Prostate Multiparametric MRI: Evaluation of Recurrence and Post-treatment Changes

F. A. Carpagnano1,2 · L. Eusebi3 · W. Giannubilo4 · F. Fenu5 · M. Safi6 · F. Bartelli3 · G. Guglielmi1,2,7

Accepted: 18 August 2022 / Published online: 23 November 2022 © The Author(s) 2022

Abstract

Purpose of Review This article reviews all the most common therapeutic strategies of prostate cancer, systemic or local, and all the following morpho-structural alterations, with the aim of helping the radiologist to recognize the signs of recurrence by using mp-MRI.

Recent Findings According to the most recent evidences, prostate mp-MRI has now become a strong, non-invasive, and valid tool to evaluate all patient treated for prostatic carcinoma across the time, especially in the suspicion of biochemical recurrence.

Summary The minimal signs of focal recurrence can put a strain on radiologists, especially if they are novice with multi-parametric prostate MRI. Familiarizing themselves with the outcomes of treatment, local or systemic, and its characteristics to MR imaging is indispensable to avoid diagnostic pitfalls and, subsequently, unnecessary reinterventions.

Keywords Prostate cancer · Biochemical recurrence · Radical prostatectomy · Radiotherapy treatment · Focal therapy

Introduction

In the vast field of cancer diseases that most frequently affect the male sex of Western Europe, prostate cancer (PCa) is undoubtedly one of the most numbered, representing one of the main causes of neoplastic death along with skin and lung cancers [1]. Although significant progress has been made in early detection as well as in the treatment of prostate cancer, the greatest challenge at the moment is the management and follow-up of patients following treatment, whether it be focal or radical. Specifically, the first-line therapeutic choice with curative intervention is represented by radical prostatectomy (RP), followed by radiotherapy treatment (RT), with external beam radiotherapy (EBRT) or with brachytherapy, as a viable alternative in patients with medium and low-risk...
PCa (below T3a in the TNM staging system) and, in addition, in patients not eligible for surgery by age or comorbidity [2]. In addition, in recent years, further therapeutic proposals focused mainly on focal ablation techniques (FA) such as laser therapy, cryotherapy or high-intensity focused ultrasound (HIFU) have been developed [3].

Regardless of treatment, biochemical recurrence (BR) is not uncommon in patients treated for PCa and strongly influences their management and subsequent therapeutic choices [4]. Especially in the category of high-risk patients, who are subjected to RP, the probability of a BR occurring within the next 15 years after treatment amounts to about 50%; so high percentage is explained by the frequent need to preserve the vascular beam-nervous and the urethral sphincter during the surgical procedure [5]; no less is the probability of risk of BR after RT treatment, that is around 67% [6].

BR, also called biochemical failure (BF), does not necessarily indicate a recurrence of disease confined to the prostate bed and surrounding tissues, but may also refer to metastases at a distance, that is why attention should be paid to which parameters to assess for a correct distinction between the two conditions [4].

The first approach in the diagnosis of recurrence of prostatic disease is represented by the serum dosage of prostatic specific antigen (PSA) and the evaluation of its kinetics over time, specifically the PSA-Doubling Time (PSA-DT) and the PSA-velocity (PSA-VE), parameters closely related to the treatment to which the patient has been subjected. As a general rule, in patients undergoing RP, one would expect to find an undetectable PSA or PSA with values very close to zero (0.1 ng/ml) after 21–30 days of surgery, considering any increment, even minimum, a possible warning sign of persistence or recurrence of disease [4]. In contrast, serum levels of PSA that are low but still measurable with certainty after RT or FA, given the persistence of normally functioning residual glandular tissue, should be considered physiological [7].

According to the most recent evidence and in agreement with the European Urology Association (UAE) two consecutive values of PSA > 0.2 ng/ml after RP are strongly suggestive of BR, but is not sufficient to distinguish between locoregional and systemic relapse [8]. Therefore, in order to ensure an appropriate therapeutic choice, an evaluation of serum PSA levels and their evolution over time will be necessary. Broadly speaking, reference PSA values have been identified for one condition or another and are given in Table 1 [9].

On the contrary, estimating the risk of BR following RT is a much more complex undertaking and the PSA itself has a poorly defined role in pursuing this aim, since it may happen that after radiation treatment serum PSA levels have a very slow descent or never reach undetectable values. This phenomenon obviously occurs due to the presence of residual and functioning prostatic tissue, which causes the achievement of the so-called “PSA nadir” after RT even 3 or more years later than the RP. According to the 2005 American Society of Therapeutic Radiology and Oncology’s “Phoenix Criteria”, two consecutive PSA values above 0.2 ng/ml are highly suggestive of relapse of disease after RT [10].

