Published in final edited form as:

Abdom Radiol (NY). 2017 January ; 42(1): 290–297. doi:10.1007/s00261-016-0881-x.

Detection of prostate cancer local recurrence following radical prostatectomy: assessment using a continuously acquired radial golden-angle compressed sensing acquisition

Andrew B. Rosenkrantz¹, Anunita Khasgiwala¹, Ankur M. Doshi¹, Justin M. Ream¹, Samir S. Taneja², and Herbert Lepor²

¹Department of Radiology, NYU School of Medicine, NYU Langone Medical Center, 660 First Avenue, Third Floor, New York 10016, NY, USA

²Department of Urologic Oncology, NYU School of Medicine, NYU Langone Medical Center, 660 First Avenue, Third Floor, New York 10016, NY, USA

Abstract

Purpose—To compare image quality and diagnostic performance for detecting local recurrence (LR) of prostate cancer after radical prostatectomy (RP) between standard dynamic contrast-enhanced (DCE) magnetic resonance imaging (MRI) and a high spatiotemporal resolution, continuously acquired Golden-angle RAdial Sparse Parallel acquisition employing compressed sensing reconstruction (“GRASP”).

Methods—A search was conducted for prostate MRI examinations performed in patients with PSA ≥ 0.2 ng/mL after RP in whom follow-up evaluation allowed classification as positive ($\geq 50\%$ PSA reduction after pelvic radiation or positive biopsy) or negative ($<50\%$ PSA reduction after pelvic radiation; spontaneous PSA normalization) for LR, yielding 13 patients with standard DCE (11 LR+) and 12 with GRASP (10 LR+). Standard DCE had voxel size $3.0 \times 1.9 \times 1.9$ mm and temporal resolution 5.5 s. GRASP had voxel size $1.0 \times 1.1 \times 1.1$ cm and was retrospectively reconstructed at 2.3 s resolution. Two radiologists evaluated DCE sequences for image quality measures (1–5 scale) and the presence of LR.

Results—GRASP achieved higher scores than standard DCE from both readers ($p < 0.001$ –0.136) for anatomic clarity (R1: 4.4 ± 0.8 vs. 2.8 ± 0.67 R2: 4.8 ± 0.5 vs. 3.2 ± 0.6), sharpness (3.6 ± 0.9 vs. 2.5 ± 0.7 ; 4.6 ± 0.5 vs. 2.6 ± 0.5), confidence in interpretation (3.8 ± 0.8 vs. 3.1 ± 0.9 ; 3.8 ± 1.0 vs. 3.1 ± 1.2), and conspicuity of detected lesions (4.7 ± 0.5 vs. 3.8 ± 1.1 ; 4.5 ± 0.5 vs. 3.8 ± 1.0). For detecting LR, GRASP also achieved higher sensitivity (70% vs. 36%; 80% vs. 45%),

Correspondence to: Andrew B. Rosenkrantz; Andrew.Rosenkrantz@nyumc.org.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent The requirement for written informed consent was waived by the IRB.

Conflicts of interest None.

Disclosures Remaining others: No relevant disclosures.

specificity (R1 and R2: 100% vs. 50%), and accuracy (75% vs. 38%; 83% vs. 46%) for both readers.

Conclusion—Although requiring larger studies, high spatiotemporal resolution GRASP achieved substantially better image quality and diagnostic performance than standard DCE for detecting LR in patients with elevated PSA after prostatectomy.

