Magnetic Resonance Imaging of the Prostate, Including Pre- and Postinterventions

Pritesh Patel, MD¹ Aytekin Oto, MD¹

¹Department of Radiology, University of Chicago, Chicago, Illinois

Semin Intervent Radiol 2016;33:186–195

Address for correspondence Pritesh Patel, MD, Department of Radiology, University of Chicago, 5841 S. Maryland Avenue, Room P220, MC 2026, Chicago, IL 60637
(e-mail: ppatel@radiology.bsd.uchicago.edu).

Abstract

Keywords

- prostate cancer
- prostate MRI
- focal therapy
- laser ablation
- high-intensity focused ultrasound

This article systematically reviews the rationale for magnetic resonance imaging in prostate cancer, in detection and following various treatment methods. A basic discussion of the identification of prostate cancer is imperative to understand post-intervention imaging. Each available therapy, including surgery, radiation, hormone therapy, and focal therapies will be discussed along with associated imaging findings, providing the reader with a better understanding of current interventions in prostate cancer and imaging.

Objectives: Upon completion of this article, the reader will be able to describe a basic understanding of the identification of prostate cancer, and the variety of therapies available in the treatment of prostate cancer, including their MRI imaging findings.

Accreditation: This activity has been planned and implemented in accordance with the Essential Areas and Policies of the Accreditation Council for Continuing Medical Education (ACCME) through the joint providership of Tufts University School of Medicine (TUSM) and Thieme Medical Publishers, New York. TUSM is accredited by the ACCME to provide continuing medical education for physicians.

Credit: Tufts University School of Medicine designates this journal-based CME activity for a maximum of **1 AMA PRA Category 1 Credit™**. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Rationale

Prostate magnetic resonance imaging (MRI) is increasingly being utilized for several indications in the management of prostate cancer, including follow-up and detection of recurrence after therapy. Increasing coverage in the media and patient as well as referring physician knowledge of the various approaches to both detection and therapy are playing an important role in rapid growth.

As most prostate cancer grows slowly, men who have other serious conditions or are older may not undergo treatment, and instead are placed in active surveillance, in which some combination of prostate-specific antigen (PSA), ultrasound and MR-guided or MR/ultrasound-fused biopsies, and MRI is performed until there is a change in the cancer behavior as evidenced by biopsy results, rising PSA, or worsening imaging findings.

However, those with evidence of cancer needing intervention, or those who are not comfortable with active surveillance, have an increasing number of nonsurgical options available to them.

Unfortunately, only 30% of initial biopsies are positive and biopsy-based Gleason scores are not reliable. Furthermore, at an approximate cost of 2 billion USD/year for 1.2 million prostate biopsies, there is no significant improvement in mortality, and complications of therapy and diagnosis are concerning. This uncertainty ultimately led the U.S. Preventive Task Force (USPTF) in 2012 to recommend against PSA screening,¹ leaving a need for a new diagnostic algorithm, for which MRI can play a significant role in both diagnosis and management.

MR Imaging Protocol

Conventional prostate MRI includes imaging on 1.5 or 3T MRI scanners using a gadolinium-enhanced contrast agent

with or without endorectal coils. Although the utility of endorectal coils is debated at 3T imaging, at 1.5T, the use of an endorectal coil in combination with an external phased array coil is considered to be the best method to evaluate the prostate.²

Multiparametric imaging including T1 pre- and post-dynamic contrast-enhanced MR (DCE-MR), high-resolution T2, and diffusion-weighted imaging (DWI), including high b value images ($>1,000$ second/mm²) and apparent diffusion coefficient (ADC) maps, should be routinely obtained. Multiplanar acquisitions, including sagittal and coronal T2-weighted images, are the backbones of multiparametric prostate MRI. Yacoub and colleagues¹ eloquently discuss each parameter technique and image acquisition in more detail.

MRI Detection of Cancer

The detection of cancer on MRI is extensively discussed in the literature, and is not the primary focus of this article. In general, most cancers are within the peripheral zone (70%) and appear as a reasonably well-defined focal T2 hypointensity with associated low ADC signal. These lesions are bright on high b value DWI and typically demonstrate early enhancement on DCE-MR (**Fig. 1**). Additionally, special attention should be paid to determine extracapsular extension, neurovascular bundle invasion, and seminal vesicle involvement of tumor.

