

Revised PROPELLER for T2-weighted imaging of the prostate at 3 Tesla: impact on lesion detection and PI-RADS classification

Michael Meier-Schroers¹ · Christian Marx¹ · Frederic Carsten Schmeel¹ ·
Karsten Wolter¹ · Jürgen Gieseke² · Wolfgang Block¹ · Alois Martin Sprinkart¹ ·
Frank Traeber¹ · Winfried Willinek³ · Hans Heinz Schild¹ · Guido Matthias Kukuk¹

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Abstract

Purpose To evaluate revised PROPELLER (RevPROP) for T2-weighted imaging (T2WI) of the prostate as a substitute for turbo spin echo (TSE).

Materials and methods Three-Tesla MR images of 50 patients with 55 cancer-suspicious lesions were prospectively evaluated. Findings were correlated with histopathology after MRI-guided biopsy. T2 RevPROP, T2 TSE, diffusion-weighted imaging, dynamic contrast enhancement, and MR-spectroscopy were acquired. RevPROP was compared to TSE concerning PI-RADS scores, lesion size, lesion signal-intensity, lesion contrast, artefacts, and image quality.

Results There were 41 carcinomas in 55 cancer-suspicious lesions. RevPROP detected 41 of 41 carcinomas (100%) and 54 of 55 lesions (98.2%). TSE detected 39 of 41 carcinomas (95.1%) and 51 of 55 lesions (92.7%). RevPROP showed fewer artefacts and higher image quality (each $p < 0.001$). No differences were observed between single and overall PI-RADS scores based on RevPROP or TSE ($p = 0.106$ and $p = 0.107$). Lesion size was not different ($p = 0.105$). T2-signal intensity of lesions was higher and T2-contrast of lesions was lower on RevPROP (each $p < 0.001$).

Conclusion For prostate cancer detection RevPROP is superior to TSE with respect to motion robustness, image quality

✉ Michael Meier-Schroers
michael.meier@ukbonn.de

Christian Marx
christian.marx@ukbonn.de

Frederic Carsten Schmeel
carsten.schmeel@ukbonn.de

Karsten Wolter
karsten.wolter@ukbonn.de

Jürgen Gieseke
juergen.gieseke@philips.com

Wolfgang Block
wolfgang.block@ukbonn.de

Alois Martin Sprinkart
sprinkart@uni-bonn.de

Frank Traeber
frank.traeber@ukbonn.de

Winfried Willinek
w.willinek@bk-trier.de

Hans Heinz Schild
hans.schild@ukbonn.de

Guido Matthias Kukuk
guido.kukuk@ukbonn.de

¹ Department of Radiology, University Hospital Bonn, Sigmund-Freud-Str 25, 53127 Bonn, Germany

² Philips Healthcare Germany, Lübeckertordamm 5, 20099 Hamburg, Germany

³ Department of Radiology, Neuroradiology, Sonography and Nuclear Medicine, Hospital of Barmherzige Brüder, Nordallee 1, 54292 Trier, Germany

and detection rates of lesions. Therefore, RevPROP might be used as a substitute for T2WI.

Key points

- Revised PROPELLER can be used as a substitute for T2-weighted prostate imaging.
- Revised PROPELLER detected more carcinomas and more suspicious lesions than TSE.
- Revised PROPELLER showed fewer artefacts and better image quality compared to TSE.
- There were no significant differences in PI-RADS scores between revised PROPELLER and TSE.
- The lower T2-contrast of revised PROPELLER did not impair its diagnostic quality.

Keywords MRI · Prostate · T2-weighted imaging · PROPELLER · Motion correction

Abbreviations

| | |
|-----------|--|
| DCE | dynamic contrast enhancement |
| DWI | diffusion-weighted imaging |
| MRGB | MRI-guided biopsy |
| MRS | MR-spectroscopy |
| mpMRI | multiparametric MRI |
| MVXD | MultiVane XD (Philips Healthcare, Best, The Netherlands) |
| PI-RADS | Prostate Imaging-Reporting and Data System |
| PROPELLER | Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction |
| SENSE | Sensitivity Encoding (Philips Healthcare, Best, The Netherlands) |
| TSE | turbo spin echo |
| THRIVE | T1 High-Resolution Isotropic Volume Excitation (Philips Healthcare, Best, The Netherlands) |

