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ABDOMINAL IMAGING

ORIGINAL ARTICLE

Assessment of the compliance with minimum acceptable technical parameters proposed by PI-RADS v2 guidelines in multiparametric prostate MRI acquisition in tertiary referral hospitals in the Republic of Turkey

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PURPOSE

Although the clinical use of multiparametric prostate magnetic resonance imaging (mpMRI) is increasing, the adherence to parameters for mpMRI, which had been described in the Prostate Imaging-Reporting and Data System version 2 (PI-RADS v2) for an optimum image acquisition is unknown. In this paper, we aimed to determine the compliance with the minimum acceptable technical parameters for prostate mpMRI defined by PI-RADS v2 in tertiary care centers in Turkey.

METHODS

We sent a survey to all radiology departments of tertiary referral hospitals in Turkey (n=120) to evaluate their adherence to PI-RADS v2 technical specifications. Statistical analysis was performed using chi-square, Fisher exact, ANOVA, and the Student t tests. The cutoff values for image acquisition times were also determined with receiver operating characteristics (ROC) analysis. P values <0.05 were considered statistically significant.

RESULTS

One hundred and eleven clinics responded to our survey (response rate, 92.5%). Prostate MRI was reported to be performed in 61 centers, of which 26 (42.6%) used 3 T (Tesla) scanner while 35 (57.4%) used 1.5 T. The adherence to slice thickness, in-plane phase and frequency resolutions on T2-weighted imaging were 68.9%, 41%, and 9.8%, respectively. The adherence to the same parameters on diffusion-weighted imaging (DWI) were higher compared with T2-weighted imaging (85.2%, 62.3%, and 78.7%, respectively). In comparative analysis, the adherence to slice thickness, field of view (FOV) and in-plane phase resolution on T2-weighted imaging were higher for 3 T compared with 1.5 T scanners ($P = 0.004$, $P = 0.041$, and $P = 0.001$, respectively). T2-weighted imaging acquisition time was significantly longer for the centers that adhered to FOV ($P = 0.034$) and in-plane T2-weighted imaging phase resolution ($P = 0.028$). The DWI scan time was significantly longer when they adhered to DWI-FOV ($P = 0.014$) and b value ≥1400 s/mm^2 ($P = 0.008$). The calculated cutoff of scan times were 220 s in T2-weighted imaging and 312 s in DWI to ensure the compliance with voxel sizes and b value criteria.

CONCLUSION

The tertiary referral centers in Turkey did not meet majority of the technical specifications of PI-RADS v2 during prostate MRI acquisition. Awareness to the minimum acceptable technical parameters of mpMRI should be increased to potentially improve the quality of prostate cancer imaging.

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The Prostate Imaging-Reporting and Data System (PI-RADS) was first published in 2012. The minimum acceptable technical parameters for multiparametric prostate magnetic resonance imaging (mpMRI) had been described in this document elaborately (1). In 2015, the PI-RADS guidelines were revised and version 2 (v2) was released. The technical specifications have been updated and acquisition recommendations for axial T2-weighted imaging, diffusion-weighted imaging (DWI), and dynamic contrast enhanced (DCE) imaging have been detailed in that edited version (2). Use of prostate MRI in prostate cancer has substantially increased (3), and prostate MRI is recognized as one of the biomarkers such as blood tests (e.g., serum prostate specific antigen [PSA], 4K test) and tissue based genomic classifiers (e.g., Oncotype DX, Decipher) (4). The biggest concern about prostate MRI as a potential biomarker amongst others is its inhomogeneous quality regarding image acquisition and interpretation (5, 6). Currently, only one study

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has evaluated the adherence of imaging centers to the technical specifications of PI-RADS v2 (7).