However, increasing studies are showing the importance of transitional zone tumors. Kitzing et al³ describe them as having homogenous low signal intensity (erased

Fig. 1 Appearance of typical prostate cancer in the peripheral zone. Axial T2 image shows a left apical peripheral zone low T2 lesion (arrow) (a) with contrast enhancement on DCE (b) and low ADC signal (c).

charcoal sign), ill-defined margins, lack of capsule, and a lenticular shape with or without invasion of the anterior fibromuscular stroma. To contrast, stromal hyperplasia is typically more well defined and encapsulated.⁴

Several pitfalls in interpretation are present, detailed by Rosenkrantz and Taneja,⁵ and include mistaking the central zone, thickening of the surgical capsule, periprostatic venous plexus, neurovascular bundle, postbiopsy hemorrhage, stromal benign prostatic hyperplasia (BPH) nodules, prostatitis and postinflammatory scars, and atrophy for cancer. Additional challenges include anatomic distortion and lack of suppression of benign prostate tissue on high b value imaging and suboptimal windowing of the ADC map. Some of these pitfalls are further supported by Kitzing et al,³ who also add the anterior fibromuscular stroma and calcium as important cancer mimics on MRI.

More recently, computer extracted features (image analysis algorithms that extract subvisual image features that are not readily apparent to the human eye such as texture analysis) show the ability to improve discrimination of

benign disease classes from prostate cancer, and furthermore distinguish between cancer grades.⁶

Intervention and Postintervention Imaging

Surgery

The current mainstay of surgical therapy, *radical prostatectomy*, is typically performed when the cancer has not spread outside the gland (stage T1 or T2) cancers, and is performed via open, laparoscopic, and robot-assisted approaches. Partial prostatectomy is less commonly performed.

Posttreatment Imaging

Vargas and colleagues⁷ discuss postsurgical findings, starting with a descent of the bladder and levator sling into the prostatic bed (→Fig. 2). Retained seminal vesicles may be present (20%), which may be of variable signal intensity depending on the degree of postsurgical fibrosis. If lymphadenectomy is performed, lymphoceles may be present as low T1, high T2 signal, thin-walled cystic lesions. Other

Fig. 2 Normal postresection appearance showing the bladder and levator sling descending to occupy the space created by the absent prostate in T2W coronal (a) and sagittal (b) images. (c) Variable signal is often seen at the vesicourethral anastomosis (arrow). (d) Approximately 20% of patients have residual seminal vesicles (arrows).

postoperative collections including hematoma, abscess, or urinoma may also be present.

The most common site of local recurrence (→ **Fig. 3**) is the vesicourethral anastomosis around the urinary bladder and/or membranous urethra, manifesting typically as an enhancing soft-tissue nodule that is isointense to muscle on T1WI and slightly hyperintense to muscle on T2WI.⁷ Other common sites of local recurrence include between the bladder and rectum, within retained seminal vesicles, or at the anterior or lateral surgical margins. Normal postoperative fibrosis is low signal intensity on all sequences and has little to no enhancement in the venous phase. Another pitfall is residual prostatic tissue which may account for PSA elevation. DCE-MRI images and T2-weighted images are the most helpful sequences in the detection of recurrence following prostatectomy.⁸

Radiation

Radiation therapy (RT) can be used in localized (T1–T2) or locally advanced prostate cancer (T3–T4). In locally advanced prostate cancer, RT combined with androgen deprivation therapy (ADT) or surgical resection combined with adjuvant RT is available depending on severity of the local extension.⁹

Two main types of RT include external beam radiation therapy (EBRT) and brachytherapy (internal).

EBRT can be performed in several ways. Most modern methods used advanced computer-based planning systems to deliver photons or protons, thus allowing highly targeted radiation with reduced dose to normal tissue. The use of ultrasound-guided fiducial marker placement to guide RT is one example of this.

