



MRI-Guided Interventions for the Treatment of Prostate Cancer

Joyce G. R. Bomers¹
J. P. Michiel Sedelaar²
Jelle O. Barentsz¹
Jurgen J. Fütterer¹

OBJECTIVE. The purpose of this article is to evaluate MRI-guided therapies and to investigate their feasibility for focal therapy in prostate cancer patients. Relevant articles were retrieved using the PubMed online search engine.

CONCLUSION. Currently, MRI-guided laser ablation and MRI-guided focused ultrasound are the most promising options for focal treatment of the prostate in patients with prostate cancer. Other techniques—that is, cryosurgery, microwave ablation, and radiofrequency ablation—are, for several and different reasons, less suitable for MRI-guided focal therapy of the prostate.

Prostate cancer is the most frequently diagnosed cancer, accounting for 28% (218,000) of the total number of new cancer cases [1].

Prostate cancer is the second major cause of cancer death in men, responsible for 11% (32,000) of the total number of cancer deaths in men in the United States in 2010 [1]. Because of the widespread use of the prostate-specific antigen (PSA) test and the lowered PSA threshold for biopsy, the number of newly diagnosed prostate cancers has strongly increased [2]. At present, radical treatment—that is, radical prostatectomy or any form of radiotherapy—is not necessary to treat low-grade prostate cancer (Gleason score ≤ 6). Consensus exists that radical treatment is essential to treat aggressive prostate cancer (Gleason score > 6) [3]. However, whole-gland treatment can lead to significant complications, such as incontinence (20% for radical prostatectomy and 5% for radiotherapy) and impotence (64% for radical prostatectomy and 66% for radiotherapy), and can have a substantial impact on quality of life [4].

Consequently, promising techniques such as cryosurgery, high-intensity focused ultrasound, and laser-induced thermal therapy have emerged as feasible minimally invasive focal treatment options. Although most of these techniques are still considered experimental for focal treatment of prostate cancer and have not been approved by the American Urological Association or European Association of Urology and have not been incorporated in national guidelines, most have

been approved by the U.S. Food and Drug Administration, European Medicines Agency, or both. Over the past decade these techniques have been applied more and more in the treatment of prostate cancer [5–7]. Imaging guidance is imperative in all these types of treatment and is provided by transrectal ultrasound (3D), CT, or MRI. Of these imaging modalities, MRI—especially multiparametric MRI—is the most sensitive and specific imaging technique for prostate cancer [8].

Focal therapy of prostate cancer has the potential to reduce treatment-related complications such as incontinence and impotence without making concessions to cancer-specific outcome [9]. According to Meiers et al. [10], 13–33% of patients with prostate cancer have a unifocal prostate cancer lesion and would be eligible for focal therapy. Consistent with the “index lesion theory,” even more patients would be suitable [11].

In 2010, a consensus panel of urologic surgeons, radiation oncologists, radiologists, and histopathologists from Europe and North America defined focal therapy of the prostate as follows [12]:

A type of treatment that aims to eradicate known cancer within the prostate and at the same time preserve uninvolved prostatic tissue with the aim of preserving genitourinary function.

Despite this definition, different varieties of focal therapy are described in the literature: hemiablation (i.e., treatment of the tumor affected lateralized hemisphere of the prostate),

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¹Department of Radiology, Radboud University Nijmegen Medical Centre, Geert Grooteplein 10, 6525 GA, Nijmegen, Gld, The Netherlands. Address correspondence to J. G. R. Bomers (j.bomers@rad.umcn.nl).

²Department of Urology, Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands.

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hockey-stick ablation (i.e., hemiablation of the prostate plus one half of the contralateral hemisphere), and targeted focal therapy (i.e., only the tumor itself is treated).

On one hand, ample discussion exists about how to select the appropriate patient for focal therapy. However, on the other hand, there is almost no discussion about the optimal focal therapy method. The latter must meet numerous requirements: first, to be able to treat a specific area or one lobe of the prostate; second, to accurately shape the ablation zone with no significant effect on the surrounding tissue; third, to be minimally invasive with a low pre- and postoperative complication rate; and, fourth, to be reproducible.