Keywords

Prostate cancer; Radical prostatectomy; Biochemical recurrence; MRI; Dynamic contrast-enhanced imaging

Radical prostatectomy (RP) is the mainstay curative treatment for prostate cancer in the United States, having excellent cancer-specific survival up to 30 years following surgery [1]. Shortly after surgery, serum prostate-specific antigen (PSA) levels drop to an undetectable level (<0.04 ng/mL) in over 95% of cases [2]. However, based on data obtained in men undergoing post-operative monitoring after RP performed during the era of PSA screening, up to approximately 20% of such men will develop biochemical recurrence (BCR) within a 10-year interval [1], typically defined as occurring at a PSA threshold of 0.2 ng/mL [1, 3–5]. Men with BCR are at increased risk of subsequent metastases and death [4, 5]. BCR may occur due to recurrent disease involving the local operative bed, distant anatomic sites, or both. Local salvage radiation therapy (SRT) is likely to be curative only in those patients in whom disease recurrence is limited to the operative bed [6, 7]; patients with distant sites of disease are unlikely to be cured and warrant concomitant hormonal therapy. Properly selecting candidates for isolated SRT is useful for optimizing clinical outcomes. However, the differentiation of local and distant recurrences at the time of biochemical recurrence is challenging.

Numerous investigations have applied magnetic resonance imaging (MRI) for detecting local recurrences in men with BCR after RP [6–16]. MRI provides high spatial resolution and excellent soft tissue contrast that facilitate the visualization of small soft tissue nodules in the operative bed. Several studies have shown that dynamic contrast-enhanced (DCE) imaging substantially improves diagnostic performance compared with other MR sequences [7, 8, 12, 14, 17]. While post-treatment scarring and fibrosis may cause reactive soft tissue changes mimicking recurrent tumor, the avid hypervascularity of recurrences depicted by DCE may help in the differentiation of these. In one study, DCE was the highest performing sequence, outperforming diffusion-weighted imaging (DWI) for detecting local recurrences [8]. Given such experiences, DCE currently has a central role in prostate MRI interpretation in the post-treatment setting.

Despite the value of DCE in assessing for local recurrences, the sequence's technical optimization can be challenging. DCE acquisition entails an inherent tradeoff between spatial and temporal resolution and also is vulnerable to motion artifact during the extended scan duration. A recently described acquisition technique combining a continuously acquired radial k-space trajectory with golden-angle sampling and sparse parallel reconstruction employing compressed sensing offers simultaneous high spatial and high temporal resolution as well as motion robustness to DCE MRI of the prostate [18]. It is

possible that this approach facilitates evaluation in patients with BCR. Thus, the aim of this study was to compare this DCE method with a standard DCE sequence in terms of image quality and diagnostic performance for detecting local recurrence after RP for prostate cancer.

Methods

Patients

This retrospective study was HIPAA compliant and received approval from our institutional review board, which provided a waiver of the requirement for written informed consent. A departmental database was searched for prostate MRI reports between 2012 and 2015 containing the phrase “radical prostatectomy,” identifying approximately 300 examinations. Examinations were then excluded for the following reasons: MRI was not performed in the setting of BCR following RP, PSA at time of MRI less than 0.2 ng/mL, adjuvant therapy for prostate cancer before the MRI, MRI performed at outside institution, MRI not performed at 3T, MRI performed without intravenous contrast, hormonal therapy after the MRI, and unable to categorize the examination as positive or negative for local recurrence (based on the reference standard described below). These exclusions resulted in a final included cohort of 25 patients. The mean patient age was 67 ± 8 years (median 66 years; range 48–80 years). The mean interval between RP and the MRI was 5.8 ± 5.1 years (median 4 years; range 0–16 years). The mean PSA at the time of MRI was 0.7 ± 0.8 ng/mL (median 0.4; range 0.2–3.7). Three of the 25 patients were included in an earlier study that evaluated the utility of tumor ADC metrics derived from the pre-prostatectomy MRI for predicting BCR after prostatectomy [19]; however, that earlier study did not evaluate any post-prostatectomy imaging.