Brachytherapy is typically low dose or high dose, with the former more commonly utilized. In low-dose therapy, tiny titanium seeds containing radiation are inserted near or in the tumor via ultrasound guidance. During the procedure, with the help of CT and computer software, the appropriate seeds are selected to deliver precise radiation dose. Similar technology is implemented in high-dose brachytherapy, in which ultra-high bursts of radiation are delivered via radioactive pellets.

To help combat intraprostatic recurrence, a higher dose delivery to the dominant tumor (dose painting) can occur with modern EBRT or brachytherapy.

Pretreatment Imaging

Well discussed by Boonsirikamchai et al,⁹ the main importance of MR lies in the detection of extraprostatic extension (EPE) and seminal vesicle invasion (SVI). Patients with EPE or SVI (T3) are not eligible for brachytherapy or proton therapy alone, and supplemental EBRT may be required. To help with planning, the pretreatment assessment should include the three dimensions of the prostate; the location of the dominant tumor; the presence of EPE, SVI, rectal, or bladder wall involvement; extent of nodal and bone metastases, and evidence of transurethral resection of the prostate.

In EBRT, although CT is frequently used in RT planning, MRI is superior to CT in anatomic delineation, particularly the genitourinary diaphragm–prostate interface at the apex and the bladder–prostate interface at the base. On MR, the diaphragm is seen as a flat plate of fibromuscular tissue suspended between

Fig. 3 Recurrence of prostate cancer after surgical resection. Axial T2 (a) image shows a large lobulated T2 gray mass (arrow). Postcontrast T1 (b) shows heterogeneous enhancement (arrow). ADC (c) image shows low signal of the mass (arrow).

the inferior pubic rami just below the symphysis pubis. Also of interest is Denonvilliers fascia, which attaches to the peritoneal lining above and diaphragm below, restricting extension of prostatic cancer into the rectum. The apex, which has more than 30% of prostate cancers, is often under-irradiated to prevent undue radiation to the penile bulb (impotence), leading to high risk of treatment failure. MR also allows better approximation of visible gross tumor volume for delivery of escalated radiation

doses. Thus, while it may be optimal to use CT-MR coregistration imaging, a major limitation is the lack of endorectal coil use in CT, which makes fusion images problematic given the distortion with use of the coil—use of 3T without an endorectal coil may help mitigate this.

In brachytherapy, use of MRI in the planning process may facilitate more accurate placement of seeds—radiation seeds in the urinary bladder, rectal wall, urethra, corpus spongiosum, or cavernosa penis should be reported to the radiation oncologist.⁹

Posttreatment Imaging

Local recurrence after radical prostatectomy is amenable to salvage RT. According to the Phoenix Criteria¹⁰, an increase in PSA of 2 ng/mL or more above the nadir (usually in 2–4 years) suggests recurrence.

RT typically decreases prostate size and diffusely decreases T2 signal intensity due to glandular loss and fibrosis (►Fig. 4). Thus, recurrence can be difficult to detect on T2 images, and use of an ADC map (low signal) and DCE-MR (rapid early enhancement and washout) to aid in detection is often necessary, but variably helpful. Typically, the prostatectomy bed has minimal scar tissue or none at all. Recurrent disease (►Fig. 5) is most often seen at the site of prior tumor.

Hormone Therapy

Androgens, or male sex hormones, are necessary for prostate cancer to grow by activating androgen receptors (ARs) on both normal and cancerous prostate cells. In early development, cancers need a relatively high volume of androgens to grow. Castration (the testicles are considered to be the main producer of androgens) is accomplished either surgically or chemically via systemic delivery of antiandrogens, commonly known as ADT.

ADT is generally accepted to cause a reduction in the amount of PSA, which consequently induces a notable decrease in the circulating tumor cell count. Resistance to both castration methods is relatively common after some time, and the disease progresses to a more detrimental form, castration-resistant prostate cancer. Furthermore, despite castration, AR signaling continues to play a large role in the development and progression of prostate cancer.¹¹

Currently, ADT is typically used to treat metastatic prostate cancer, as an adjuvant with radiotherapy in locally advanced prostate cancer when the patient is not a candidate for radical local treatment, and in rising PSA levels after local treatment.