It has become a common practice to use MRI in healthcare all over the world in the last decade. Interestingly, based on 2015 data of the Organisation for Economic Co-operation and Development (OECD), Turkey is the country where the highest number of MRI scans (n=144 per 1000 individuals per year) were performed whereas corresponding numbers were 36 and 118 for the European Union (EU) and the United States (US), respectively. However, the number of MRI scanners per million was 10.2 in Turkey, whereas corresponding numbers were 13.7 and 39 for the EU and the US, respectively (8). While use of MRI has become more popular in clinical care in Turkey in the last decade, the share of prostate MRI within this workload is still unknown. On the other hand, localized prostate cancer care has already started to implement prostate MRI and few centers reported use of MRI and its guidance in targeted biopsies and surgery in Turkey (9–11). In this study, we aimed to determine the compliance with the minimum acceptable technical parameters for prostate mpMRI defined by PI-RADS v2 in tertiary care reference centers in Turkey.

Methods

This retrospective study was approved by the ethics committee (approval number: 31829978-050.01.04-E.1800012835). We reached the radiology departments (n=120) of all third level referral hospitals in Turkey, including state university hospitals, training and research hospitals of the Ministry of Health, and private university hospitals by phone or mail in February 2018. We asked them to complete a survey form on mpMRI parameters, if prostate mpMRI was being performed in their departments (Table 1). The responses were compared with PI-RADS v2 minimum acceptable technical parameters. Turkey's 2017 population data were received from the official website of the Turkish Statistical Institute (TSI) (12).

Main points

- The adherence to MRI acquisition parameters of PI-RADS v2 is low in Turkey.
- Some recommendations of PI-RADS v2 for technical specifications may need to be revised.
- The image acquisition duration of T2-weighted imaging longer than 220 s can enhance the compliance with voxel size, which can potentially improve image quality.

Statistical analysis

The comparison of field strength and institute types for the compliance with the parameters was done by chi-square and

Table 1. The questionnaire sent to all tertiary referral centers in Turkey

Questions
Magnet strength?
Brand of MRI scanner?
Are you using endorectal coil?
How many channels does your pelvic-surface coil have?
Do you obtain coronal T2?
Do you obtain sagittal T2?
Do you obtain precontrast axial T1?
Do you obtain postcontrast T1?
Do you obtain at least one sequence encompassing aortic bifurcation?
For axial T2, slice thickness?
For axial T2, gap between slices?
For axial T2, FOV (two plane)?
For axial T2, matrix (phase x frequency)?
For axial T2, NEX?
For axial T2, total acquisition time?
For DWI, TR?
For DWI, TE?
For DWI, slice thickness?
For DWI, gap between slices?
For DWI, FOV (two plane)?
For DWI, matrix (phase x frequency)?
For DWI, maximum *b* value (acquisition)?
For DWI, NEX for maximum *b* value?
For DWI, total acquisition time?
For DCE, temporal resolution?
For DCE, TR?
For DCE, TE?
For DCE, slice thickness?
For DCE, gap between slices?
For DCE, FOV (two plane)?
For DCE, matrix (phase x frequency)?
For DCE, total acquisition time?

MRI, magnetic resonance imaging; FOV, field of view; NEX, number of excitations; DWI, diffusion-weighted imaging; TR, repetition time; TE, echo time; DCE, dynamic contrast enhancement.

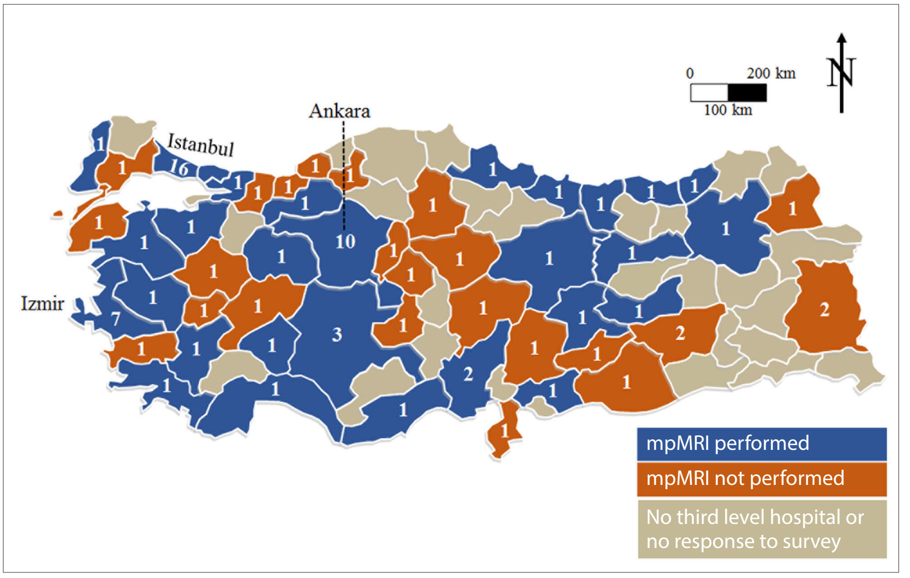

Figure 1. Map shows the status and number of tertiary referral centers performing MRI of the prostate in Turkey.