As mentioned above, the need to identify and differentiate with certainty a local recidivism from a systemic one, aims to choose with accuracy an appropriate treatment as tailored as possible on each patient. In general, according to the UAE guidelines, in cases of locoregional relapse, which therefore presupposes the presence of residual and functioning prostatic tissue in the prostate bed, a treatment with RT defined “rescue”, before the PSA levels exceed the value of 1 ng/ml, is indicated, keeping in mind, as a general rule, that the treatment will be able to have better effects the lower the initial PSA is: in particular, recent evidences show that the best results are obtained specifically when the PSA level is lower than 0.5 ng/ml [11].

Alternative therapies to RT and equally useful in the treatment of local relapse can be represented by RP or FA, whose choice is guided by an overall assessment of the patient’s health status, his comorbidities and, not least, to the location and extent of residual tumor tissue.

On the contrary, the certain diagnosis of systemic disease renders completely useless the only RT as a first-

### Table 1 PSA and its index values related to local or systemic relapse

| PSA        | PSA-VE | PSA-DT | Lymph nodes | SV invasion | Surgical margins | Original gleason | Original pathologic stage |
|------------|--------|--------|-------------|-------------|------------------|-----------------|--------------------------|
| Local relapse | Detectable after 1 year | < 0.75 ng/ml/year | > 6 months | Negative | Negative | Negative | < 7 | < pT3a, pN0, pTx |
| Systemic relapse | Detectable before 1 year | > 0.75 ng/ml/year | < 6 months | Positive | Positive | Positive | > 7 | pT3b, pN1, pTx |

PSA prostatic specific antigen, PSA-VE PSA velocity, PSA-DT PSA doubling time, SV seminal vesicles
choice treatment, which is therefore supplanted in most cases by androgen deprivation therapy (ADT).

Regardless of the serum levels of PSA which are obviously one of the first alarm bells of possible disease’s recovery, the decisive step in the definition of locoregional or systemic BF is made by using imaging. In the field of PCa imaging, mp-MRI is the master technique thanks to its excellent potential to provide excellent anatomical spatial resolution (with T1w and T2w sequences) as well as good functional information with dynamic sequences (DCE) and diffusion (DWI) [12].

Although in the mp-MRI of the BF the same imaging sequences are used, as those suggested by the PIRADS v 2.1 for the primitive PCa, it is necessary to take into account any anatomical changes, functional or simply signal that is likely to incur in the assessment of MR imaging depending on the type of treatment the patient has been subjected to (e.g., anatomical changes or simply ferromagnetic artifacts for the presence of metal clips after RP) [13].

The aim of this article is to review all the possible changes that the prostate undergoes as a result of therapy, radical or focal, as well as describing the mp-MR imaging characteristics of locoregional relapse and/or potential pitfalls in its interpretation.

**mp-MRI in the Active Surveillance and the Precise Score**

As mentioned in the introductory paragraph, mp-MR has been used for several years in many centers as a choice imaging technique in the diagnosis of PCa. The combined use of functional and anatomical sequences, in fact, increased the sensitivity and specificity of mp-MRI in the detection of clinically significant PCa, thus pushing the European Society of Urology and the American College of Radiology to develop guidelines on standardized acquisition and interpretation protocols known as “Prostate Imaging-Reporting and Data System (PI-RADS)”’ (latest version PI-RADS v2.1 released in 2019) [14].

In general, T2-weighted hinge sequences (T2w) have been identified for the anatomical study of the gland and male pelvis as a whole, together with a functional study with diffusion sequences (DWI), dynamics (DCE), and spectroscopy. Moreover, among these, preferential and more significant tailored sequences were chosen on the zonal anatomy of the prostate: the T2w sequences for the transition zone (TZ) and the DWI sequences for the peripheral zone (PZ) [15*].

In view of the above, it is clear that, in addition to diagnosis, mp-MRI is useful in the management of patients with locally developed and/or low-risk PCa and in those who undergone treatment with RP, RT, or FT. The aforementioned categories of patients, in fact, are subjected to active surveillance (AS) which has as its ultimate aim to reduce overtreatment and to determine how much a treatment is deferable, always remaining in the time window of curability.