Consequently, the purpose of this article is to evaluate MRI-guided therapies and to investigate their feasibility for focal therapy in prostate cancer patients.

Materials and Methods

A systematic literature search was performed. Relevant articles published before January 1, 2012, in English, German, or Dutch were retrieved using combinations of both medical subject headings and free search terms in the PubMed online search engine (U.S. National Library of Medicine). A combination of the following search terms was used: MRI, MRI-guided, prostate, ablation, radio-frequency, laser, cryosurgery, microwave, brachytherapy, (high-intensity) focused ultrasound, focal, and therapy. The references of retrieved relevant articles were checked for additional valuable articles. *Ex vivo*, *in vitro*, and phantom studies were excluded, as well as all studies published before 2000 because equipment and techniques have changed tremendously since that time.

All studies were scored: In each study, data about the study population, sample size, ablation technique, adverse events, and MRI methods were documented.

Results

Cryosurgery

In cryosurgery, tumor tissue is ablated by freezing. Cryosurgery was acknowledged as an established treatment option for men with newly diagnosed or recurrent organ-confined

prostate cancer by the American Urological Association in 2008 [13]. Cryosurgery is usually performed under transrectal ultrasound guidance with a transperineal approach; however, cryosurgery can also be performed under CT or MRI guidance [14, 15].

In prostate cryosurgery, the patient is placed in the lithotomy position. A template for needle positioning is placed against the perineum. The 17-gauge cryoneedles are, under imaging guidance, transperineally inserted into the prostate. Because of the Joule-Thompson effect, the argon gas within the needle cools to -186°C and causes the formation of ice at the tip of the probe and congelation of the surrounding tissue. The thawing process can be active (with helium gas) or passive [16]. Correct needle positioning is essential to freeze as much of the tumor as possible and to avoid damaging the surrounding tissues to prevent complications.

To date, only limited data about MRI-guided cryosurgery study of the prostate are available (Table 1). The first results were reported after two canine studies were performed using an open 0.5-T MR system [17, 18]: The two groups of investigators concluded that MRI-guided cryosurgery is technically feasible. However, van den Bosch et al. [18] concluded that the volume of the ice ball formation during cryosurgery of healthy canine prostates as imaged with T1 sequences did not match the volume of tissue necrosis induced by the low temperatures. They found that contrast-enhanced MRI is a more consistent method for the prediction of tissue damage after cryosurgery, with an accuracy rate of 91% (Pearson $r^2 = 0.97$).

Currently, the results of two patient studies have been reported: a study by Reisiger et al. [19] and a study by Tsoumakidou et al. (presented at the 2011 annual meeting of Cardiovascular and Interventional Radiological Society of Europe). Reisiger et al. treated 12 patients with prostate cancer recurrence after radical cryosurgery, in a 1.5-T wide-bore scanner. No direct complications were seen. However, within 3 months

of cryosurgery, local recurrence abutting the urethra was found in two patients. Another patient reported urine retention. Tsoumakidou et al. performed MRI-guided prostate cryosurgery in a wide-bore 1.5-T scanner in seven patients with newly diagnosed prostate cancer and in two patients with local recurrence. Besides some minor complications such as hematuria, dysuria, and urine retention, one major complication was reported: a rectal fistula that spontaneously healed 3 months after cryosurgery. An advantage of performing cryosurgery under MRI guidance instead of transrectal ultrasound guidance is the possibility to insert a rectal balloon with warm water to protect the rectal wall from freezing.