Introduction

The Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction (PROPELLER) technique was first presented by Pipe et al. in 1999 as a new method to reduce motion artefacts in magnetic resonance imaging (MRI) of the brain and the heart using radial k-space sampling [1]. In the past 15 years, several studies have confirmed this improvement for different body regions, e.g. the brain, neck, thorax, abdomen, and pelvis [2–9]. In 2014, Pipe et al. advanced the PROPELLER technique to further reduce noise and artefacts allowing for very robust motion corrected images [10]; this revised PROPELLER technique is called MultiVane XD (MVXD, Philips Healthcare, Best, The Netherlands).

Prostate MRI is based on multiparametric imaging, combining T2-weighted imaging (T2WI) for morphological aspects together with diffusion-weighted imaging (DWI), dynamic contrast enhancement (DCE), and MR spectroscopy (MRS) for functional aspects [11, 12]. The structured Prostate Imaging-Reporting and Data System (PI-RADS) developed by the European Society of Urogenital Radiology (ESUR) and the American College of Radiology (ACR) has made multiparametric MRI a powerful tool for prostate cancer detection [11–15]. The most important sequence for the assessment of transitional zone lesions is high-resolution T2WI. In addition, T2-weighted sequences are the basis for zonal anatomy assessment as well as for planning and performing MRI-guided biopsy (MRGB) [12, 13].

Although less frequently encountered than in the upper abdomen, motion artefacts caused by bowel or abdominal wall movement can be detrimental also for prostate imaging [16, 17]. Especially high-resolution T2WI necessitating long acquisition times is prone to motion artefacts and generally harbours the risk of masking relevant lesions and repeating parts of the MR examination.

The aim of our study is to evaluate T2-weighted MVXD imaging in comparison to a standard T2-weighted turbo spin echo (TSE) sequence with respect to lesion detection, PI-RADS classification, and image quality.

Methods

The study was approved by the local ethics committee, and written informed consent was obtained from all patients.

Two board-certified radiologists (*Michael Meier-Schroers and Guido Matthias Kukuk*) prospectively evaluated multiparametric MRI (mpMRI) of 176 consecutive patients for cancer-suspicious lesions in consensus reading, but only those who went on to have biopsy ($n = 50$; mean age 68.0 ± 7.3 years) were included in this study.

MRI was performed at 3 T (Ingenia, Philips Healthcare, Best, The Netherlands) with a standardised protocol using a phased array body coil. Acquired sequences were transverse T2-weighted MVXD, transverse T2-weighted TSE, transverse diffusion-weighted images with three b-values (0, 50, and 800 s/mm²), transverse dynamic enhanced 3D T1-weighted images (THRIVE, Philips Healthcare, Best, The Netherlands), and MR spectroscopy. For the scan protocol and technical data, see Table 1. Our patients did not receive spasmolytic agents such as butylscopolamine.

Each lesion was assigned a single PI-RADS score for each parameter (T2 MVXD, T2 TSE, DWI, DCE, MRS) as well as an overall PI-RADS score. Scoring ranged from 1 (clinically significant cancer is highly unlikely to be present) to 5 (clinically significant cancer is highly likely to be present) [13]. MRS is not part of the PI-RADS scoring system anymore, but

Table 1 Imaging parameters of the scan protocol

| | tra T2 MVXD | tra T2 TSE | tra DWI | tra THRIVE |
|-------------------------------|-----------------|-----------------|-----------------|------------|
| TR (ms)/TE (ms)/FA (°) | 3500-4000/80/90 | 4000-4800/80/90 | 5200-5300/53/90 | 3.1/1.5/10 |
| Field of view (mm) | 420 | 420 | 320 | 400 |
| Acquired matrix (mm) | 676 × 676 | 676 × 676 | 160 × 160 | 268 × 268 |
| Slice thickness (mm) | 3 | 3 | 4 | 4 |
| Voxel size (mm ³) | 1.15 | 1.15 | 8 | 6 |
| Parallel imaging | SENSE | SENSE | SENSE | SENSE |
| Partial Fourier | Yes | Yes | Yes | Yes |
| Acquisition time (min) | 5:29 | 7:53 | 3:35 | 4:29 |