Posttreatment Imaging

Therapeutic response is based on PSA, testosterone, and a screening test for metabolic syndrome. However, disease progression occurs after ADT in approximately 20% of patients with PSA levels of less than 4.0 ng/mL, and it is unclear whether PSA is a valid surrogate for survival in hormonally treated prostate cancer. Furthermore, no reliable PSA parameter can conclusively distinguish between local and distant tumor recurrence,¹² although PSA doubling time can occasionally be useful as described previously.

Fig. 4 Normal appearance after radiation therapy. The entire prostate gland and seminal vesicle show decreased size and signal on T2 images (a). There is a loss of differentiation between the peripheral (PZ) and transitional zone (TZ) seen with both EBRT (b) and internal (c) brachytherapy radiotherapy. Additionally, there is decreased ADC signal of the benign PZ and TZ. Changes can also be seen in the bowel, bladder, muscles, and bones. Note that radiation seeds do not cause artifacts on MRI.

Therefore, MRI can be useful in monitoring for recurrence, which typically presents in a similar fashion as with RT (best

Fig. 5 Recurrence after RT. Axial T2W image shows nodular low T2 signal in the peripheral zone (arrow, a). This same area is low on ADC images (arrow, b), demonstrates contrast enhancement on DCE images (arrow, c) and color-encoded contrast-enhanced images (arrow, d). MR-guided biopsy confirmed recurrence in this case.

seen on DCE-MR images), but without RT-induced changes in adjacent anatomy (► **Fig. 6**).

DWI may also detect and localize prostate cancer before ADT and can supply qualitative or quantitative information for measuring therapeutic response in prostate cancer patients during and after ADT.

Higher ADC values result in more water mobility via decreased cellularity, and lower ADC values indicate less water mobility. The former can be seen with fibrosis, edema, or tumor progression. Previous studies demonstrated that ADC values before ADT were significantly lower in prostate tumors than in benign prostate tissue. Kim et al¹² show that ADC values of prostate tumors increased significantly after ADT and ADC values decrease significantly in normal-appearing PZ and TZ after ADT (likely secondary to histopathologic changes including glandular atrophy, fibrosis, and stromal hypercellularity among others). Although the data are not yet conclusive, DWI may be useful as a noninvasive tool for monitoring therapeutic response to ADT, and possibly radiotherapy as well.¹³

Focal Therapy

High-Intensity Focused Ultrasonic Ablation

Endorectal HIFU generates a cavitation effect causing coagulation necrosis in the targeted tissue, and is a good alternative in the management of well and moderately differentiated localized prostate cancer and of local recurrence after EBRT.¹⁴ Some limitations include ablating a large prostate gland and treatment of anterior tumors.

Posttreatment Imaging

Immediately after HIFU, there is complete loss of prostatic zonal anatomy, resulting in an inability to differentiate central gland from peripheral zone. Prostate tissue can have diffuse or multifocal low T2 signal, thus making differentiation between benign and malignant tissues difficult. Additionally, there may be mottling of the periprostatic fat, extraprostatic necrosis, and patchy hemorrhage. Kirkham et al showed a series of expected changes based on time after HIFU.¹⁵

Fig. 6 Normal post-hormonal (ADT) treatment appearance. Series of images show similar changes as seen after radiotherapy, but changes are confined to the prostate. Loss of zonal differentiation is again noted (arrow) (a) with no significant change in ADC in the actual cancer (arrow) (b) and decreased ADC signal in normal prostatic tissue (c).

At 1 to 3 months, there was a “double rim” sign in which there is thin curvilinear enhancement along either side of the T2 hypointense prostate gland capsule.

At 6 months, the prostatic volume is decreased by more than 45%, with the majority of the persisting prostate of low

T2 signal intensity (although areas at the apex and posteriorly may have high/intermediate signal), poor definition of the capsule, and persistent heterogeneity of the periprostatic fat. No significant enhancing tissue should be present.

At all times, there may be residual enhancing prostatic tissue, and it is usually found at the periphery near the apex and the rectum. The initial ablation zone itself is typically an unenhanced hypointense, zone surrounded by a subcentimeter peripheral thick rim of enhancement, appearing within 1 month after HIFU and disappearing within 3 to 5 months.¹⁶

Most patients with residual cancer showed early evidence of incomplete ablation—large volume of enhancing prostate initially—and later, large volume of high T2 signal at 6 months.