In 2014, the National Institute for Health and Care Excellence (NICE) suggested that mp-MRI also acquired a role in the management of PCa, alongside or replacing prostate biopsy for restaging in patients with suspicion of recurrence [16].

Mp-MRI could clearly be considered a viable alternative to prostate biopsy during active surveillance, as it would prevent patients from undergoing invasive procedures on a regular basis or at least limit their frequency.

In 2016, a team of experts in the field of urological oncology and radiology elaborated recommendations on the standardized management of patients in AS with the mp-MRI, today known as the Prostate Cancer Radiological Estimation of Change in Sequential Evaluation (PRECISE) system and built on a 5-point scale (Table 2); its clinical usefulness, however, requires official validation due to a still small number of literature data [17].

**MRI After Radical Prostatectomy**

RP is the primary therapeutic choice for healthy patients younger than 70, with PCa confined to the prostate gland. Post-surgical recurrence is not an infrequent phenomenon and, for this reason, the early detection of a BR becomes, therefore, of vital importance to undertake as soon as possible a second-level therapeutic process (e.g., radiation therapy with external beams with or without androgen deprivation therapy). In a study conducted on 84 patients subjected to RP, Panebianco et al. [18] have shown that mp-MRI has a much higher diagnostic accuracy than the most common methods used (PET/TC in particular) in the diagnosis of BR, reporting a sensitivity of 92% (versus 62%) and a specificity of 75% (versus 50%).

### Table 2: Prostate cancer radiological estimation of change in sequential evaluation (PRECISE) system

| Score | Mp-MRI findings during active surveillance (AS) |
|-------|-------------------------------------------------|
| 1     | Complete resolution of previous mp-MRI findings |
| 2     | Reduction in volume/extension of previous mp-MRI findings |
| 3     | Stable appearance of prostate aspect at mp-MRI (e.g., stable volume of a prostate suspicious lesion) |
| 4     | Significant increase in volume of a previously identified suspicious area or a new one |
| 5     | Clearly radiological progression (e.g., local invasion as extracapsular extension, etc.) |
Compared to detection of in situ PCa, BR often appears either a hypointense or as a hyperintense nodular formation in T2w sequences, compared to pelvic muscles, located near the vesicourethral anastomosis (VUA), typically a low signal strength area related to post-surgical fibrosis. The dynamic sequences show a typical nodular-shape contrast-enhancement (with an Is/T ''wash-in/wash-out“ curve of type III) near the VUA, very suggestive finding of local recidivism (Fig. 1) and much more significant than the classic hyperintensity of restricted signal in DWI (with relative low intensity in the ADC-map), an mp-MRI sequence strongly susceptible to artifacts from metal clips [19].

Although RP is by definition the complete removal of the prostate and seminal vesicles, mp-MRI is useful in this sense because it can differentiate the local recurrence from possible glandular residues, as well as from inflammatory processes. The presence of a glandular residue may appear as a hyperintense nodule in the T2w anatomical sequences, making it difficult to distinguish with relapsing PCa which could appear as a slightly hyperintense nodule as well, using pelvic muscles as a benchmark for signal strength. Functional sequences are used for this purpose, since they allow to lean toward a radiological diagnosis of benignity in the presence of a lack of signal restriction in DWI/ADC and a focal, slow, and progressive contrast-enhancement (Is/T curve of type I-II) or a “mute” DCE sequence (Fig. 2).

Always within the scope of post-surgical residues, even seminal vesicles are to be considered a confusing element in the mp-MRI evaluation of the prostate bed; their tubular conformation, however, makes them more easily identifiable with T2w sequences yet, in which they show a typical hyperintense signal due to their fluid content [20, 21].

Another considerable challenge is the possible presence of granulation tissue which, like fibrosis, typically occurs in the vicinity of VUA but, contrary to it, shows signal hyperintensity in T2w and a high perfusion given its hypervascularity, like a BR; on the contrary, its signal restriction characteristics (no DWI signal) are more typical of a benign finding.