Tra = transversal, MVXD = MultiVane XD, TSE = turbo spin echo, DWI = diffusion weighted imaging, THRIVE = T1 High-Resolution Isotropic Volume Excitation, TR = time of repetition, TE = echo time, FA = flip angle, SENSE = sensitivity-encoded

it is still part of our scan protocol for two reasons. First, the PI-RADS Steering Committee strongly supports the continued development of additional and promising MRI methods, such as MRS [13]. Second, even though the single score for MRS did not directly contribute to the overall score, MRS still yielded information for the detection of prostate cancer. According to the PI-RADS guidelines, the overall score is aggregated from all single parameter scores (T2WI, DWI, and DCE), yet there are primary determining sequences depending on the localisation of the lesion (DWI for the peripheral zone, T2WI for the transitional zone) [13].

Directly after the MRI examination, in the first reading session, either T2 MVXD or T2 TSE images alone were presented to the readers. Each lesion was assigned a PI-RADS T2 single score without having viewed DWI, DCE, and MRS. After the scores of both T2 TSE and MVXD had been noted, the other sequences (DWI, DCE, and MRS) were presented together with both T2-weighted sequences to assign an overall PI-RADS score.

Overall PI-RADS scores were separately calculated based on T2 MVXD and T2 TSE. An overall PI-RADS score of 4 or 5 was defined as suspicious for prostate cancer and resulted in a strong recommendation to perform MRGB. In cases of different overall PI-RADS scores made with either T2 MVXD or T2 TSE, the highest score was always decisive for the recommendation to perform biopsy in order not to miss a carcinoma.

An experienced pathologist performed the histopathological analysis. The results were discussed with the pathologist and then served as the reference standard.

In the second reading session, the T2 MVXD and T2 TSE images were again presented to the readers to measure region of interest (ROI)-based signal intensities. In this session, the average T2-signal intensity from ROIs was measured inside the lesion and in the adjacent periprostatic fat for both T2 MVXD and T2 TSE (defined as T2-signal intensity). First, the circular ROI was placed inside the lesion in such way that it filled the lesion with a maximum possible size (avoiding the inclusion of non-lesion tissue). Second, it was placed in the

periprostatic fat with a predefined ROI size of 50 mm². The fat-to-lesion contrast ratio was calculated for both T2-weighted sequences (defined as T2 contrast).

Also in this second session, phase-encoded artefacts attributable to breathing and patient movement (“motion artefacts”) and artefacts resulting from bowel peristalsis and contraction of the urinary bladder (“contraction artefacts”) as well as overall image quality were rated in consensus using a four-point score (1 = severe artefacts/non-diagnostic quality, 2 = moderate artefacts/poor quality, 3 = mild artefacts/fair quality, and 4 = (almost) no artefacts/good quality).

Images were evaluated on a professional medical monitor using IMPAX EE (AGFA Healthcare, Bonn, Germany). Statistical analyses were performed using SPSS 22 (IBM, Armonk, NY, USA). Differences between MVXD and TSE concerning the PI-RADS scores, lesion size, T2-signal intensity, T2-contrast, and rating of artefacts and image quality were analysed using the Wilcoxon signed-rank test.

Results

There were 41 proven prostate carcinomas in 55 cancer-suspicious lesions in our study group. In addition, we detected 14 cancer-suspicious lesions that were chronic prostatitis ($n = 5$), hyperplasia ($n = 2$), fibromuscular tissue ($n = 3$), and non-specified benign tissue ($n = 4$).

41 of 41 cancers (100%) were detected by T2 MVXD and 39 of 41 cancers (95.1%) by T2 TSE. Regarding cancer-suspicious lesions, 54 of 55 lesions (98.2%) were detected by T2 MVXD and 51 of 55 (92.7%) by T2 TSE.

T2 MVXD accurately detected 30 of 31 lesions (26 of 26 carcinomas) in the peripheral zone (PZ) and 24 of 24 lesions (15 of 15 carcinomas) in the transitional zone (TZ). T2 TSE accurately detected 30 of 31 lesions (26 of 26 carcinomas) in the peripheral zone (PZ) and 22 of 25 lesions (13 of 15 carcinomas) in the transitional zone (TZ).