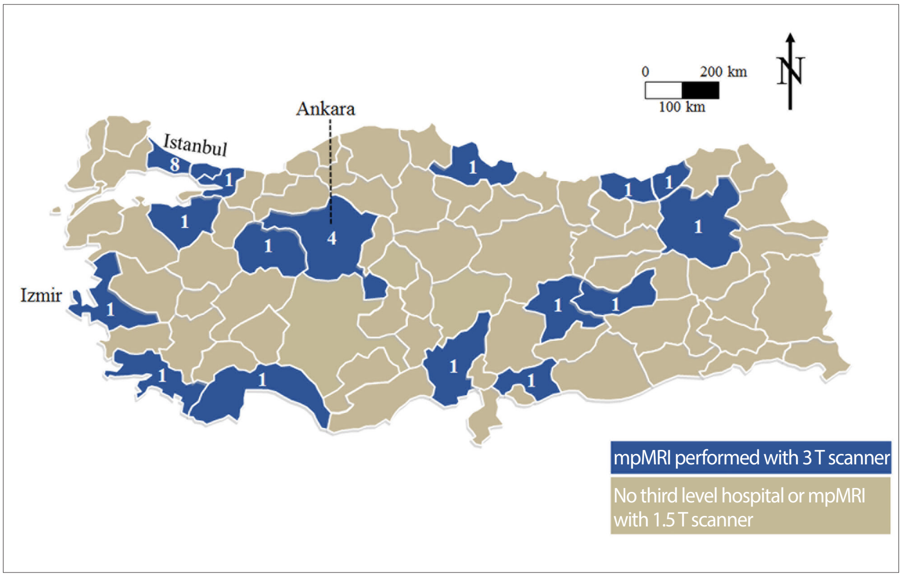

Figure 2. Number of tertiary referral centers performing MRI of the prostate with 3 Tesla scanners in Turkey.

Fisher exact test. The acquisition times of the institutes were compared with each other by the ANOVA test (with Bonferroni correction). The data showed a normal distribution and Student t test was used to compare acquisition time with the adherence to technical specifications. The cutoff image acquisition times to reach compliance with PI-RADS v2 specifications were calculated with receiver operating characteristic (ROC) analysis. Statistical analysis was performed with Statistical Package for the Social Sciences (SPSS version 20.0; IBM Corp.). *P* values <0.05 were considered statistically significant (alpha error level <5%).

Results

One hundred and eleven of 120 clinics responded to our survey (response rate, 92.5%). Sixty-one of 111 (55%) centers reported to perform MRI of the prostate (59 centers multiparametric, 2 centers biparametric) (Fig. 1). 3 Tesla (T) scanner was used in 26 (42.6%), while 1.5 T scanner was used in 35 (57.4%) clinics (Fig. 2). The vendors of MRI devices were Siemens in 35, Philips in 17 and General Electric in 9 clinics.

Thirty-three clinics (54.1%) were in the three largest cities of Turkey (Fig. 1). MpMRI of the prostate was documented to be performed only in 13 of 59 cities with <1 million population according to 2017 data of TSI. Of the 61 centers performing prostate MRI, 36 were state universities, 14 were private universities, and 11 were training and research hospitals of the Ministry of Health.

