also showed that median readout times for RI-QUAL were significantly shorter than for *m*PI-QUAL, indicating that RI-QUAL could potentially improve workflow efficiency in a busy clinical setting. However, the difference was rather small. This was certainly in part due to the fact that our cohort was composed mostly of bpMRI, alleviating the fact of assessing the dynamic contrast enhanced images. At our institution, mpMRI is only used in the posttreatment setting [16,17], resulting in the maximum *m*PI-QUAL score assigned in our cohort being 4 instead of 5. Another reason for our relatively short readout time of < 1 min when compared to the PI-QUAL literature (circa 6–8 min in [18]) is that we did not fill out a form for every case, but rather performed a step-wise *m*PI-QUAL assessment, as described in the methods. Both readers in our study are subspecialized radiologists and probably took imaging parameters implicitly into account when subjectively scoring the scans. Future studies could investigate whether this be the case for less experienced readers, who may exhibit higher variability in subjec- tive RI-QUAL assessment, and thus may benefit from the detailed and robust framework PI-QUAL provides [6].

The aim of this study was not to replace PI-QUAL or other targeted quality scoring systems, but rather compare RI-QUAL to an established reference standard. As a matter of fact, if such specific scoring systems are available, they should be preferred over the generic RI-QUAL unless there are strong arguments to do otherwise. One such argument may be standardization across a whole department/institution, although sys- tems like PI-QUAL may well be integrated into such institutional guidelines. Since quality assessment is usually not at the center of the report, we would not advocate to give multiple scores in a single report, as this may unnecessarily complicate interpretation and hamper acceptance by radiologists and referring physicians.

Our study has some limitations that should be considered when interpreting the results. First, albeit conceived with general applicability in mind, we only evaluated the interreader agreement of RI-QUAL and *m*PI-QUAL in a small sample of prostate MRI scans read by two sub- specialized radiologists. Future investigations should aim to evaluate its application in a more heterogeneous environment, including general radiologists, other organs/modalities, and potentially across multiple healthcare systems. Furthermore, as PI-QUAL is an evolving initiative, improvements to future versions, for example, the inclusion of bipara-metric MRI, will need to be taken into account. Second, since this was a QA initiative, we were unable to assess the diagnostic performance of RI- QUAL or *m*PI-QUAL in terms of sensitivity, specificity, or accuracy. A growing body of literature suggests an association between PI-QUAL and diagnostic accuracy [12,13]. Such comparisons should be performed for RI-QUAL in the future. Similarly, since the proposed RI-QUAL was conceived with a clear quality assurance/improvement aim, it does explicitly not include endogenous factors (T1 hyperintense postbiopsy changes, (post)inflammatory peripheral zone heterogeneity), as evalu- ated previously by Hötker et al. [12,19]. Whether the merit of cleanly separating different sources of uncertainty outweighs the added complexity to workflow and report text remains to be investigated. Third, neither PI-QUAL nor RI-QUAL assign a specific weight or priority to any of the pulse sequences. In practice, DCE is sometimes used to compensate for artifacts in DWI. However, the overall performance of biparametric MRI without DCE has been shown to be comparable [17]. Fourth, whenever multiple sequences and anatomical regions are sum- marized into a single score, there is an inevitable loss of information. In RI-QUAL, we suggest the possibility to "bump" the score up if the artifact do not affect an important region. For example, if no prostate tumor is seen, an artifact obscuring a few locoregional lymph nodes may be deemed inconsequential. Nevertheless, assigning a standardized score does not absolve the radiologist from the duty to describe location and magnitude in the (ideally structured) report under the respective anatomical section, and/or in the impression or conclusion of the report.

The introduction of automated extraction of these scores from the radiology report or from the images, and their incorporation into interactive dashboards should be a future priority. This capability would enable real-time tracking of scanner performance, facilitate early iden- tification of systematic issues, and may promote overall quality improvement in MRI operations. As these data become more accessible, it might also encourage proactive discussions about quality between radiologists, technologists, and referring physicians.

In conclusion, our study showed that our newly developed RI-QUAL has high interreader agreement and shorter readout times compared to *m*PI-QUAL in prostate MRI. The proposed RI-QUAL holds promise for standardizing quality assessment and communication in radiology. Further research should focus on its broader implementation, i.e., investigate interreader agreement in other MRI protocols and cross- sectional modalities, and integration into routine clinical workflows. In particular its real-world impact potential for improving MRI quality and operations in large, diverse healthcare systems should be prospec- tively investigated.

Availability of data and code

All data contained within the article.

Ethics approval

Exempt (health care operations/quality assurance project).

CRediT authorship contribution statement

Anton S. Becker: . **Francesco Giganti:** Investigation, Methodology, Validation, Writing – review & editing. **Andrei S. Purysko:** Methodol- ogy, Validation, Writing – original draft, Writing – review & editing. **Jonathan Fainberg:** Investigation, Supervision, Writing – original draft, Writing – review & editing. **Hebert Alberto Vargas:** . **Sungmin Woo:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Valida- tion, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi. org/10.1016/j.ejrad.2023.110955.

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