The one lesion that could not be detected with the MVXD sequence was also not visible on TSE images. In this particular case, biopsy was performed because of an overall PI-RADS score of 4 assigned on the basis of DWI. Subsequent MRGB revealed non-specified benign tissue for this lesion.

Besides the aforementioned lesion, three lesions clearly detectable by MVXD could not be detected by TSE. These three lesions were located in the transitional zone; two of them were carcinomas (Gleason 6 and 7a) and one was chronic prostatitis according to MRGB. Figure 1 displays the one Gleason 6 carcinoma, which was not detectable on T2 TSE images because of distinct artefacts, but clearly visible on T2 MVXD.

The PI-RADS single score for T2-weighted imaging was congruent for T2 MVXD and T2 TSE in 42 of 55 lesions (76.4%); i.e. in 13 lesions, there was a discrepant T2 single score between the MVXD and the TSE sequence. This did not change the resulting overall PI-RADS score in five cases, since those lesions were located in the peripheral zone for which DWI is the dominant sequence in the PI-RADS scoring system. So, the overall PI-RADS score was different in 8 of 55 lesions depending on whether the T2 single score was based on MVXD or TSE.

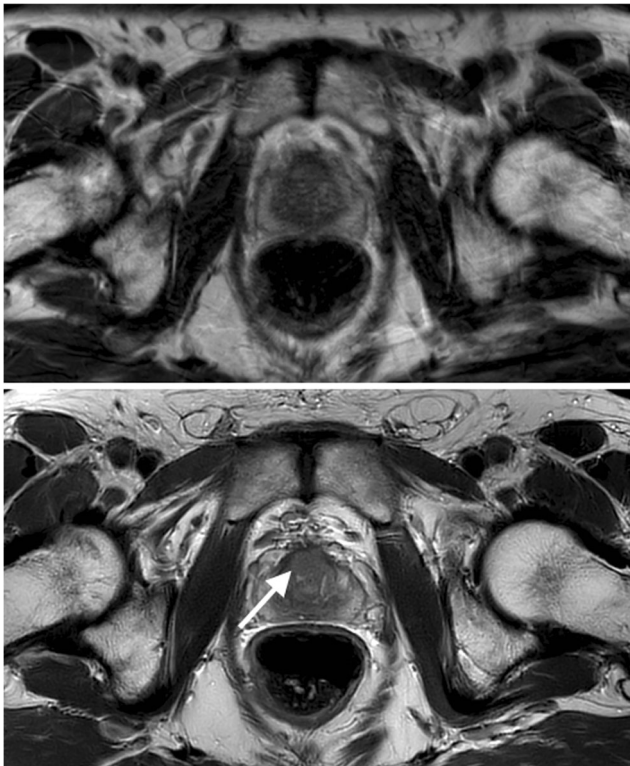


Fig. 1 Focal hypointense lesion in the anterior transitional zone on T2 TSE (*top*) and T2 MVXD (*bottom*). This lesion was hardly detectable by TSE, but clearly visible on MVXD (*arrow*). Histopathologic analysis after subsequent MRI-guided prostate biopsy revealed an adenocarcinoma of the prostate (Gleason score 3 + 3 = 6)

In two of these eight lesions, results of MVXD led to an upgrading of the overall PI-RADS score from 2 to 4, i.e. from a low likelihood of clinically significant cancer to a high likelihood. Subsequent MRGB confirmed Gleason 7a prostate cancer in one patient and prostatitis in the other one. In four of the eight lesions, results of MVXD led to an upgrading from 4 to 5 with two Gleason 6 and two Gleason 7a cancers in subsequent biopsy. In the two remaining lesions, applying MVXD led to a downgrading from 3 to 2 and from 4 to 3, respectively. In these last two cases, subsequent MRGB revealed benign findings (fibromuscular tissue and prostatitis). Table 2 summarises the information of these eight cases.

For lesion size as determined by T2WI, no statistically significant difference was found between MVXD and TSE ($p = 0.105$).

T2-signal intensity of lesions was significantly higher and T2-contrast was significantly lower for MVXD in comparison to TSE (each $p < 0.001$).