MRI protocol

All patients underwent prostate MRI using a 3T system (Siemens MAGNETOM Trio, Skyra, Prisma, or Biograph mMR; Erlangen Germany) and a pelvic phased array coil (six-element coil arrays for the Trio and Biograph mMR; 18-element coil arrays for the Skyra and Prisma). Examinations included multi-planar turbo spin-echo T2-weighted imaging (T2WI) and DWI, although these were not evaluated as part of this study. Each examination also included a DCE sequence of the prostate. Prior to July 2013, a standard DCE technique was included in our routine prostate MRI protocol. During an approximately six-month period beginning in July 2013, a radial golden-angle DCE sequence was implemented on our institution's various MR systems [18], after which this became the routine DCE sequence for prostate MRI examinations throughout our institution. Clinical characteristics of the examination did not influence which DCE technique was performed in a given case. DCE was performed using 0.1 mmol/kg of intravenous contrast administered at 3 cc/s, followed by a saline flush, both administered using a power injector. Examinations performed prior to 2014 used gadopentetate dimeglumine (Magnevist; Bayer Healthcare Pharmaceuticals), while subsequent examinations used gadobutrol (Gadavist, Bayer Healthcare Pharmaceuticals), reflecting a change in the routine contrast agent for all MRI examinations at our institution.

The standard DCE sequence entailed a 3D Cartesian gradient echo T1-weighted sequence using the following pulse parameters: TR 2.84 ms, TE 0.94 ms, flip angle 16°, slice thickness 3 mm, field-of-view (FOV) 240 × 240 mm, matrix 128 × 128, one signal average, and no parallel imaging. The sequence obtained 24 slices at a spatial resolution (slice × in-plane) of 3.0 × 1.9 × 1.9 mm. The DCE acquisition was initiated at the time of contrast injection and lasted for a duration of 5 min and 5 s. During this time, 55 post-contrast time points were obtained at a temporal resolution of 5.5 s.

The alternative approach was performed using the Golden-Angle Radial Acquisition Sparse Parallel (GRASP) acquisition. This technique used a fat-suppressed 3D gradient echo T1-weighted sequence with a “stack-of-stars” sampling scheme based on in-plane radial sampling and z-axis Cartesian sampling (as forms the basis of the radial VIBE sequence [20]). Radial spokes were acquired in a continuous fashion based on a golden-angle sampling scheme, beginning prior to contrast injection that occurred after a 20-s injection delay. Pulse parameters were as follows: TR 4.10 ms, TE 1.89 ms, flip angle 12°, slice thickness 3 mm, FOV 240 × 240 mm, and matrix 224 × 224. The sequence obtained 21 slices at a spatial resolution of 3.0 × 1.1 × 1.1 mm. In view of the fundamentally different natures of the standard DCE sequence and GRASP, it was not possible to match pulse parameters between these. Alternatively, each sequence had previously undergone independent optimization. The raw MR data from the GRASP acquisition were reconstructed using the k-t SPARSE-SENSE method based on joint parallel imaging and compressed sensing. Dynamic time points contained 21 consecutive radial spokes, providing a temporal resolution of 2.3 s. The acquisition duration for GRASP was 5 min 18 s prior to February 2015, although it was subsequently reduced to 3 min 2 s upon release of the Prostate Imaging Reporting and Data System (PI-RADS) Version 2 (V2) guidelines advising an abbreviated DCE duration of 2 min [21].

These parameters for the two DCE sequences have been previously reported [18]. Among the 25 patients, 13 underwent standard DCE [using combination of Trio ($n = 11$) and Biograph mMR ($n = 2$) systems] and 12 underwent GRASP [using combination of Trio ($n = 9$), Skyra ($n = 2$), and Prisma ($n = 1$) systems].

Imaging assessment

Two fellowship-trained radiologists (AD and JR) with 3 years of experience in prostate MRI independently reviewed the examinations in a random order using a standard clinical PACS (iSite; Philips Healthcare). The radiologists were aware that the patients had an elevated PSA following RP, but were blinded to other clinical details including the specific PSA value. The radiologists viewed only the DCE acquisitions; T2WI and DWI were not assessed in order to ensure that all findings reported by the readers were based on the given DCE sequences under evaluation. The visual assessment was performed by scrolling through serial dynamic time points using the PACS. Pharmacokinetic mapping was not performed.