The adherence to the minimum acceptable technical parameters of PI-RADS v2 is presented in Table 2. The compliance with the parameters was as follows for T2-weighted imaging: slice thickness, 68.9%; inter-slice gap, 32.8%; field-of-view (FOV), 75.4%; in-plane frequency resolution, 9.8%; in-plane phase resolution, 41%. The adherence to slice thickness, inter-slice gap, in-plane frequency, and phase resolution were higher in DWI compared with T2-weighted imaging and were 85.2%, 50.8%, 78.7%, and 62.3%, respectively. The compliance with FOV in DWI was 37.7% and there were 2 centers using narrower FOV than 160 mm, which is suggested as the lower limit in PI-RADS v2 (2). These 2 centers were considered to be incompatible with the PI-RADS v2 technical specifications. The adherence to highest *b* value ≥1400s/mm² was 57.4%. The adherence to slice thickness, inter-slice gap, in-plane frequency, and phase resolution in DCE were 39%, 50.8%, 93.2%, and 89.9%, respectively. The adherence to temporal resolution ≤10 seconds (s) in DCE MRI was 55.9%. The mean acquisition times of axial T2-weighted imaging, DWI, and DCE imaging were 233, 274, and 247 s, respectively.

In comparative analysis, the adherence to slice thickness, FOV, and in-plane phase resolution at T2-weighted imaging were significantly higher for the centers using 3 T scanners ($P = 0.004$, $P = 0.041$, and $P = 0.001$, respectively). No significant difference was found regarding compliance with the other parameters between 1.5 T and 3 T scanners (Table 3).

There was no significant difference between institution types regarding compliance with any of the parameters. Mean durations of three major sequences were shorter in the private universities, but it was not statistically significant (Table 4).

In comparison of acquisition times with the adherence to the minimum acceptable technical specifications, T2-weighted imaging acquisition time was significantly longer for the centers which adhered to FOV and in-plane phase resolution for T2-weighted imaging ($P = 0.034$ and $P = 0.028$, respectively) (Table 5). DWI acquisition time was also significantly longer when they adhered to FOV for DWI and *b* value ≥1400s/mm² (*P*

Table 2. Adherence to the technical parameters of PI-RADS v2 in Turkey

Questions		PI-RADS v2 recommendation	Mean	Min–max	Adherence, n (%)
Pelvic coil, how many channels?		≥16 channel	16.8	2–64	52 (85.2)
Coronal T2		Should be obtained			55 (90.2)
Sagittal T2		Should be obtained			58 (95.1)
Precontrast axial T1		Should be obtained			59 (96.7)
Postcontrast T1		Should be obtained			53 (86.9)
One sequence covering aortic bifurcation		Should be obtained			42 (68.9)
Axial T2:	Slice thickness (mm)	≤3	3.25	2.5–4.5	42 (68.9)
	Gap	0	0.42	0–2.5	20 (32.8)
	Field of view (mm)	120–200	205	140–320	46 (75.4)
	Frequency voxel size (mm)	≤0.4	0.67	0.31–1.05	6 (9.8)
	Phase voxel size (mm)	≤0.7	0.81	0,31–1.34	25 (41)
	NEX		2.5	1–5	
	Acquisition time (s)		233	76–490	
Diffusion:	Slice thickness (mm)	≤4	3.67	3–6	52 (85.2)
	Gap	0	0.38	0–1.5	31 (50.8)
	Field of view (mm)	160–220	255	140 - 461	23 (37.7)
	Frequency voxel size (mm)	≤2.5	2.02	0.7–3.24	48 (78.7)
	Phase voxel size (mm)	≤2.5	2.32	0.89–3.96	38 (62.3)
	TR (ms)	≥3000	4876	400–8300	54 (88.5)
	TE (ms)	≤90	80	55–116	47 (77)
	Maximum *b* value (s/mm2)	≥1400	1302	600–2400	35 (57.4)
	NEX of maximum *b* value		6.9	1–20	
	Acquisition time (s)		274	54–639	
Dynamic*:	Temporal resolution (s)	≤10, preferred <7	14.5	3.4–61	33 (55.9), 10 (16.9)
	Slice thickness (mm)	≤3	3.34	0.9–4.8	23 (39)
	Gap	0	0.4	0–3	30 (50.8)
	Frequency voxel size (mm)	≤2	1.38	0.58–3.54	55 (93.2)
	Phase voxel size (mm)	≤2	1.64	0.66–3.85	53 (89.9)
	TR (ms)	≤100	30	2.7–500	56 (94.9)
	TE (ms)	≤5	3.18	0.8–50	56 (94.9)
	Acquisition time (s)	≥120	247	63–551	53 (89.9)

PI-RADS v2, Prostate Imaging-Reporting and Data System; min, minimum; max, maximum; NEX, number of excitations; TR, repetition time; TE, echo time.
*Results of 59 clinics.