The MVXD sequence showed significantly fewer artefacts and better image quality compared to TSE (each $p < 0.001$) with no cases of severe artefacts or non-diagnostic image quality for all 50 patients (Table 3). On TSE images, we observed severe artefacts in 6 of 50 patients (12%) and non-diagnostic image quality in 2 of 50 patients (4%). Figure 2 shows typical artefacts of the TSE sequence.

Discussion

Motion artefacts due to patient movement, breathing, peristalsis, and contraction of hollow organs are a general problem of abdominal and pelvic MRI.

In standard MRI sequences such as TSE, the k-space is read out sequentially along parallel lines (rectilinear or Cartesian sampling). In contrast, PROPELLER techniques such as MVXD use radial k-space sampling with parallel data lines rotating around the centre of k-space at each time of repetition [1, 10]. In this approach, the centre of k-space is oversampled, since data lines partially overlap. This oversampling can be used for correction of phase, rotation, translation, and weighting to reduce spatial inconsistencies [1–4, 10]. Furthermore, the signal-to-noise ratio can be increased because of the redundancy in data sampling [1–4, 10]. Advanced methods of radial k-space sampling have been shown to reduce motion artefacts in different body regions [1–9].

In this study, we evaluated the application of an MVXD T2-weighted sequence in technically demanding high-resolution imaging of the prostate. Although contrast was slightly better using conventional TSE imaging, we found general advantages of the MVXD technique because of a significant reduction of artefacts. This effect was mainly attributable to the inherent correction of phase-encoded aberrations.

Table 2 Information of eight lesions with different PI-RADS overall scores depending on whether T2 TSE or T2 MVXD was applied

| Single score of T2 TSE | Single score of T2 MVXD | Single score of DWI | Single score of DCE (+/-) | Single score of MRS | Overall score with T2 TSE | Overall score with T2 MVXD | Upgrading or downgrading using MVXD | Histopathology | |
|------------------------|-------------------------|---------------------|---------------------------|---------------------|---------------------------|----------------------------|-------------------------------------|----------------|----------------------|
| 1 | 2 | 3 | 5 | - | 4 | 2 | 4 | Upgrading | PCa (Gleason 7a) |
| 2 | 2 | 3 | 5 | - | 2 | 2 | 4 | Upgrading | Prostatitis |
| 3 | 4 | 5 | 5 | + | 5 | 4 | 5 | Upgrading | PCa (Gleason 7a) |
| 4 | 4 | 5 | 5 | + | 3 | 4 | 5 | Upgrading | PCa (Gleason 6) |
| 5 | 3 | 5 | 5 | + | 3 | 4 | 5 | Upgrading | PCa (Gleason 6) |
| 6 | 4 | 5 | 5 | + | 4 | 4 | 5 | Upgrading | PCa (Gleason 7a) |
| 7 | 3 | 2 | 4 | + | 2 | 3 | 2 | Downgrading | Fibromuscular tissue |
| 8 | 4 | 3 | 4 | - | 3 | 4 | 3 | Downgrading | Prostatitis |

The MVXD sequence could detect three more cancer-suspicious lesions and two more proven cancers than the TSE sequence and achieved significantly higher ratings in terms of artefacts and image quality. Yet, because T2 MVXD and T2 TSE both have a distinctive appearance, there might be a potential bias regarding the qualitative rating of artefacts and image quality in our study, since both sequences are read in consensus. A study design with different viewers for each T2-weighted sequence would have been more blinded.

A further advantage of the T2 MVXD sequence is that high-resolution imaging of the prostate could be performed in a significantly shorter acquisition time of 5:29 min as compared to 7:53 min for T2 TSE.

Even though the T2-contrast of the MVXD sequence was lower in comparison to TSE images in our study, this did not have an impact on the detection of prostate cancer.

The drawback of a lower T2-contrast has also been described in studies on T2-weighted imaging (T2WI) of the pelvis, both using a PROPELLER equivalent [8, 9]. According to an experimental preclinical study, the lower T2-contrast of MR sequences using radial sampling might be explained by a non-uniform weighting of k-space data in the phase-encode direction [18]. In contrast, a study on T2-weighted neck imaging did not show any contrast differences between T2 PROPELLER and T2 FSE [5]. Thus, further investigation of this problem is desirable.