The radiologists assessed each examination on a 1–5 scale (5 = highest quality) in terms of anatomic clarity and image sharpness. In addition, the radiologists recorded in a binary fashion whether a local recurrence was visualized. The confidence in this determination was recorded for all cases on a 1–5 scale (5 = highest confidence). For those examinations in

which a recurrence was visualized, the finding's conspicuity was recorded on a 1–5 scale (5 = highest conspicuity).

Reference standard

All available clinical, imaging, histologic, and laboratory follow-up were reviewed to determine the reference standard in all patients. Composite sets of criteria were applied for considering patients positive or negative for local recurrence, derived from criteria used in early studies [6, 8–10, 12, 14]. Twenty-one of the patients were classified as positive for local recurrence (11 imaged by standard DCE; 10 imaged by GRASP) on the basis of 50% reduction in serum PSA following pelvic radiation ($n = 19$) or positive TRUS-guided biopsy of the operative site ($n = 2$). Patients were classified as negative for local recurrence on the basis of either an increase or a <50% reduction in serum PSA following pelvic radiation ($n = 3$), or subsequent return to a normal serum PSA level without interval therapy, indicating a spurious PSA elevation ($n = 1$).

Statistical assessment

Results were summarized using descriptive statistics. The radiologists' assessments recorded using a 1–5 scale were compared between standard DCE and GRASP using unpaired t-tests. Sensitivity, specificity, and accuracy of the two sequences for detection of local recurrences were computed for the two sequences, although formal significance testing was not applied to these measures given the very low counts for some entries in the associated 2×2 contingency tables. The statistical analysis was performed using MedCalc for Windows (MedCalc Software, Ostend, Belgium).

Results

For both readers, GRASP achieved higher scores than standard DCE which were either statistically significant or trended toward significance for anatomic clarity (R1: 4.4 ± 0.8 vs. 2.8 ± 0.7 , R2: 4.8 ± 0.5 vs. 3.2 ± 0.6 ; $p < 0.001$), sharpness (R1: 3.7 ± 0.9 vs. 2.5 ± 0.8 , R2: 4.6 ± 0.5 vs. 2.6 ± 0.5 ; $p = 0.001$), confidence in interpretation (R1: 3.8 ± 0.8 vs. 3.1 ± 0.9 , R2: 3.8 ± 1.0 vs. 3.1 ± 1.2 ; $p = 0.036$ – 0.136), and conspicuity of detected lesions (R1: 4.7 ± 0.5 vs. 3.8 ± 1.0 , R2: 4.5 ± 0.5 vs. 3.8 ± 1.0 $p = 0.076$ – 0.128). Also for both readers, for detecting local recurrences, GRASP achieved higher sensitivity (R1: 70% vs. 36%; R2: 80% vs. 45%), specificity (R1 and R2: 100% vs. 50%), and accuracy (R1: 75% vs. 38%; R2: 83% vs. 46%). Tables 1 and 2 summarize these results. Figures 1 and 2 provide representative images.

Discussion

Existing literature strongly supports the role of DCE in detecting local recurrences in patients with BCR after RP [7, 8, 12, 14, 17], such that continued attention to the optimization of DCE in this setting is warranted. In our study, high spatiotemporal resolution DCE acquired using the GRASP technique achieved substantially improved image quality and a trend toward improved diagnostic performance than standard DCE for detecting local recurrence of prostate cancer following RP. In our small patient sample, both readers had at

least a 30% improvement in overall diagnostic accuracy using GRASP, with suggested improvements in confidence in their interpretation and perceived conspicuity of the detected lesion. Our findings support a potential role for GRASP in improving the clinical performance of MRI in the detection of suspected local recurrence following RP.