All the aforementioned advantages of MRI guidance, compared with other imaging modalities, do count for cryosurgery except the possibility of temperature mapping. Temperature mapping is unfortunately not possible for temperatures below 0°C with the currently available clinical MR temperature sequences. Although the temperature gradient within the ice ball is not measurable with MR temperature mapping, ice ball formation is visible on real-time MRI. Nevertheless, investigators have reported that the volume of the ice ball does not match the volume of tissue necrosis [18]. As a consequence, attention should be paid to the size and location of the lesion that needs to be ablated and a safety margin of a few millimeters should be applied. Another disadvantage is that the cryoneedles cause an image artifact that is more pronounced on a T1-weighted sequence than on a T2-weighted sequence.

Laser Ablation Treatment

Laser ablation, sometimes also referred to as laser-induced thermal therapy, is a relatively new technique that was originally developed to treat brain tumors [20]. During this therapy, a laser fiber is positioned in the tumor under imaging guidance (ultrasound or MRI). When the position of the fiber is correct, a laser light with a wavelength of 980 nm is delivered through the fiber and

TABLE 1: Literature Overview on MRI-Guided Cryosurgery of the Prostate

Authors	Year	Study Type	No. of Subjects	MR Field Strength and Configuration	Treatment Method
Reisiger et al. [19]	2011	Patient	12	1.5 T, wide bore	Transperineal
Tsoumakidou et al. ^a	2011	Patient	9	1.5 T, wide bore	Transperineal
Josan et al. [17]	2009	Canine	13	0.5 T, open bore	Percutaneous
van den Bosch et al. [18]	2009	Canine	6	0.5 T, open bore	Percutaneous

^aPresented at the 2011 annual meeting of the Cardiovascular and Interventional Radiological Society of Europe.

the temperature of the tissue around the tip of the fiber increases. When the temperature of the tissue reaches more than 60°C, the tissue is irreversibly damaged and destroyed. The total ablation process takes up to 3 minutes. The laser fiber is placed inside a cooling catheter throughout the ablation to prevent carbonization of the adjacent tissue and to increase laser light penetration depth.

Studies reporting on MRI-guided prostate laser ablation are scarce because it is a considerably new technique (Table 2). Stafford et al. [21] and Peters et al. [22] were the first to report on MRI-guided laser ablation in prostates, although both groups reported the results of animal studies. The most important conclusion was that the damage predicted with MR temperature mapping correlated with the damage seen on 3D T1-weighted contrast-enhanced images, with a slope near unity and excellent correlation ($r^2 = 0.94$) [21]. Complication rates were not reported because the animals were sacrificed immediately after the procedure.

Raz et al. [23] treated two patients with MRI-guided transperineal focal laser ablation at 1.5 T. Real-time MRI guidance was used during targeting of the tumor with the laser fiber and to control tissue temperature during the ablation. Patients were discharged 3 hours after treatment. No adverse events were found in the 1 month of follow-up. Woodrum et al. [24] described MRI-guided focal laser ablation at 3-T field strength; however, their study was a feasibility study performed using cadaveric prostates [24]. The same group also treated a patient with local recurrence of prostate cancer after a radical prostatectomy at 3-T field strength [25]. Early follow-up showed no posttreatment incontinence, rectal wall injury, or other complications [25]. In both studies, investigators concluded that MRI-guided laser ablation on a 3-T system is uniquely suited and is a promising technique for accurate focal targeting of prostate cancer because of the inherent high spatial and temporal resolution of MRI [24, 25].

One of the key features of laser ablation is that the fibers used during laser ablation cause no distortion of the electromagnetic field, so no image artifacts exist in the region of interest [26]. In addition, the treatment time is quite short and the ablation zone is sharply defined compared with other ablation techniques [21, 27].

Focused Ultrasound

Compared with the aforementioned techniques, focused ultrasound is the only real noninvasive ablation technique. A transducer directs a high-intensity ultrasound beam to converge and focus at a certain point in the tissue with this technique. The energy of the ultrasound waves is sufficient to heat up the tissue and to surpass the thermal dose threshold obligatory for coagulative necrosis in a few seconds. When the transducer consists of multiple piezoelectric elements, greater flexibility in targeting and shaping of the focal spot can be reached [28].