In contrast to a recent study by Rosenkrantz et al. [9], we applied our findings to PI-RADS (second version). In our study, taking all PI-RADS scoring data together, applying MVXD instead of TSE would have meant performing MRGB in one patient who was ultimately not diagnosed with prostate cancer. On the other hand, applying TSE instead of MVXD would have meant missing one clinically significant prostate cancer.

Rosenkrantz et al. [9] did not recommend routinely replacing standard T2 TSE with a PROPELLER sequence because of the smaller number of correctly localised tumours; instead, they recommended using PROPELLER particularly in patients with known prostate cancer to specifically assess extra-prostatic extension or in patients with prominent motion artefacts. However, in our study, we found that the advantages of the further improved MVXD technique outweigh the disadvantages. Based on our study results, MVXD (or other revised PROPELLER techniques) should be preferentially used instead of TSE for T2WI mainly because of its robustness to artefacts. Nevertheless, the results of this study should be confirmed by subsequent investigators to give a general recommendation for either a revised PROPELLER sequence or a TSE sequence for high-resolution T2WI of the prostate.

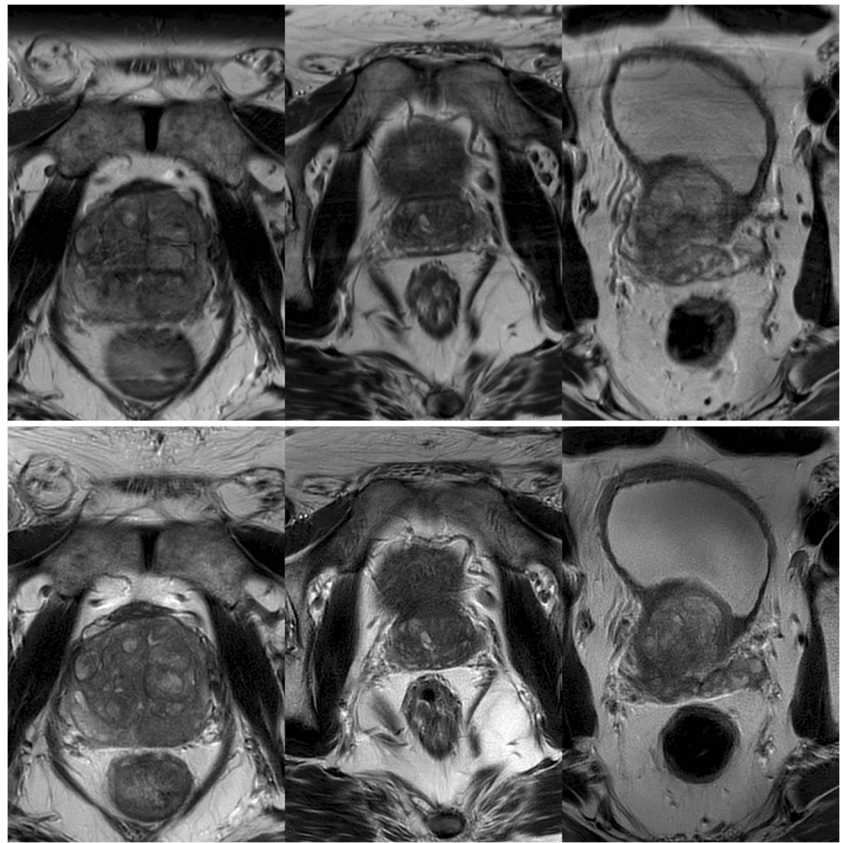
Intravenous application of spasmolytic agents such as butylscopolamine can help to reduce motion artefacts from the bowel and the urinary bladder in MRI of the pelvis [16].