Previously, high spatiotemporal resolution DCE using the GRASP technique has been applied for the evaluation of bladder cancer at MR urography [22], inflammatory bowel disease at MR enterography [23], and liver perfusion at upper abdominal MR imaging [24]. In addition, in a preliminary study, the GRASP technique was applied for prostate cancer imaging in the pretreatment imaging [18]. GRASP takes advantages of data sparsity, attributable to extensive spatiotemporal correlations in the data, to achieve substantial temporal acceleration without an associated loss in spatial resolution of the images [18]. This acceleration entails marked undersampling of k-space in a random and incoherent fashion using the golden-angle sampling scheme, with subsequent iterative reconstruction and recovery of the undersampled information using compressed sensing [18]. Moreover, the radial trajectory entails a rotating phase-encoding gradient, thereby avoiding the ghosting, aliasing, and other artifacts encountered when using a traditional rectilinear phase-encoding gradient. This effect contributes to a sharper image appearance, which also resulted in a greater clarity in the interpretation for both readers in the present study.

Improved noninvasive detection of local recurrences following RP by MRI has important clinical implications. The reliable determination of the presence of a local soft tissue lesion can expedite the initiation of salvage pelvic radiation, which in turn has been shown to improve outcomes [25–27]. Moreover, with increasing application of 3D conformal radiation approaches, the precise anatomic localization of the recurrence within the pelvis may potentially enable dose escalation at that specific site, thereby improving efficacy of radiation therapy while limiting collateral damage to adjacent structures [6, 17]. Moreover, reports have described focal high-intensity focused ultrasound or focal cryotherapy as salvage therapy for local recurrences after RP [28, 29]. Such targeted interventions require precise knowledge of the specific site of the recurrence. Beyond the above considerations, more reliable imaging in patients with BCR also benefits patients without a local recurrence by avoiding unnecessary salvage radiation therapy.

This study has a number of limitations. First, standard DCE and GRASP were performed in two distinct patient groups. However, given the need for dynamic imaging immediately after intravenous contrast injection, it was not possible to perform both techniques as part of a single examination. Second, our reference standard for classifying patients in terms of the presence or absence of local recurrence reflected a composite of various laboratory- and histology-based follow-up measures. As past authors have acknowledged, biopsy is not routinely performed of the operative site [7, 8, 10], and definitively proving or excluding local recurrence is challenging [6]. We classified patients to the best of our ability, using clinical criteria as have been used in numerous prior studies on this topic [6, 8–10, 12, 14]. If anything, our inclusion criteria may have been more stringent than earlier investigations that classified patients based on serial MRI findings [8–10], a standard that has an inherent reference test bias when evaluating the diagnostic performance of an initial MRI. Nonetheless, the inability to classify many patients using our selected reference criteria

resulted in small sample sizes, particularly for patients classified as not having local recurrence, and limited our statistical power. Third, the sensitivities for local recurrence achieved by the two readers were moderate. However, the readers only evaluated DCE in isolation, such that the sensitivities may have been higher if assessing a complete multi-parametric prostate MRI examination. The readers evaluated only the DCE sequence given our specific aim of performing a comparison of the two DCE methods. This viewing of only DCE avoided the readers' reporting of recurrences primarily visualized on other sequences, which would have obscured potentially important differences between standard DCE and GRASP. Fourth, all patients in our cohort had a PSA under 4 ng/mL, and many patients had very low PSA values approaching 0.2 ng/mL, as occurs in the setting of small-volume local recurrences, further contributing to the low sensitivities. Fifth, two different extracellular contrast agents were used in our study cohort given a change in the contrast agent routinely used at our institution. Sixth, given that salvage radiation after prostatectomy routinely treats the entire pelvis, it was not possible to assess for a correspondence between the exact location of the detected lesion and a localized treatment size. Thus, any lesion detected by the readers in a patient with treatment response was considered to represent a true positive finding. Seventh, only GRASP was acquired using fat suppression. As previously described [18], fat suppression was required for GRASP to avoid off-resonance artifacts that otherwise would be encountered given the radial acquisition scheme, whereas its use for standard DCE would have further lowered the temporal resolution of standard DCE. Eighth, although not evaluated in our study, compressed sensing could also be combined with a standard Cartesian DCE acquisition to improve spatial resolution. However, such an approach would not attain other benefits of GRASP, including greater motion robustness as well as the ability for image reconstruction following a continuous acquisition at a flexible temporal resolution, including faster resolutions than typically attained using standard DCE. Finally, given the inherent differences in image appearance between standard DCE and GRASP, it was not possible to effectively blind the readers to which sequence was being assessed. We recognize these numerous limitations of our study. Nonetheless, the visual difference in image quality between the two DCE techniques appears striking, as supported by improvements for all image quality measures and large gains in diagnostic accuracy for both readers, such that we feel this preliminary study supports continued clinical investigation of the GRASP technique for local recurrence detection.