For prostate cancer, the transducer can be applied in various ways: transrectal [29, 30], which is the most applied method; transurethral [31, 32]; extracorporeal, with the transducer placed against the perineum [33]; and interstitial [34], with the transducer inserted transperineally, which is no longer noninvasive.

Experience in MRI-guided focused ultrasound has been gained in the treatment of uterine fibroids [35, 36]. Gradually the treatment area is now being extended to other organs and tissues such as breast, liver, and bone [37–39].

To date, only a few studies have been published about MRI-guided focused ultrasound of the prostate; however, most were performed using dogs (Table 3). McDannold et al. [30] performed the only study of focused ultrasound treatment under 3-T MRI guidance on four dogs using a transrectal probe. They concluded that MRI-guided focused ultrasound is feasible in the prostate. However, prostate movement was an important issue. Other results described

in these animal studies were the small transition zones of 0.4–2.0 mm present between ablated tissue and viable tissue [30, 32, 40].

Siddiqui et al. [32] treated five patients with clinically proven prostate cancer (PSA < 15 ng/mL, T1c or T2a, and Gleason score ≤ 7 [3 + 4]) using transurethral MRI-guided focused ultrasound immediately before radical prostatectomy. Approximately 30% of the prostate volume was ablated to examine the technical feasibility of the technique. The treatment was well tolerated by patients and no complications were seen during or after surgery [32]. Overlapping results of the same research group were reported by Chopra et al. [40].

A substantial limitation of MRI-guided focused ultrasound is the extensive ablation time (≈ 2 –2.5 hours, with incidental peaks to > 6 hours [41]), which makes this technique more suitable for focal therapy than for whole-gland therapy. Another disadvantage is that the focal spot loses its correct position in relation to the tumor if the patient moves or if there is any movement of the tumor within the body during treatment.

Besides thermal ablation, focused ultrasound has another promising clinical application: targeted drug delivery. The drug—for example, a chemotherapeutic agent—can be encapsulated and can be systematically administered to the body. The release of the drug can be locally activated by heat from or mechanical oscillation of the focused ultrasound waves [42].

Radiofrequency Ablation

During radiofrequency ablation (RFA), a needle electrode needs to be inserted into the tumor tissue. This electrode produces electromagnetic waves with a maximal frequency of 30 MHz. The waves cause friction within the tissue that raises the temperature and causes cell death [43].

Terraz et al. [44] performed MRI-guided RFA of 16 small liver malignancies in 10 patients. All patients were treated successfully,

TABLE 2: Literature Overview on MRI-Guided Laser Ablation of the Prostate

Authors	Year	Study Type	No. of Subjects	MR Field Strength and Configuration	Treatment Method
Woodrum et al. [25]	2011	Patient	1	3 T	Transperineal
Raz et al. [23]	2010	Patient	2	1.5 T	Transperineal
Woodrum et al. [24]	2010	Human cadaver	5	3 T	Transperineal
Stafford et al. [21]	2010	Canine	7	1.5 T	Laparotomy ^a , transperineal ^b
Peters et al. [22]	2000	Canine	2	1.5 T	Percutaneous

^aTwo dogs.

^bFive dogs.

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TABLE 3: Literature Overview on MRI-Guided Focused Ultrasound of the Prostate

Authors	Year	Study Type	No. of Subjects	MR Field Strength and Configuration	Treatment Method
Siddiqui et al. [32]	2010	Patient	5	1.5 T	Transurethral
Chopra et al. [40]	2010	Patient	8	1.5 T	Transurethral
Siddiqui et al. [32]	2010	Canine	17	1.5 T	Transurethral
Chopra et al. [40]	2010	Canine	25	1.5 T	Transurethral
McDannold et al. [30]	2009	Canine	4	3 T	Transrectal
Chen et al. [31]	2008	Canine	6	0.5 T, open bore	Transurethral ^a , interstitial ^b
Nau et al. [34]	2005	Canine	2	0.5 T, open bore	Interstitial

^aFour dogs.