= 0.014 and P = 0.008, respectively) (Table 6). The compliance with temporal resolution ≤10 s was also related with echo time (TE) and repetition time (TR) in DCE imaging (P = 0.011 for both).

In ROC analysis, the optimal cutoff value of T2 acquisition time was found as 220 s for adherence to voxel sizes (for phase: sensitivity 76%, specificity 69.4%, and area under the curve [AUC] 0.707; for frequency: sensitivity 83.3%, specificity 54.5%, and AUC 0.665). The cutoff value of DWI duration was calculated as 221 s (sensitivity 85.7%, specificity 65.4%, and AUC 0.74) for compliance with *b* value ≥1400s/mm^2. When the cutoff time

Table 3. Comparison of tertiary referral centers using 1.5 T and 3 T devices regarding compliance with the parameters of PI-RADS v2

Parameters/adherence	1.5 T (n=35), n (%)	3 T (n=26), n (%)	P
T2 slice thickness	19 (54.3)	23 (88.5)	0.004
T2 gap	13 (37.1)	7 (26.9)	0.40
T2 FOV	23 (65.7)	23 (88.5)	0.041
T2 voxel (frequency)	3 (8.6)	3 (11.5)	0.70
T2 voxel (phase)	8 (22.9)	17 (65.4)	0.001
DWI TR	31 (88.5)	23 (88.5)	0.99
DWI TE	30 (85.7)	17 (65.4)	0.062
DWI slice thickness	29 (82.9)	23 (88.5)	0.54
DWI gap	20 (57.1)	11 (42.3)	0.25
DWI FOV	12 (34.3)	11 (42.3)	0.52
DWI voxel (frequency)	30 (85.7)	18 (69.2)	0.12
DWI voxel (phase)	23 (65.7)	15 (57.7)	0.52
DWI maximum *b* value	17 (48.6)	18 (69.2)	0.11
*DCE temporal resolution (7 s)	7 (21.2)	3 (11.5)	0.49
*DCE temporal resolution (10 s)	20 (64.5)	13 (50)	0.42
*DCE TR	31 (93.9)	25 (96.2)	1.00
*DCE TE	31 (93.9)	25 (96.2)	1.00
*DCE slice thickness	12 (36.4)	11 (42.3)	0.64
*DCE gap	15 (45.4)	15 (57.7)	0.35
*DCE voxel (frequency)	31 (93.9)	24 (92.3)	1.00
*DCE voxel (phase)	28 (84.8)	25 (96.2)	0.22
*DCE duration	29 (82.9)	24 (92.3)	0.69

T, Tesla; FOV, field of view; DWI, diffusion-weighted imaging; TR, repetition time; TE, echo time; DCE, dynamic contrast enhancement.
*DCE results of 59 clinics (1.5 T n=33, 3 T n=26).

was taken as 312 s, sensitivity and specificity were found as 40% and 76.9%, respectively. The mean sequence duration of the centers which did not adhere to *b* value ≥1400s/mm² was 228 s, while it was 308 s for the centers meeting the *b* value criteria. The cutoff was calculated as 1.87 milliseconds (ms) for TE (sensitivity 100%, specificity 61.5%, and AUC 0.72) and 7.06 ms for TR (sensitivity 100%, specificity 15.4%, and AUC 0.553) to be able to comply with temporal resolution ≤10 s in DCE imaging.