---

**Fig. 1** A 65-year-old man who presented two consecutive serum PSA levels above 4.3 ng/ml, 3 years after radical prostatectomy (RP) and candidate for mp-MRI evaluation in the suspicion of biochemical recurrence (BR). Axial T2w (A) shows a hypointense nodule (red arrow), which can be confused with post-surgical fibrosis located at the left side of vesico-urethral anastomosis (VUA). The restricted signal on DWI (B) and the corresponding ADC-map (C) increase the suspicion of a local recurrence of disease, which is largely confirmed by dynamic sequences after contrast medium injection (DCE), which show a hyperintense signal on the corresponding area (D) with type II-III Is/T curve (E), suggesting an hyper-vascular behavior (Color figure online)

---

**Fig. 2** An 80-years-old man who underwent periodical follow-up mp-MRI after radical prostatectomy (RP). Axial ADC-map (A) highlights a nodular area with low signal intensity (red arrow) suggestive, in the first hypothesis, for local recurrence. The DWI sequence (B), on the other hand, shows no signal restriction in the corresponding area, demonstrating a phenomenon of “DWI-ADC decoupling” that makes the hypothesis of disease’s recurrence decay. DCE sequences (C) appear mute and ferromagnetic artifacts are visible from the presence of surgical clips (Color figure online)
In general, in the light of the above, each mp-MRI sequence has its usefulness in post-RP imaging and it is equally clear that dynamic sequences, with intravenous contrast medium administration, are the key point to the discrimination of the various pathogenic noxae that can mimic a BR: a "mute" contrast-enhancement in the arterial phase and progressively intense during the acquisitions in the venous phase is defined as a finding of normality; on the contrary, a slight change or even a reversal of the contrast medium dynamics of the post-operative prostatic bed is a highly suggestive alarm bell of locoregional recurrence [3].

In order to support the aforementioned, several studies highlight the usefulness of DCE sequences after RP. Among these, an analysis of 46 patients conducted by Casciani et al. [22] which showed an increase in sensitivity from 48 to 88% and specificity from 52 to 100% given by the choice to add dynamic sequences to T2w alone. Or, moreover, Cyril et al. [23] which reported similar results on a cohort of 72 patients with specificity values of about 89.3% (versus 82.1%) and sensitivity of 84% (versus 61.4%).

MRI After Radiation Therapy

Radiation therapy (RT) is currently the second therapeutic option for medium- and low-risk PCa (stages I-III) after RP and, for obvious reasons, does not make the patient totally immune from recurrence of locoregional disease and with an average time of onset of distance metastasis of about 3 years [24].

Used in about 40% of patients over 65 and in about 25% of those under 65 years old, RT can be used both with external beams (EBRT), generally in the earliest stages of the disease, either in a more targeted form with brachytherapy.

Because of all the morpho-structural changes that the prostate face as a result of RT, regardless of whether it is EBRT or brachytherapy, the imaging method of choice for a more sensitive detection and localization of relapsing PCa is mp-MRI.

In the evaluation of pelvic MR imaging after RT, it is important not only to keep in mind the changes that directly affect the PCa (reduction of its own volume, reduction of capsular bulging and/or ECE), but also glandular atrophy and fibrotic changes mainly responsible for morphological/anatomical variations and signal strength [25].

The post-RT changes, moreover, affect the anatomical structures placed in close proximity of the prostate gland and can be visible both in the form of morpho-structural alterations, such as the wrinkled appearance of the seminal vesicles.
vesicles, or the thickening of the peri-rectal fascia, bladder, and rectal wall, either as variations in signal intensity (e.g., adipose bone marrow replacement in skeletal segments of the pelvis, visible as increased signal in T1w and hypo-intensity in T2w) [26].

It is important to keep in mind that the variations, both anatomical and signal, which follow the RT are different depending on the mode of delivery of the radiation and, therefore, it is necessary to assess specifically the consequences of EBRT and brachytherapy separately.

**External Beam Radiation Therapy (EBRT)**

The imaging evaluation after EBRT represents a real challenge for the radiology, especially considering all the post-RT changes that involve the prostate gland in its entirety. The irradiated glandular tissue, in fact, undergoes fibrotic changes and a significant reduction in volume, which result on the one hand in an overall reduction of the signal intensity in the T2w sequences, on the other hand in a loss of a clear distinction of the zonal anatomy of the gland. The widespread hypo-intensity of the gland in T2w, in particular, diminishes the usefulness of this sequence in the identification of a recurrent PCa, making it difficult to differentiate between healthy and neoplastic tissue.

The recurrent PCa, similar to a radio-treated neoplastic nodule, in the T2w images is presented as a focal hypo-intensity nodular morphology, difficult to distinguish from the surrounding glandular tissue, but that may nevertheless show indirect signs related to its localization within the prostate, such as capsular bulging derived from rather rapid tumor growth. Knowledge of the previous location of the tumor is also a factor not to be underestimated in the search for cancer recurrence, since only a very low percentage of prostatic cancer, ranging between 4 and 9%, occurs in a different location from the primitive [27].