Recurrence has a similar appearance as described previously, T2 hypointense with rapid early enhancement and washout on DCE-MR. In a study by Kim et al,¹⁴ MRI was performed on patients who had consecutively increasing PSA levels or a marked PSA increase after HIFU without ADT. The study concluded that DCE-MRI proved more sensitive than T2W MRI with DWI, and T2W MRI with DWI was more specific than DCE-MRI in the detection of local recurrence.

Photodynamic Therapy

Photodynamic therapy (PDT) involves the exposure of target tissue to light after administration of a photosensitizing agent. This stimulates the production of reactive oxygen species, resulting in cell death. Haider et al¹⁷ extensively discuss one of the more popular PDT agents in prostate cancer therapy, palladium-bacteriopheophorbide (Tookad, Steba Biotech, Luxembourg), of which the main mechanism of necrosis seems to be rapid induction of vascular occlusion.

PDT is typically performed as a salvage therapy for local recurrent disease after EBRT.

Posttreatment Imaging

Given the mechanism of action, well-defined zones of necrosis (nonenhancement) surrounding the intraprostatic light fibers is expected. However, postintervention DCE-MRI shows a more irregular boundary of necrosis with occasional projections of enhancing viable tissue extending close to the light fibers and also between nonenhancing necrotic regions. T2 images are not particularly helpful, which is somewhat unusual given the expected increase in T2 signal in tissue necrosis, edema, and free water after intervention. This was likely secondary to the presence of coagulative and hemorrhagic necrosis, which was further supported by increased signal on T1WI. Most necrosis occurs 1 week after PDT on imaging, and is likely the optimal time to evaluate treatment response.

As with most ablative therapies, injury to the anterior rectum was occasionally observed, and should be monitored for. Additional areas of interrogation on MRI interpretation should also include the periurethral tissue and neurovascular bundle—although possibly related to variation in blood flow, the bundle was typically spared of injury, preventing impotence. Some cases in the study by Haider et al¹⁷ also showed pubic bone marrow changes of infarction, most evident at 6-month MRI.

Cryoablation

Although current tissue target temperature is -40°C , prostate cell death usually occurs closer to -20°C . As the temperature lowers, initially an osmotic gradient causes intracellular water to flow into the extracellular environment which is followed by cell damage, thrombosis, and tissue ischemia and hypoxia at increasingly lower temperatures. By -40°C , intracellular ice formation and expansion result in a disruption of remaining viable structures. Optimal positioning of the cryoprobe and the freeze zone are important, but there is no consensus on the proper amount of tissue to ablate. Levy et al¹⁸ believe at least one-fourth of the prostate in the transverse plane should be ablated at minimum, but most commonly perform a hemiablation, with attention to spare the neurovascular bundle, as new-onset erectile dysfunction was seen in up to 67% of patients with whole gland cryoablation. Other less common complications included urinary incontinence, rectourethral fistulas ($<1\%$), and urinary retention.

Cryoablation is more typically used for primary tumor ablation, but has also been used as salvage therapy in recurrence after RT.

Posttreatment Imaging

Similar to PDT and HIFU, MRI is typically performed shortly after ablative therapy (within 1 week), with DCE-MR images most useful (→Fig. 7). A region of nonenhancement corresponding with the targeted treatment area is typically demarcated by an enhancing peripheral rim of prostatic parenchyma and may contain foci of enhancing tissue internally.¹⁹ Long-term surveillance is still necessary, as some cases have shown tumor on biopsy 6 months after ablation despite nonenhancement on early MRI. Similarly, attention to the urethral wall, neurovascular bundle, rectal wall, and pelvic bone marrow should be given, and although initial posttreatment scans may seem worrisome for nonenhancement (necrosis), a partial or complete return of enhancement typically occurs on follow-up MRI. At 6 months, findings are similar to PDT described earlier.