In conclusion, compared with standard DCE, a recently described high spatiotemporal resolution continuously acquired radial golden-angle DCE sequence with compressed sensing reconstruction achieved substantially better image quality. While limited by a small sample size, the data also suggest that the superior image quality may translate to enhanced diagnostic performance for detecting local recurrence in patients with elevated PSA after RP. This sequence may facilitate the earlier detection of local recurrences at lower PSA values when health care providers are confronted with a rising PSA and need to make a clinical decision whether or not to proceed with salvage radiation therapy. Larger studies of the role of this new DCE technique in patients with suspected local recurrence are warranted.

Acknowledgments

Funding This study received support from the Joseph and Diane Steinberg Charitable Trust.

Taneja: Consultant (Hitachi-Aloka and Healthtronics), payments for lectures and travel expenses (Hitachi-Aloka), and royalties (Elsevier). Rosenkrantz: Royalties (Thieme Medical Publishers).

References

1. Mullins JK, Feng Z, Trock BJ, et al. The impact of anatomical radical retropubic prostatectomy on cancer control: the 30-year anniversary. *J Urol*. 2012; 188(6):2219–2224. [PubMed: 23083655]
2. Shen S, Lepor H, Yaffee R, Taneja SS. Ultrasensitive serum prostate specific antigen nadir accurately predicts the risk of early relapse after radical prostatectomy. *J Urol*. 2005; 173(3):777–780. [PubMed: 15711268]
3. Vargas HA, Wassberg C, Akin O, Hricak H. MR imaging of treated prostate cancer. *Radiology*. 2012; 262(1):26–42. [PubMed: 22190655]
4. Pound CR, Partin AW, Eisenberger MA, et al. Natural history of progression after PSA elevation following radical prostatectomy. *JAMA*. 1999; 281(17):1591–1597. [PubMed: 10235151]
5. Han M, Partin AW, Zahurak M, et al. Biochemical (prostate specific antigen) recurrence probability following radical prostatectomy for clinically localized prostate cancer. *J Urol*. 2003; 169(2):517–523. [PubMed: 12544300]
6. Sella T, Schwartz LH, Swindle PW, et al. Suspected local recurrence after radical prostatectomy: endorectal coil MR imaging. *Radiology*. 2004; 231(2):379–385. [PubMed: 15064390]
7. Wassberg C, Akin O, Vargas HA, et al. The incremental value of contrast-enhanced MRI in the detection of biopsy-proven local recurrence of prostate cancer after radical prostatectomy: effect of reader experience. *AJR Am J Roentgenol*. 2012; 199(2):360–366. [PubMed: 22826397]