Despite this, it is clear that T2w sequences alone are not sufficient to express themselves about the presence or not of local recurrence. Westphalen et al. [28], in a study conducted on a cohort of 64 patients, evaluated the usefulness of T2w sequences in the certain identification of recurrence of PCa, obtaining an area under the curve (AUC) only of 67%. Almost similar results emerged from another analysis carried out by Sala et al. [29] on a cohort of 45 patients diagnosed with BR, where T2w sequences showed a sensitivity between 36 and 75% and a specificity between 65 and 81%. Therefore, these data largely highlight the limitations of the exclusive use of T2w sequences.

In this scenario come into play the functional sequences DCE and DWI that, however, are not entirely free from RT-induced alterations, linked to reduced vascularity and cellularity of the fibrotic gland. Although present, morpho-structural and signal alterations of dynamic sequences do not appear to be as marked as in T2w, especially if we keep in mind that the continuous angiogenesis linked to the tumor hesitates in a perfusion activity visible in DCE sequences in contrast to the surrounding fibrotic tissue [30].

Haider et al. [31] showed significantly higher percentage of positive predictive value (49% vs 24%), negative predictive value (95% vs 88%), and sensitivity (72% vs 38%) of post-contrast dynamic sequences compared to T2w ones.

Remaining within the scope of the MR functional prostate imaging after EBRT, DWI sequences also deserve mention, since neoplastic relapse seems to have signal characteristics far similar to those of the primitive PCa, with evidence of diffusiveness restriction that results in a typical signal hyperintensity in DWI sequences with high b-values (> 1000) and a corresponding hypo-intensity in the ADC-map (Fig. 3). Several studies analyzed the usefulness of DWI used in combination with T2w sequences, compared to the latter alone, demonstrating a patient-based sensitivity and specificity for DWI of 100%, with region-based accuracy of 89% [32].

Apparently, in the evaluation of patients undergoing EBRT, there is no functional sequence that shows greater utility than another; however, there is evidence that the use of both DWI and DCE sequences greatly improves the diagnostic performance of MR imaging, especially in relation to the exclusive use of basic sequences such as T2w [33].

**Brachytherapy**

Although the alterations which the prostate undergoes after brachytherapy are almost analogous to those induced by EBRT, some peculiar aspects of this type of RT should not be underestimated, primarily related to the use of specific radioactive seeds contained in metal capsules which are responsible for some ferromagnetic artifacts, due to their intrinsic characteristics, that can distort the appearance of the gland and signal intensity especially in DWI sequences [34].

In the course of brachytherapy, as occurs in the EBRT, the prostate undergoes a progressive volumetric reduction in conjunction with the onset of fibrosis of the glandular parenchyma, resulting in widespread signal hypo-intensity in T2w sequences, in which context radioactive seeds appear as small hypointense ellipsoid bodies increasingly placed at the periphery of the atrophic gland [35].

In the presence of a confirmed BR, the nodule of PCa appears as a hypointense focus in the T2w sequences with characteristic intense and rapid contrast-enhancement in dynamic sequences and, limited to the presence of magnetic artifacts, restricted signal (hyperintense) in DWI at high b-values (> 1000). This latter aspect is the only reason why DCE sequences should be considered as pivotal sequences in the evaluation of post-brachytherapy recurrence, rather than DCE and DWI together [34].
MRI After Focal Therapy

In the field of targeted locoregional treatments there is a new emerging method known as focal therapy (FT) that brings together a series of different procedures depending on the type of energy used to attack the neoplastic lesion: cryotherapy, laser ablation focal (FLA), and high-intensity focused ultrasound (HIFU) [2].

The mp-MRI, with morphological and functional sequences, is now an excellent diagnostic method both in the assessment of the response to the treatment itself, along with biopsy and serum PSA, and in the long-term follow-up. With regard to this last aspect, in fact, it is recommended to perform an mp-MRI in the first week immediately following treatment, in order to capture the early findings and compare them with those of imaging of the next 5 years, in accordance with surveillance protocols [36].

Regardless of the type of focal therapy that the patient with PCa undergoes, in order to not incur errors of interpretation in the assessment of MR imaging, it is good to know not only the effects of FT on the tumor itself and the prostate gland as a whole, but also the treatment location, pre-procedure imaging and, last but not least, the type of energy used for FT [37].