Laser Ablation

MR-guided focal laser ablation (FLA) uses a directed laser beam under MRI guidance to thermally destroy prostatic tissue. Lindner and Trachtenberg²⁰ describe the process and principles in great detail. Depending on the laser fiber used, temperatures can range from 45°C to more than 300°C , causing various changes at the cellular level. Irreversible cell death can occur at 42°C , but with longer durations. At higher temperatures, variable light absorption results in unpredictable ablation volumes, and heating above 100°C is not suggested. Typically, there is a buffer in between the laser fiber and tissue, but with the prostate, interstitial fibers (no buffer and direct contact with tissue) are used, usually with water cooling to help prevent overheating complications. Furthermore, with the advent of MR thermometry, real-time monitoring can occur, allowing temperature/heat adjustment during the procedure.

While other focal therapies aim to eliminate cancer by regional ablation, FLA has a more focused and predictable

Fig. 7 Normal appearance post-cryotherapy. Axial T2 (a) shows very low signal corresponding to a left apical cryotherapy zone with associated distortion and extension into the adjacent pelvic structures (arrow). DCE image (b) shows no enhancement (arrow). Axial T2 image at a more superior (mid-prostate) gland (c) shows the asymmetry in both peripheral zones (arrow) and a small amount of fluid in between the PZ and TZ.

approach, aiming to destroy just the cancer and minimal surrounding tissue. First used to ablate BPH, the shift focused to use in prostate cancer with the advent of multiparametric MR and its ability to better localize lesions. Its use in treatment is still debatable, but has a wide potential of uses from first-line therapy in low-risk prostate cancer to salvage therapy.

Posttreatment Imaging

Similar to cryoablation and other focal therapies, initial early DCE-MR reveals a nonenhancing focal defect in the ablated zone, but as mentioned previously, the zone itself is much smaller and more targeted (→**Fig. 8**). Six months after ablation, there is usually near-complete resolution of the lesion with mild associated architectural distortion/scarring. Recurrence would manifest similarly as well, with enhancing tissue in the ablation zone.

Electroporation

Irreversible electroporation (IRE) is focal treatment of prostate cancer via electric pulses that travel between two electrodes, increasing the permeability of cell membranes. This can be

reversible (allowing a higher dose of chemotherapeutic agents to enter the cell) or irreversible when above a certain threshold of kV/cm.²¹ Like laser ablation, one of the major benefits of electroporation as compared with other focal therapies is the limited collateral damage to surrounding tissues.

Patients are placed in extended lithotomy positions, and transperineally inserted electrodes are placed using a brachytherapy grid under ultrasound guidance. Electric pulses are then delivered between each of the electrode pairs, resulting in ablation.

Posttreatment Imaging

In a study by van den Bos et al,²² posttreatment MRI was obtained 4 weeks after IRE treatment. On T1WI, similar to

Fig. 8 Normal appearance post-laser ablation. Axial T2 (a) and coronal T2 (b) images show mild distortion and focal low signal after ablation of a right mid prostate cancer (arrows). Postcontrast (c) and ADC (d) images show no early enhancement, and minimal low signal, respectively (arrows).

other ablative procedures, IRE effects were areas of non-enhancement on DCE-MR. On T2WI, the ablation zones had heterogeneous signal intensity, hypointense margins suggestive of fibrosis, or intralesional increased T2 signal because of edema. Some patients also had focal T1 hemorrhage on precontrast images.

Conclusion

With the increasing number of men who are diagnosed with low-risk localized prostate cancer, focal therapies are primed to make a significant impact on management and the development of new treatment algorithms. MRI has an integral role in the pretreatment assessment, actual ablative procedure, and postprocedural monitoring.

Already an integral part of conventional therapies such as RT and radical prostatectomy, multiparametric MRI will continue to become more refined as research in this topic continues, aiding in diagnosis and treatment of prostate cancer. An understanding of the MR appearance of prostate cancer and the available therapies (including related imaging) is key to effective imaging interpretation.

Disclosure

Dr. Aytekin Oto receives research grants from Philips Healthcare, Profound Healthcare, and Guerbert LLC. He is on the medical advisory board for Profound Healthcare.