^bTwo dogs.

and Terraz et al. concluded that MRI-guided RFA was technically feasible. They did not notice any influence of the radiofrequency signals (470 kHz) on the signal-to-noise ratio (SNR) [44]. To our knowledge, there are no reports about MRI-guided RFA for (focal) treatment of prostate cancer.

Obviously, clinical experience performing MRI-guided RFA of the prostate is still very limited, probably because of technical difficulties. The major drawbacks of MRI-guided RFA are possible interference with the radiofrequency pulses of the MR system and the large image artifact (up to eight times its original size) caused by the radiofrequency electrode. The latter makes temperature measurement at the vicinity of the electrode impossible [45].

Microwave Ablation

Microwave ablation is almost identical to RFA. Again, an applicator—in this setting, an “antenna”—is inserted into the lesion that needs to be ablated. Then, electromagnetic waves, with a frequency between 30 MHz and 30 GHz, are sent through the antenna and cause heating and finally destruction of the tissue [46]. A drawback of this technique is that the electromagnetic waves can interfere with the radiofrequency signals used for MRI, which can cause noise in the MR images.

Chen et al. [47] described in 2000 their first clinical results with microwave ablation using a frequency of 915 MHz under 1.5-T MRI guidance in five patients with local recurrence of prostate cancer. The microwave applicators were transperineally inserted under transrectal ultrasound guidance, and patients were then transferred to the MR room for MRI-guided microwave ablation. All patients were treated successfully, but 6 months after ablation, the PSA levels of two patients started rising again. The microwave applicators caused only little artifact on the MR images. However, when

the microwave power was turned on, a large increase of noise was seen. Consequently, the SNR and accuracy of MRI thermometry were influenced in a negative way.

Brachytherapy

Brachytherapy is a type of radiotherapy in which the radiation source is placed near or inside the treatment area. For the treatment of prostate cancer, brachytherapy can be used as permanent low-dose-rate (LDR) seed implantation or as temporary high-dose-rate (HDR) brachytherapy [48].

During LDR brachytherapy a large number of ¹²⁵I seeds are implanted in the prostate via transperineally inserted catheters. MRI-guided LDR brachytherapy has been performed by D’Amico et al. [49] and Van Gellekom et al. [50] (Table 4). The first group treated 43 patients in a 0.5-T open-bore MRI scanner. Several catheters were inserted under MRI guidance, and a median of 80 ¹²⁵I seeds (range, 43–120 seeds) were left in the prostate. One month after treatment, no sexual or gastrointestinal dysfunction was reported [49]. Van Gellekom et al. treated five patients in a conventional 1.5-T closed-bore scanner with a single-needle method. Only one needle was inserted through the perineum; it was repeatedly inserted at different angles in the prostate to implant the iodine seeds [50].

HDR brachytherapy of the prostate uses an ¹⁹²Ir source that is temporarily placed inside the treatment-requiring area via hollow closed-tip catheters that are inserted through the perineum [48]. Different groups have performed this therapy under MRI guidance [51–53]. Ares et al. [51] used HDR brachytherapy as an extra boost for only a partial volume of the prostate after external beam radiation therapy (EBRT) in 77 patients. In seven patients, only one lobe of the prostate was treated. Ares et al. reported that the long-

term toxicity has been limited and that biochemically disease-free survival rates were encouraging [51]. In all three studies, cancer localization and catheter insertion were performed under MRI guidance; thereafter, the patient was moved to a shielded room for radiation delivery [51–53]. The overall procedure time was between 4.5 and 9.5 hours [52, 53].

A key characteristic of brachytherapy is that the irradiation harms only a very small area around the radiation source and exposure of healthy tissues farther away from the sources is therefore reduced. Major drawbacks of brachytherapy are the long procedure time and use of radioactive materials. For this latter reason, extra precautionary measures need to be taken (e.g., rooms with extra shielding) when performing HDR brachytherapy.