In general, all FT treatments induce atrophy, volume reduction and reduced or absent perfusion of the treated area, visible on MRI as a focal hypo-intensity in T2w sequences and low signal in DWI, with a variable signal in ADC and DCE [38]. The effects on the tumor and the consequent appearance of MR imaging depend, in addition to the time elapsed, mainly on the type of FT used (Table 3).

At present there is still small evidence of the certain appearance of recurrent PCa in an area of prostate treated with FT, which suggests, therefore, the importance of knowing the effects of different physical energies on cancer tissue and, at the same time, the utility of integrating as always morphological and functional imaging sequences (Fig. 4).

MRI Post-hormonal Therapy

In the therapeutic protocols currently in use, patients with PCa, especially if metastatic and/or symptomatic, are subjected to hormone therapy (HT) or androgen deprivation (ADT) with the aim of inducing apoptosis of prostate cells.

ADT exerts its action either through a defined mechanism of "castration", by direct inhibition of testicular secretion of androgens, or properly through an "anti-androgenic" action by inhibition on peripheral receptors [39, 40]. It is not unusual that patients treated with ADT, both for locally advanced PCa and metastatic, are subject to rapidly progressive BR with ECE and/or seminal vesicle invasion.

Like the treatments described in the previous paragraphs, HT is also responsible for morpho-structural alterations of the prostate and possible errors of diagnostic interpretation in MR imaging. Typically, the gland will experience an overall reduction of its volume, especially if

Table 3 The most used types of focal treatment (FT) for PCa and their principal effects on the treated area

| Method | Effects on the Treated Area |
|--------|-----------------------------|
| Cryotherapy | Responsible for coagulative necrosis on a larger area than the focal neoplasia, which than appears changed in architecture and hypointense on T2w sequences, with a lower perfusion detected on DCE sequences |
| HIFU | It uses focused ultrasound in order to induce heating of the treatment area, resulting in a T2w hypo-intensity and still a slight peripheral perfusion on DCE sequences |
| FLA | It determines a heterogeneous T2 hypo-intensity, but with a restricted diffusion on DWI resulting in a high signal intensity |

Fig. 4 A 68-year-old patient who was evaluated at our institution after focal laser therapy (FLA). The use of mp-MRI, in particular functional sequences, has highlighted the absence of loco-regional recurrence due to the lack of signal restriction in DWI (A) and the corresponding ADC-map (B) both showing low intensity of the treated area (red arrow in B) (Color figure online)
the drug therapy is associated with RT, with evidence of reduction of the signal intensity in T2w sequences, mainly visible in the peripheral area (PZ), and increase of the ADC signal (Fig. 5). Functional sequences, on the other hand, will be indicative of reduced overall vascularity showing reduced perfusion of the gland in DCE sequences [41].

Conclusion

The role of MRI imaging in the study of prostate and PCa is not limited to detection and staging of the tumor itself, but also it extends to the periodic follow-up to patients following treatment. The percentage of recurrence of PCa, unfortunately, is not irrelevant in the spectrum of neo-plastic prostate disease and, given the existence of a BR through clinical-laboratory data, it is important to differentiate the local recurrence from the systemic one and, to this end, mp-MRI plays a decisive role.

Although the imaging acquisition and processing protocol does not differ at all from the classic one used for the routine study of the prostate, it is important for the radiologist to become familiar with all the changes that the gland and neighboring structures undergo, both as a result of focal and systemic therapies.

This work offers the basic tools for the radiologist not to fall into the trap of diagnostic pitfalls, describing the effects of each type of treatment on the prostate gland and listing the most frequent findings deriving from them.

Funding

Open access funding provided by Università di Foggia within the CRUI-CARE Agreement. No funds, grants, or other support was received.

Declarations

Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

Research Involving Human and Animal Participants

This article does not contain any studies with human or animal subjects performed by any of the authors.

Open Access

This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.
References

Papers of particular interest, published recently have been highlighted as:

- Of importance
- Of major importance

1. **Gaur S, Turkbey B. Prostate MR imaging for post-treatment evaluation and recurrence. Radiol Clin North Am. 2018;56(2):263–75. [https://doi.org/10.1016/j.rcl.2017.10.008]. Highlights the key points of mp-MRI in the evaluation of patients who underwent treatment for PCa.

2. Barret E, Harvey-Bryan KA, Sanchez-Salas R, et al. How to diagnose and treat focal therapy failure and recurrence? Curr Opin Urol. 2014;24(3):241–6.