References

- Moyer VA; U.S. Preventive Services Task Force. Screening for prostate cancer: U.S. Preventive Services Task Force recommendation statement. *Ann Intern Med* 2012;157(2):120–134
- Yacoub JH, Oto A, Miller FH. MR imaging of the prostate. *Radiol Clin North Am* 2014;52(4):811–837
- Kitzing YX, Prando A, Varol C, Karcmar GS, Maclean F, Oto A. Benign conditions that mimic prostate carcinoma: MR imaging features with histopathologic correlation. *Radiographics* 2016;36(1):162–175
- Oto A, Kayhan A, Jiang Y, et al. Prostate cancer: differentiation of central gland cancer from benign prostatic hyperplasia by using diffusion-weighted and dynamic contrast-enhanced MR imaging. *Radiology* 2010;257(3):715–723
- Rosenkrantz AB, Taneja SS. Radiologist, be aware: ten pitfalls that confound the interpretation of multiparametric prostate MRI. *AJR Am J Roentgenol* 2014;202(1):109–120
- Litjens GJ, Elliott R, Shih NN, et al. Computer-extracted features can distinguish noncancerous confounding disease from prostatic adenocarcinoma at multiparametric MR imaging. *Radiology* 2016;278(1):135–145
- Vargas HA, Wassberg C, Akin O, Hricak H. MR imaging of treated prostate cancer. *Radiology* 2012;262(1):26–42
- Rischke HC, Schäfer 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
- Boonsirikamchai P, Choi S, Frank SJ, et al. MR imaging of prostate cancer in radiation oncology: what radiologists need to know. *Radiographics* 2013;33(3):741–761
- Roach M III, Hanks G, Thames H Jr, 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):965–974
- Ahmed A, Ali S, Sarkar FH. Advances in androgen receptor targeted therapy for prostate cancer. *J Cell Physiol* 2014;229(3):271–276
- Kim AY, Kim CK, Park SY, Park BK. Diffusion-weighted imaging to evaluate for changes from androgen deprivation therapy in prostate cancer. *AJR Am J Roentgenol* 2014;203(6):W645–50
- Song I, Kim CK, Park BK, Park W. Assessment of response to radiotherapy for prostate cancer: value of diffusion-weighted MRI at 3 T. *AJR Am J Roentgenol* 2010;194(6):W477–82
- Kim CK, Park BK, Lee HM, Kim SS, Kim E. MRI techniques for prediction of local tumor progression after high-intensity focused ultrasonic ablation of prostate cancer. *AJR Am J Roentgenol* 2008;190(5):1180–1186
- Kirkham AP, Emberton M, Hoh IM, Illing RO, Freeman AA, Allen C. MR imaging of prostate after treatment with high-intensity focused ultrasound. *Radiology* 2008;246(3):833–844
- Rouvière O, Lyonnet D, Raudrant A, et al. MRI appearance of prostate following transrectal HIFU ablation of localized cancer. *Eur Urol* 2001;40(3):265–274
- Haider MA, Davidson SR, Kale AV, et al. Prostate gland: MR imaging appearance after vascular targeted photodynamic therapy with palladium-bacteriopheophorbide. *Radiology* 2007;244(1):196–204
- Levy DA. Cryoablation. In: Polascik TJ, ed. *Imaging and Focal Therapy of Early Prostate Cancer*. New York: Springer; 2013:345–353
- Rosenkrantz AB, Scionti SM, Mendrinis S, Taneja SS. Role of MRI in minimally invasive focal ablative therapy for prostate cancer. *AJR Am J Roentgenol* 2011;197(1):W90–96
- Lindner U, Trachtenberg J. MRI-guided laser ablation for localized prostate cancer. In: Polascik TJ, ed. *Imaging and Focal Therapy of Early Prostate Cancer*. New York: Springer; 2013:297–307
- van den Bos W, de Bruin DM, Muller BG, et al. The safety and efficacy of irreversible electroporation for the ablation of prostate cancer: a multicentre prospective human in vivo pilot study protocol. *BMJ Open* 2014;4(10):e006382
- van den Bos W, de Bruin DM, van Randen A, et al. MRI and contrast-enhanced ultrasound imaging for evaluation of focal irreversible electroporation treatment: results from a phase I-II study in patients undergoing IRE followed by radical prostatectomy. *Eur Radiol* 2015