Discussion

In this study, we found that the technical specifications of prostate mpMRI performed in tertiary referral centers in Turkey did not meet majority of the recommendations of PI-RADS v2. The lowest compliance was 9.8% in T2-weighted imaging frequency voxel size, while the highest one was 94.9% in TE and TR in DCE MRI. There was only one center meeting all technical specifications of PI-RADS v2. The minimum acceptable technical requirements was defined by expert consensus in PI-RADS v2 guidelines. There was no study focused on relation between image quality and technical specifications prior to release of PI-RADS v2. A previous study of Esses et al. (7) reported that the lowest compliance was 16.8% in T2-weighted imaging in-plane frequency dimension and the adherence to TE and TR were 100% in DCE MRI. In our study, adherence to the majority of the criteria was lower compared with that study except for some parameters such as temporal resolution, slice thickness, and in-plane phase dimension in DCE MRI.

The PI-RADS v2 recommended to perform prostate mpMRI at 3 T scanners and suggested to use endorectal coil (ERC), especially when acquired at 1.5 T (2). While prostate MRI was more often performed with 1.5 T (59%) in Turkey, ERC was reported to be used only in 2 centers (one 3 T, one 1.5 T). In Esses et al. (7), 1.5 T scanners were used in 30.8% (23.1% without ERC, 7.7% with ERC) of 107 participant centers in the US.

The centers using 3 T more often adhered to slice thickness, FOV and in-plane dimension (phase) in T2-weighted imaging in our study. In the study of Esses et al. (7), the compliance with in-plane (phase) dimension of T2-weighted imaging, gap in DWI and in-plane (frequency) dimension in DCE MRI was also significantly higher with 3 T devices. Higher field strength scanners provide higher signal-to-noise ratio and this factor might have enabled higher number of matrix or narrower FOV.

In PI-RADS v2, the recommendations mainly focused on high spatial resolution, but there was no proposal for contrast resolution of any sequence. In our study, mean number of excitations (NEX) was 2.5 for T2-weighted imaging, whereas PI-RADS v2 did not make any suggestions. In the future versions of PI-RADS, NEX≥2 may be added for higher contrast resolution in T2-weighted imaging. The scan time is directly proportional to NEX, so careful checking of acquisition times may be important, and this can potentially enhance contrast resolution. In this context, use of 3 T scanners could be encouraged.

The PI-RADS v2 had no recommendation for acquisition times of T2-weighted imaging and DWI. In our study, 220 s was calculated as a cutoff value for T2-weighted imaging duration in order to comply with voxel dimensions. Also, the compliance with *b* value ≥1400 s/mm² was significantly higher for the centers acquiring DWI in 312 s or longer. These cutoffs may increase the adherence to voxel sizes in T2-weighted imaging and *b* value ≥1400 s/mm² in DWI.

Temporal resolution should be at least ≤10 s and is preferred to be <7 s for DCE MRI in PI-RADS v2 (2). The compliance with the 10 s criterion was 55.9%, while it was 16.9%

Table 4. Image acquisition times of tertiary referral centers in Turkey

Institution type	Mean (s)	SE (s)	95% CI (s)	Min–max (s)	*P*
T2 State university (n=35)	243	17	210–275	91–490	0.45
T2 Training hospital (n=10)	237	28	182–292	150–480	
T2 Private university (n=14)	206	18	170–241	76–330	
DWI State university (n=35)	282	22	239–325	54–639	0.61
DWI Training hospital (n=10)	283	30	223–342	134–499	
DWI Private university (n=14)	246	26	195–297	62–366	
*DCE State university (n=35)	248	18	212–284	65–551	0.94
*DCE Training hospital (n=10)	254	21	213–296	145–344	
*DCE Private university (n=14)	240	33	176–304	63–439	

SE, standard error; CI, confidence interval; DWI, diffusion weighted imaging; DCE, dynamic contrast enhancement.
*DCE results of 59 clinics.

Table 5. The comparative analysis of T2-weighted imaging acquisition time with the parameters

	T2 acquisition time		
T2 parameters	Mean (s)	Standard error	*P*
Slice thickness ≤3 mm (n=19)	238	15	0.54
Slice thickness >3 mm (n=42)	222	15	
Gap = 0 mm (n=20)	254	16	0.22
Gap >0 mm (n=41)	223	16	
FOV ≤200 mm (n=46)	247	14	0.034
FOV >200 mm (n=15)	189	17	
Frequency voxel size ≤0.4 mm (n=6)	267	32	0.31
Frequency voxel size >0.4 mm (n=55)	229	13	
Phase voxel size ≤0.7 mm (n=25)	264	17	0.028
Phase voxel size >0.7 mm (n=36)	212	15	

FOV, field of view.

for 7 s criterion in our survey. The adherence to 7 s criterion was found as 9.6% in the study of Esses et al. (7). Previous clinical studies suggested that a temporal resolution faster than 10 s does not provide any additional benefit in the diagnosis of the prostate cancer (13, 14).