8. Kitajima K, Hartman RP, Froemming AT, et al. Detection of local recurrence of prostate cancer after radical prostatectomy using endorectal coil MRI at 3 T: addition of DWI and dynamic contrast enhancement to T2-Weighted MRI. *AJR Am J Roentgenol*. 2015; 205(4):807–816. [PubMed: 26397329]
9. Cha D, Kim CK, Park SY, Park JJ, Park BK. Evaluation of suspected soft tissue lesion in the prostate bed after radical prostatectomy using 3T multiparametric magnetic resonance imaging. *Magn Reson Imaging*. 2015; 33(4):407–412. [PubMed: 25527395]
10. Kitajima K, Murphy RC, Nathan MA, et al. Detection of recurrent prostate cancer after radical prostatectomy: comparison of 11C-choline PET/CT with pelvic multiparametric MR imaging with endorectal coil. *J Nucl Med*. 2014; 55(2):223–232. [PubMed: 24434294]
11. Roy C, Foudi F, Charton J, et al. Comparative sensitivities of functional MRI sequences in detection of local recurrence of prostate carcinoma after radical prostatectomy or external-beam radiotherapy. *AJR Am J Roentgenol*. 2013; 200(4):W361–W368. [PubMed: 23521479]
12. Panebianco V, Barchetti F, Sciarra A, et al. Prostate cancer recurrence after radical prostatectomy: the role of 3-T diffusion imaging in multi-parametric magnetic resonance imaging. *Eur Radiol*. 2013; 23(6):1745–1752. [PubMed: 23377546]
13. Panebianco V, Sciarra A, Lisi D, et al. Prostate cancer: 1HMRS-DCEMR at 3T versus [(18)F]choline PET/CT in the detection of local prostate cancer recurrence in men with biochemical progression after radical retropubic prostatectomy (RRP). *Eur J Radiol*. 2012; 81(4):700–708. [PubMed: 21330082]
14. Cirillo S, Petracchini M, Scotti L, et al. Endorectal magnetic resonance imaging at 1.5 Tesla to assess local recurrence following radical prostatectomy using T2-weighted and contrast-enhanced imaging. *Eur Radiol*. 2009; 19(3):761–769. [PubMed: 18825386]
15. Sciarra A, Panebianco V, Salciccia S, et al. Role of dynamic contrast-enhanced magnetic resonance (MR) imaging and proton MR spectroscopic imaging in the detection of local recurrence after radical prostatectomy for prostate cancer. *Eur Urol*. 2008; 54(3):589–600. [PubMed: 18226441]
16. Casciani E, Poletti E, Carmenini E, et al. Endorectal and dynamic contrast-enhanced MRI for detection of local recurrence after radical prostatectomy. *AJR Am J Roentgenol*. 2008; 190(5):1187–1192. [PubMed: 18430830]
17. Rischke HC, Schafer AO, Nestle U, et al. Detection of local recurrent prostate cancer after radical prostatectomy in terms of salvage radiotherapy using dynamic contrast enhanced-MRI without endorectal coil. *Radiat Oncol*. 2012; 7:185. [PubMed: 23114282]