3. McCamack KC, Raman SS, Margolis DJ. Imaging of local recurrence in prostate cancer. Future Oncol. 2016;12(21):2401–15.

4. Barchetti F, Panebianco V. Multiparametric MRI for recurrent prostate cancer post radical prostatectomy and postradiation therapy. BioMed Res Int. 2014. [https://doi.org/10.1155/2014/316272]. Discusses at detail prostate multiparametric MRI, technical considerations and important reporting information.

5. Brunocilla E, Pultrone C, Pernetti R, Schiavina R, Martorana G. Preservation of the smooth muscular internal (vesical) sphincter and of the prostatic urethra during retropubic radical prostatectomy: description of the technique. Int J Urol. 2012;19(8):783–5.

6. D’Amico AV, Crook J, Beard CJ, DeWeese TL, Hurwitz M, Kaplan I. Radiation therapy for prostate cancer. In: Walsh PC, Retik AB, editors. Campbell’s urology. 8th ed. Philadelphia: WB Saunders; 2002. p. 3170–47.

7. Mohler J, Kantoff P, Armstrong A, et al. Prostate cancer, version 2.2014. J Natl Compr Cancer Netw. 2014;12(5):686–718.

8. Heidenreich A, Bastian PJ, Bellmunt J, et al. EAU guidelines on prostate cancer. Part II: treatment of advanced, relapsing, and castration-resistant prostate cancer. Eur Urol. 2014;65(2):467–79.

9. Stephenson AJ, Kattan MW, Eastham JA, et al. Defining biochemical recurrence of prostate cancer after radical prostatectomy: a proposal for a standardized definition. J Clin Oncol. 2006;24(24):3973–8.

10. Roach M 3rd, Hanks G, Thames HJ, et al. Defining biochemical failure following radiotherapy with or without hormonal therapy in men with clinically localized prostate cancer: recommendations of the RTOG-ASTRO Phoenix Consensus Conference. Int J Radiat Oncol Biol Phys. 2006;65(4):965–74.

11. Cooperberg MR, Broering JM, Carroll PR. Time trends and local variation in primary treatment of localized prostate cancer. J Clin Oncol. 2010;28(7):1117–23.

12. Wu LM, Xu JR, Gu HY, et al. Role of magnetic resonance imaging in the detection of local prostate cancer recurrence after external beam radiotherapy and radical prostatectomy. Clin Oncol. 2013;25(4):252–64.

13. 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. Am J Roentgenol. 2013;200(4):W361–8.

14. Eusebi L, Carpinagno FA, Sortino G, Bartelli F, Guglielmi G. Prostate multiparametric MRI: common pitfalls in primary diagnosis and how to avoid them. Curr Radiol Rep. 2021;9(3):1–17.

15. **Carpinagno FA, Eusebi L, Tuppuri U, Testini V, Giannubilo W, Bartelli F, Guglielmi G. Multiparametric MRI: local staging of prostate cancer. Curr Radiol Rep. 2020;8(12):1–11. Discusses at detail prostate multiparametric MRI, technical considerations and important reporting information.

16. Moore CM, et al. Reporting magnetic resonance imaging in men on active surveillance for prostate cancer: the PRECISE recommendations—a report of a European school of oncology task force. Eur Urol. 2016. [https://doi.org/10.1016/j.eururo.2016.06.011].

17. Caglic I, Sushentsev N, Gnanapragasam VJ, Sala E, Shaida N, Koo BC, Kozlov V, Warren AY, Kastner C, Barrett T. MRI-derived PRECISE scores for predicting pathologically-confirmed radiological progression in prostate cancer patients on active surveillance. Eur Radiol. 2021;31(5):2696–705.

18. Panebianco V, Sgiorra 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):700–8.

19. Vargas HA, Wassberg C, Akin O, Hricak H. MR imaging of treated prostate cancer. Radiology. 2012;262:26–42. [https://doi.org/10.1148/radiol.11101996].

20. Notley M, Yu J, Fulcher AS, et al. Pictorial review. Diagnosis of recurrent prostate cancer and its mimics at multiparametric prostate MRI. Br J Radiol. 2015;88(1054):20150362.

21. Lopes Dias J, Lucas R, Magalhães Pina J, et al. Post-treated prostate cancer: normal findings and signs of local relapse on multiparametric magnetic resonance imaging. Abdom Imaging. 2015;40(7):2814–38.