Discussion

In modern medicine the drive is toward the development and improvement of treatments and techniques that minimize intervention to the patient and hospitalization. MRI-guided interventions provide a minimally invasive approach to cancer therapy that is gaining clinical acceptance. Of the available techniques, we consider MRI-guided focal laser ablation to be the most sophisticated focal therapy treatment option in the prostate. It appears to be fast and feasible because of the sharply defined ablation zone, no distortion of laser fibers, few anticipated low adverse events and complications, quick recovery of patients, and possibility to repeat the therapy as often as needed. Furthermore, it is easy to fit in clinical practice.

MRI-guided focused ultrasound alone or combined with local drug delivery is a promising technique for focal therapy in the prostate. It has the potential to surpass focal laser ablation as the most sophisticated technique because it is not invasive and is highly accurate given the small focal spot. However, to

TABLE 4: Literature Overview on MRI-Guided Brachytherapy of the Prostate

Authors	Year	Study Type	No. of Subjects	MR Field Strength and Configuration	Treatment Method
Permanent low-dose-rate seed implantation					
Van Gellekom et al. [50]	2004	Patient	5	1.5 T	Transperineal ^a
D'Amico et al. [49]	2000	Patient	43	0.5 T, open bore	Transperineal
Temporary high-dose-rate brachytherapy					
Ares et al. [51]	2009	Patient	77	0.23 T, open bore	Transperineal
Ménard et al. [52]	2004	Patient	5	1.5 T	Transperineal
Susil et al. [53]	2004	Patient	4	1.5 T	Transperineal

^aSingle needle.

achieve this, the relative long treatment time even for small lesions needs to be shortened and the first experiments of patients need to be performed.

HDR brachytherapy can be performed under MRI guidance to give a local boost to the tumor as a supplement to EBRT of the entire prostate. For both types of brachytherapy, MR images can be used to localize the tumor and to monitor the insertion of the catheter and seeds in real time. During the actual therapy, MRI has no surplus value because this cannot be seen on the MR images.

The other techniques—cryosurgery, microwave ablation, and RFA—are, for several and different reasons, less suitable to use for MRI-guided focal therapy of the prostate. According to the first results in patients and animals [17, 18, 30] and earlier results under ultrasound guidance [6, 54–58], MRI-guided cryosurgery of the prostate is feasible even for focal therapy. However, because of the indistinct ablation zone, a safety margin of a few millimeters should be applied. Furthermore, MRI-guided focal cryosurgery can be repeated, is minimally invasive, and has a relative low complication rate.

Microwave ablation and RFA work with electromagnetic waves that can possibly interfere with the radiofrequency signals of the MR system itself [45]. These signals are dependent of the field strength of the magnet, in the range of 0–128 MHz when using a 1.5- or 3-T magnet. This possible interference makes these treatments less suitable for focal therapy because the tissue temperature of the adjacent healthy structures needs to be monitored carefully.

In general, the benefits of performing an intervention under MRI guidance (i.e., the accuracy during needle placement or the possibility of temperature mapping during the procedure) should be considered carefully against the disadvantages. These disadvantages

include increased costs, difficult patient selection considering the multifocality of prostate cancer (this also accounts for transrectal ultrasound-guided procedures), limited amount of space during the procedure for the patient and physician, the need for special MR-compatible materials, and the limited time available in MRI scanners. Nevertheless, MR systems are increasingly being adjusted to allow interventional MRI. New systems with shorter and wider bores are being produced to provide more space for the patient and the physician as well.

Another way to overcome the accessibility problem and to speed up the procedure is to perform part of the procedure with the help of an MRI-compatible robot. Several robots for needle placement and LDR seed implantation have been described in the literature and the results of these studies are promising [59–62].