Table 3 Rating of artefacts and overall image quality of T2 MVXD and T2 TSE (number of each rating, mean and median)

| Score | T2 MVXD | | | | | | T2 TSE | | | | | |
|---------------|---------|---|---|----|-----------|-------------|--------|----|----|----|-----------|-------------|
| | 1 | 2 | 3 | 4 | \bar{x} | \tilde{x} | 1 | 2 | 3 | 4 | \bar{x} | \tilde{x} |
| Motion | 0 | 4 | 9 | 37 | 3.7 | 4.0 | 5 | 18 | 19 | 8 | 2.6 | 3.0 |
| Contraction | 0 | 1 | 4 | 45 | 3.9 | 4.0 | 1 | 9 | 23 | 17 | 3.1 | 3.0 |
| Image quality | 0 | 2 | 7 | 41 | 3.8 | 4.0 | 2 | 13 | 22 | 13 | 2.9 | 3.0 |

MVXD = MultiVane XD, TSE = turbo spin echo; four-point rating for severity of artefacts (1 = severe, 2 = moderate, 3 = mild, 4 = almost none) and for overall image quality (1 = non-diagnostic, 2 = poor, 3 = fair, 4 = good); \bar{x} = average scores, \tilde{x} = median scores. Note: a higher score means fewer artefacts and better image quality

Fig. 2 Typical artefacts of the T2 TSE sequence (*top*) with significant artefact reduction on MVXD images (*bottom*). *Left*: Artefacts from rectal peristalsis. *Middle*: Artefacts from motion of the abdominal wall. *Right*: Artefacts from rectal peristalsis, urinary bladder contraction, and motion of the abdominal wall. *Slight shading* inside the urinary bladder is due to B1-inhomogeneity and equally present in both sequences



Yet, in two studies on prostate MRI, the application of butylscopolamine did not have a positive effect on image quality [17, 19].

Our study showed that peristalsis artefacts, especially from the sigmoid and the rectum, can distinctly degrade image quality of the T2 TSE sequence. In contrast, T2 MVXD images were not significantly affected by these artefacts. Thus, when T2-weighted sequences with radial k-space sampling such as MVXD are not available, we recommend the application of butylscopolamine to reduce artefacts.

Our study has some limitations. First is the small number of patients included in this study. Second, we did not assess an intra-organ reference for lesion contrast analysis, since signal intensity of regions of interest (ROIs) was not measured inside the prostate but in the periprostatic fat. However, this method was chosen because placing an ROI inside the peripheral zone of hyperplastic prostates is hard to perform, because hyperplasia is usually associated with a heterogeneous transitional zone or a thinned peripheral zone. Another limitation is that we did not evaluate inter-rater reliability.

In conclusion, the MVXD technique is suitable for T2WI of the prostate. Based on the results of this study, MVXD could be used as a substitute for TSE, since MVXD showed fewer motion artefacts and higher image quality in combination with a slightly better detectability of cancer-suspicious

lesions. Disadvantages in the contrast of MVXD did not impair lesion assessment.

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Guido Matthias Kukuk.

Conflict of interest One co-author of this manuscript, Jürgen Gieseke, is an employee of Philips Healthcare Germany. However, he did not have any influence on the study design, evaluation, and interpretation of results. He mainly worked on optimising the MR sequences.

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Statistics and biometry No complex statistical methods were necessary for this article.

Informed consent Written informed consent was obtained from all patients in this study.

Ethical approval Institutional Review Board approval was obtained.