Temporal resolution is directly related to the number of matrix (phase) and TR (15). The adherence to TE and TR were relatively high (94.9%) in our study. Mean durations of the centers were 3.18 and 30 ms for TE and TR, respectively. The average durations of TE and TR were 1.62 and 4.44 ms for the centers with temporal resolution ≤10 s. The adherence to temporal resolution ≤10 s was higher when TE and TR was below 1.87 and 7.06 ms, respectively. Esses et al. (7) found mean TE and TR as 1.7 and 4.4 ms, respectively. The respective TE, TR, and temporal resolution values of previous studies on MRI of the prostate were as follows: 2.3 ms, 3.7 ms, 5.6 s; 1.89 ms, 4.1 ms, 2.3 s; and 1.96 ms, 5.5 ms, 3 s (16–18). The PI-RADS v2 recommendations of TE <5 ms and TR <100 ms seem to be too long. In subsequent versions, shortening the TE and TR may be considered to improve the adherence to temporal resolution in DCE MRI.

The most important limitation of our study was that the data was based on the questionnaires and not on the actual DICOM data. It was assumed that all centers responded to our survey correctly. Another limitation was the inclusion of only tertiary referral centers, excluding private practice where mpMRI of the prostate is also being performed. Although the direct impact of adherence to PI-RADS technical standards on image quality is still unknown, our results can potentially assist others on which technical specifications among minimum acceptable technical parameters in PI-RADS guidelines should be further investigated to obtain good quality prostate MRI. Although the results may not be generalized to the entire clinical practice in Turkey, this is a relatively powerful survey with a high response rate of 92.5%. Larger scale studies evaluating the adherence to PI-RADS specifications in the entire world is needed, considering increasing popularity of the prostate MRI.

In conclusion, the adherence to voxel dimensions in T2-weighted imaging, *b* value ≥1400 s/mm^2 in DWI and temporal resolution <7 s in DCE were low in Turkey. The adherence to slice thickness, FOV, and in-plane dimension (phase) in T2-weighted imaging was higher when 3 T (vs. 1.5 T) scanners were used. Inclusion of recommendations regarding acquisition times and contrast resolution in the future versions of PI-RADS can potentially enhance the compliance with the technical specifications. Awareness to the minimum acceptable technical parameters of mpMRI can potentially improve the quality of pros-

Table 6. The comparative analysis of DWI acquisition time with the parameters

DWI parameters	DWI acquisition time		
	Mean (s)	Standard error	*P*
TR ≥3000 ms (n=54)	274	17	0.95
TR <3000 ms (n=7)	276	25	
TE ≤90 ms (n=47)	284	16	0.21
TE >90 ms (n=14)	239	21	
Slice thickness ≤3 mm (n=52)	282	16	0.20
Slice thickness >3 mm (n=9)	227	46	
Gap = 0 mm (n=31)	301	21	0.075
Gap >0 mm (n=30)	247	21	
160 mm ≤ FOV ≤220 mm (n=23)	321	28	0.014
FOV <160 mm or FOV >220 mm (n=38)	245	16	
Frequency voxel size ≤0.4 mm (n=48)	280	17	0.43
Frequency voxel size >0.4 mm (n=13)	251	33	
Phase voxel size ≤0.7 mm (n=38)	289	20	0.21
Phase voxel size >0.7 mm (n=23)	250	22	
Maximum *b* value ≥1400 s/mm² (n=35)	308	17	0.008
Maximum *b* value <1400 s/mm² (n=26)	228	25	

DWI, diffusion-weighted imaging; TR, repetition time; TE, echo time; FOV, field of view.

tate cancer imaging and future research is needed to explore impact of adherence to PI-RADS technical specifications on the resultant prostate MRI quality.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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