18. Rosenkrantz AB, Geppert C, Grimm R, et al. Dynamic contrast-enhanced MRI of the prostate with high spatiotemporal resolution using compressed sensing, parallel imaging, and continuous golden-angle radial sampling: preliminary experience. *J Magn Reson Imaging*. 2015; 41(5):1365–1373. [PubMed: 24833417]
19. Rosenkrantz AB, Ream JM, Nolan P, et al. Prostate cancer: utility of whole-lesion apparent diffusion coefficient metrics for prediction of biochemical recurrence after radical prostatectomy. *Am J Roentgenol*. 2015; 205(6):1208–1214. [PubMed: 26587927]
20. Chandarana H, Block TK, Rosenkrantz AB, et al. Free-breathing radial 3D fat-suppressed T1-weighted gradient echo sequence: a viable alternative for contrast-enhanced liver imaging in patients unable to suspend respiration. *Invest Radiol*. 2011; 46(10):648–653. [PubMed: 21577119]
21. Weinreb JC, Barentsz JO, Choyke PL, et al. PI-RADS prostate imaging—reporting and data system: 2015, Version 2. *Eur Urol*. 2016; 69(1):16–40. [PubMed: 26427566]
22. Parikh N, Ream JM, Zhang HC, et al. Performance of simultaneous high temporal resolution quantitative perfusion imaging of bladder tumors and conventional multi-phase urography using a novel free-breathing continuously acquired radial compressed-sensing MRI sequence. *Magn Reson Imaging*. 2016; 34(5):694–598. [PubMed: 26740058]
23. Ream JM, Doshi A, Lala SV, et al. High spatiotemporal resolution dynamic contrast-enhanced MR enterography in crohn disease terminal ileitis using continuous golden-angle radial sampling, compressed sensing, and parallel imaging. *Am J Roentgenol*. 2015; 204(6):W663–W669. [PubMed: 26001254]
24. Chandarana H, Block TK, Ream J, et al. Estimating liver perfusion from free-breathing continuously acquired dynamic gadolinium-ethoxybenzyl- diethylenetriamine pentaacetic acid-enhanced acquisition with compressed sensing reconstruction. *Invest Radiol*. 2015; 50(2):88–94. [PubMed: 25333309]
25. Botticella A, Guarneri A, Levra NG, et al. Biochemical and clinical outcomes after high-dose salvage radiotherapy as monotherapy for prostate cancer. *J Cancer Res Clin Oncol*. 2014; 140(7):1111–1116. [PubMed: 24744191]
26. Kwon O, Kim KB, Lee YI, et al. Salvage radiotherapy after radical prostatectomy: prediction of biochemical outcomes. *PLoS One*. 2014; 9(7):e103574. [PubMed: 25072938]
27. Lohm G, Lutcke J, Jamil B, et al. Salvage radiotherapy in patients with prostate cancer and biochemical relapse after radical prostatectomy: long-term follow-up of a single-center survey. *Strahlenther Onkol*. 2014; 190(8):727–731. [PubMed: 24577132]
28. Murota-Kawano A, Nakano M, Hongo S, et al. Salvage high-intensity focused ultrasound for biopsy-confirmed local recurrence of prostate cancer after radical prostatectomy. *BJU Int*. 2010; 105(12):1642–1645. [PubMed: 19922544]
29. Siddiqui SA, Mynderse LA, Zincke H, et al. Treatment of prostate cancer local recurrence after radical retropubic prostatectomy with 17-gauge interstitial transperineal cryoablation: initial experience. *Urology*. 2007; 70(1):80–85. [PubMed: 17656213]

Fig. 1.
Panel of local recurrences (*arrows*) detected using obliques axial standard DCE sequence in different patients.

Fig. 2.
Panel of local recurrences (*arrow*) detected using oblique axial GRASP DCE sequence in different patients.

Table 1

Comparison of image quality measures (1–5 score; 5 = highest quality) between standard DCE and GRASP for detecting local recurrence following radical prostatectomy

	R1		R2		p
	Conventional	GRASP	Conventional	GRASP	
Anatomic clarity	2.8 ± 0.7	4.4 ± 0.8	3.2 ± 0.6	4.8 ± 0.5	<0.001
Image sharpness	2.5 ± 0.8	3.7 ± 0.9	2.6 ± 0.5	4.6 ± 0.5	<0.001
Confidence in interpretation	3.1 ± 0.9	3.8 ± 0.8	3.1 ± 1.2	3.8 ± 1.0	0.136
Conspicuity of detected lesion	3.8 ± 1.0	4.7 ± 0.5	3.8 ± 1.0	4.5 ± 0.5	0.128

Table 2Comparison of standard DCE and GRASP for measures of diagnostic performance for local recurrence^a

	R1		R2	
	Conventional	GRASP	Conventional	GRASP
Sensitivity	36% (4/11)	70% (7/10)	45% (5/11)	80% (8/10)
Specificity	50% (1/2)	100% (2/2)	50% (1/2)	100% (2/2)
Accuracy	38% (5/13)	75% (9/12)	46% (6/13)	83% (10/12)

^aFormal statistical significance testing not performed given small sample sizes