22. Cesciani E, Polettini E, Carmени E, et al. Endor- ectal and dynamic contrast-enhanced MRI for detection of local recurrence after radical prostatectomy. AJR Am J Roentgenol. 2011;196(5):1187–92.

23. 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):761–9.

24. Bianco FJ Jr, Scardino PT, DiBlasio CJ, Fearn PA, Eastham JA. Long-term oncologic results of salvage radical prostatectomy for locally recurrent prostate cancer after radiotherapy. Int J Radiat Oncol Biol Phys. 2005;62(2):448–53.

25. Coakley FV, Hricak H, Wefer AE, Speight JL, Kurhanewicz J, Roach M. Brachytherapy for prostate cancer: endorectal MR imaging of local treatment-related changes. Radiology. 2001;219(3):817–21.

26. De Visschere PJ, De Meerleer GO, Futterer JJ, et al. Role of MRI in follow-up after focal therapy for prostate carcinoma. AJR Am J Roentgenol. 2010;194(6):1427–33.

27. Jaloh M, Leaupman MS, Cowen JE, et al. Patterns of local failure following radiation therapy for prostate cancer. J Urol. 2015;194(4):977–82.

28. Westphalen AC, Kurhanewicz J, Cunha RM, et al. T2-Weighted endorectal magnetic resonance imaging of prostate cancer after external beam radiation therapy. Int J Radiat Oncol Biol Phys. 2009;75(2):171–80 (discussion: 181–2).

29. Sala E, Eberhardt SC, Akin O, et al. Endorectal MR imaging before salvage prostatectomy: tumor localization and staging. Radiology. 2006;238(1):176–83.

30. Kara T, Akata D, Akylol F, Karcaaltincaba M, Ozmen M. The value of dynamic contrast-enhanced MRI in the detection of recurrent prostate cancer after external beam radiotherapy: correlation with transrectal ultrasound and pathological findings. Diagn Interv Radiol. 2011;17(1):38–43.

31. Haider MA, Chung P, Sweet J, et al. Dynamic contrast-enhanced magnetic resonance imaging for localization of recurrent prostate cancer after external beam radiotherapy. Int J Radiat Oncol Biol Phys. 2008;70(2):425–30.

32. Harai H, Inoue Y, Saitoh T, et al. Diffusion-weighted imaging of local recurrent prostate cancer after radiotherapy:
comparison with 22-core three-dimensional prostate mapping biopsy. Magn Reson Imaging. 2012;30(8):1091–8.
33. Kim CK, Park BK, Park W, et al. Prostate MR imaging at 3T using a phased-arrayed coil in predicting locally recurrent prostate cancer after radiation therapy: preliminary experience. Abdom Imaging. 2010;35(2):246–52.
34. Rouviere O, Vitry T, Lyonnet D. Imaging of prostate cancer local recurrences: why and how? Eur Radiol. 2010;20(5):1254–66.
35. Skowronek J. Low-dose-rate or high-dose-rate brachytherapy in treatment of prostate cancer - be-tween options. J Contemp Brachyther. 2013;5(1):33–41.
36. Lindner U, Weersink RA, Haider MA, et al. Image guided photothermal focal therapy for localized prostate cancer: phase I trial. J Urol. 2009;182(4):1371–7.
37. Truesdale MD, Cheetham PJ, Hruby GW, et al. An evaluation of patient selection criteria on predicting progression-free survival after primary focal unilateral nerve-sparing cryoablation for prostate cancer: recommendations for follow up. Cancer J. 2010;16(5):544–9.
38. Rouvière O, Girouin N, Glas L, et al. Prostate cancer transrectal HIFU ablation: detection of local recurrences using T2-weighted and dynamic contrast-enhanced MRI. Eur Radiol. 2010;20(1):48–55.
39. Sharifi N, Gulley JL, Dahut WL. Androgen deprivation therapy for prostate cancer. JAMA. 2005;294(2):238–44.
40. Hussain M, Tangen C, Higano C, et al. absolute prostate-specific antigen value after androgen deprivation is a strong independent predictor of survival in new metastatic prostate cancer: data from Southwest Oncology Group Trial 9346 (INT-0162). J Clin Oncol. 2006;24(24):3984–90.
41. Stewart A, Scher H, Chen M, et al. Prostate-specific antigen nadir and cancer-specific mortality following hormonal therapy for prostate-specific antigen failure. J Clin Oncol. 2005;23(27):6556–60.

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.