Methodology

- prospective
- diagnostic study
- performed at one institution

References

- Pipe JG (1999) Motion correction with PROPELLER MRI: application to head motion and free-breathing cardiac imaging. *Magn Reson Med* 42(5):963–9
- Wintersperger BJ, Runge VM, Biswas J et al (2006) Brain magnetic resonance imaging at 3 Tesla using BLADE compared with standard rectilinear data sampling. *Invest Radiol* 41:586–592
- Forbes KP, Pipe JG, Karis JP, Farthing V, Heiserman JE (2003) Brain imaging in the unsedated pediatric patient: comparison of periodically rotated overlapping parallel lines with enhanced reconstruction and singleshot fast spin-echo sequences. *AJNR Am J Neuroradiol* 24:794–798
- Nyberg E, Sandhu GS, Jesberger J, Blackham KA, Hsu DP, Griswold MA, Sunshine JL (2012) Comparison of brain MR images at 1.5T using BLADE and rectilinear techniques for patients who move during data acquisition. *AJNR Am J Neuroradiol* 33(1):77–82
- Ohgiya Y, Suyama J, Seino N, Takaya S, Kawahara M, Saiki M, Sai S, Hirose M, Gokan T (2010) MRI of the neck at 3 Tesla using the periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) (BLADE) sequence compared with T2-weighted fast spin-echo sequence. *J Magn Reson Imaging* 32(5):1061–7
- Meier-Schroers M, Kukuk G, Homsy R, Skowasch D, Schild HH, Thomas D (2016) MRI of the lung using the PROPELLER technique: Artifact reduction, better image quality and improved nodule detection. *Eur J Radiol* 85(4):707–13
- Hirokawa Y, Isoda H, Maetani YS, Arizono S, Shimada K, Togashi K (2008) Evaluation of motion correction effect and image quality with the periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) (BLADE) and parallel imaging acquisition technique in the upper abdomen. *J Magn Reson Imaging* 28(4):957–62
- Froehlich JM, Metens T, Chilla B, Hauser N, Klarhoefer M, Kubik-Huch RA (2012) Should less motion sensitive T2-weighted BLADE TSE replace Cartesian TSE for female pelvic MRI? *Insights Imaging* 3(6):611–8
- Rosenkrantz AB, Bennett GL, Doshi A, Deng FM, Babb JS, Taneja SS (2015) T2-weighted imaging of the prostate: Impact of the BLADE technique on image quality and tumor assessment. *Abdom Imaging* 40(3):552–9
- Pipe JG, Gibbs WN, Li Z, Karis JP, Schar M, Zwart NR (2014) Revised motion estimation algorithm for PROPELLER MRI. *Magn Reson Med* 72(2):430–7
- Barentsz JO, Richenberg J, Clements R, Choyke P, Verma S, Villeirs G, Rouviere O, Logager V, Fütterer JJ, European Society of Urogenital Radiology (2012) ESUR prostate MR guidelines 2012. *Eur Radiol* 22(4):746–57
- Hoeks CM, Barentsz JO, Hambroek T, Yakar D, Somford DM, Heijmink SW, Scheenen TW, Vos PC, Huisman H, van Oort IM, Witjes JA, Heerschap A, Fütterer JJ (2011) Prostate cancer: multiparametric MR imaging for detection, localization, and staging. *Radiology* 261(1):46–66
- Weinreb JC, Barentsz JO, Choyke PL, Cornud F, Haider MA, Macura KJ, Margolis D, Schnall MD, Shtern F, Tempny CM, Thoeny HC, Verma S (2016) PI-RADS Prostate Imaging-Reporting and Data System: 2015, Version 2. *Eur Urol* 69(1):16–40
- Barentsz JO, Weinreb JC, Verma S, Thoeny HC, Tempny CM, Shtern F, Padhani AR, Margolis D, Macura KJ, Haider MA, Cornud F, Choyke PL (2016) Synopsis of the PI-RADS v2 guidelines for multiparametric prostate magnetic resonance imaging and recommendations for use. *Eur Urol* 69(1):41–9
- Schimmöller L, Quentin M, Arsov C, Hiester A, Buchbender C, Rabenalt R, Albers P, Antoch G, Blondin D (2014) MR-sequences for prostate cancer diagnostics: validation based on the PI-RADS scoring system and targeted MR-guided in-bore biopsy. *Eur Radiol* 24(10):2582–9
- Zand KR, Reinhold C, Haider MA, Nakai A, Rohoman L, Maheshwari S (2007) Artifacts and pitfalls in MR imaging of the pelvis. *J Magn Reson Imaging* 26(3):480–97
- Wagner M, Rief M, Busch J, Scheurig C, Taupitz M, Hamm B, Franiel T (2010) Effect of butylscopolamine on image quality in MRI of the prostate. *Clin Radiol* 65(6):460–4
- Pandit P, Qi Y, King KF, Johnson GA (2011) Reduction of artifacts in T2-weighted PROPELLER in high-field preclinical imaging. *Magn Reson Med* 65(2):538–43
- Roethke MC, Kuru TH, Radbruch A, Hadaschik B, Schlemmer HP (2013) Prostate magnetic resonance imaging at 3 Tesla: Is administration of hyoscine-N-butyl-bromide mandatory? *World J Radiol* 5(7):259–263