To date, the issue of how to select the appropriate patient for focal therapy has been discussed extensively. Several methods are used for prostate cancer diagnosis and staging: digital rectal examination, PSA test, and transrectal ultrasound-guided prostate biopsy. Nevertheless, these techniques are not accurate enough and fail to reveal a large fraction of clinically significant tumors [63]. Transrectal ultrasound-guided transperineal mapping or saturation biopsies were introduced to avoid missing clinically significant tumors. However, these biopsies have major disadvantages such as the need for anesthetics, patient discomfort, and intensive pathologic processing [64, 65]. Currently, MRI, especially multiparametric MRI, is the most sensitive and specific imaging technique for prostate cancer [8] and should certainly be used for proper patient selection for focal therapy.

The largest limitation of this review is the sparse amount of data. Unfortunately data published on this subject are limited and most of the studies have a small study group and a short follow-up.

Future steps will be to validate these new procedures in prospective clinical trials with more patients and longer follow-up periods and to compare them with active surveillance and radical therapies in randomized controlled trials.

Conclusion

MRI-guided focal therapy of the prostate seems possible with the present techniques; however, the one method is more feasible than another.

References

1. Jemal A, Siegel R, Xu J, Ward E. Cancer statistics, 2010. *CA Cancer J Clin* 2010; 60:277–300
2. Cooperberg MR, Broering JM, Kantoff PW, Carroll PR. Contemporary trends in low risk prostate cancer: risk assessment and treatment. *J Urol* 2007; 178:S14–S19
3. Heidenreich A, Bellmunt J, Bolla M, et al.; European Association of Urology. EAU guidelines on prostate cancer. Part 1. Screening, diagnosis, and treatment of clinically localised disease. *Eur Urol* 2011; 59:61–71
4. Sanda MG, Dunn RL, Michalski J, et al. Quality of life and satisfaction with outcome among prostate-cancer survivors. *N Engl J Med* 2008; 358:1250–1261
5. Lindner U, Weersink RA, Haider MA, et al. Image guided photothermal focal therapy for localized prostate cancer: phase I trial. *J Urol* 2009; 182:1371–1377
6. Onik G, Vaughan D, Lotenfoe R, Dineen M, Brady J. The “male lumpectomy”: focal therapy for prostate cancer using cryoablation results in 48 patients with at least 2-year follow-up. *Urol Oncol* 2008; 26:500–505
7. Crouzet S, Rebillard X, Chevallier D, et al. Multicentric oncologic outcomes of high-intensity focused ultrasound for localized prostate cancer in 803 patients. *Eur Urol* 2010; 58:559–566
8. Sciarra A, Barentsz J, Bjartell A, et al. Advances in magnetic resonance imaging: how they are changing the management of prostate cancer. *Eur*

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- Urol* 2011; 59:962–977
9. Eggener S, Salomon G, Scardino PT, De la Rosette J, Polascik TJ, Brewster S. Focal therapy for prostate cancer: possibilities and limitations. *Eur Urol* 2010; 58:57–64
10. Meiers I, Waters DJ, Bostwick DG. Preoperative prediction of multifocal prostate cancer and application of focal therapy: review 2007. *Urology* 2007; 70(suppl 6):3–8
11. Stamey TA, Freiha FS, McNeal JE, Redwine EA, Whittemore AS, Schmid HP. Localized prostate cancer: relationship of tumor volume to clinical significance for treatment of prostate cancer. *Cancer* 1993; 71:933–938
12. de la Rosette J, Ahmed H, Barentsz J, et al. Focal therapy in prostate cancer: report from a consensus panel. *J Endourol* 2010; 24:775–780
13. Finley DS, Pouliot F, Miller DC, Beldegrun AS. Primary and salvage cryotherapy for prostate cancer. *Urol Clin North Am* 2010; 37:67–82
14. Atwell TD, Farrell MA, Callstrom MR, et al. Percutaneous cryoablation of large renal masses: technical feasibility and short-term outcome. *AJR* 2007; 188:1195–1200
15. Li C, Wu L, Song J, Liu M, Lv Y, Sequeiros RB. MR imaging-guided cryoablation of metastatic brain tumours: initial experience in six patients. *Eur Radiol* 2010; 20:404–409
16. Mogami T, Harada J, Kishimoto K, Sumida S. Percutaneous MR-guided cryoablation for malignancies, with a focus on renal cell carcinoma. *Int J Clin Oncol* 2007; 12:79–84
17. Josan S, Bouley DM, van den Bosch M, Daniel BL, Butts Pauly K. MRI-guided cryoablation: in vivo assessment of focal canine prostate cryoleSIONS. *J Magn Reson Imaging* 2009; 30:169–176
18. van den Bosch MA, Josan S, Bouley DM, et al. MR imaging-guided percutaneous cryoablation of the prostate in an animal model: in vivo imaging of cryoablation-induced tissue necrosis with immediate histopathologic correlation. *J Vasc Interv Radiol* 2009; 20:252–258
19. Radiological Society of North America Website. Reisiger KE, Mynderse LA, Woodrum DA. MR-guided cryoablation of prostate adenocarcinoma recurrence: the Mayo Clinic experience (abstr). http://rsna2011.rsna.org/pregen_pdfs/Subspecialty/10Genitourinary%20Radiology.pdf. Accessed June 12, 2012
20. Kangasniemi M, McNichols RJ, Bankson JA, Gowda A, Price RE, Hazle JD. Thermal therapy of canine cerebral tumors using a 980 nm diode laser with MR temperature-sensitive imaging feedback. *Lasers Surg Med* 2004; 35:41–50
21. Stafford RJ, Shetty A, Elliott AM, et al. Magnetic resonance guided, focal laser induced interstitial thermal therapy in a canine prostate model. *J Urol* 2010; 184:1514–1520
22. Peters RD, Chan E, Trachtenberg J, et al. Magnetic resonance thermometry for predicting thermal damage: an application of interstitial laser coagulation in an in vivo canine prostate model. *Magn Reson Med* 2000; 44:873–883
23. Raz O, Haider MA, Davidson SR, et al. Real-time magnetic resonance imaging-guided focal laser therapy in patients with low-risk prostate cancer. *Eur Urol* 2010; 58:173–177 [Erratum in *Eur Urol* 2010; 58:473]
24. Woodrum DA, Gorny KR, Mynderse LA, et al. Feasibility of 3.0T magnetic resonance imaging-guided laser ablation of a cadaveric prostate. *Urology* 2010; 75:1514.e1–1516.e6
25. Woodrum DA, Mynderse LA, Gorny KR, Amrami KK, McNichols RJ, Callstrom MR. 3.0T MR-guided laser ablation of a prostate cancer recurrence in the postsurgical prostate bed. *J Vasc Interv Radiol* 2011; 22:929–934
26. Lindner U, Lawrentschuk N, Trachtenberg J. Focal laser ablation for localized prostate cancer. *J Endourol* 2010; 24:791–797
27. McNichols RJ, Gowda A, Kangasniemi M, Bankson JA, Price RE, Hazle JD. MR thermometry-based feedback control of laser interstitial thermal therapy at 980 nm. *Lasers Surg Med* 2004; 34:48–55
28. Jolesz FA. MRI-guided focused ultrasound surgery. *Annu Rev Med* 2009; 60:417–430
29. Ahmed HU, Freeman A, Kirkham AP, et al. Focal therapy for localized prostate cancer: a phase I/II trial. *J Urol* 2011; 185:1246–1254
30. International Society for Optics and Photonics Website. McDannold N, Ziso H, Assif B, et al. MRI-guided focused ultrasound (MRgFUS) system for thermal ablation of prostate cancer: pre-clinical evaluation in canines (Proceedings paper). http://spie.org/x648.html?product_id=811178. Published February 23, 2009. Accessed June 12, 2012
31. Chen J, Daniel BL, Diederich CJ, et al. Monitoring prostate thermal therapy with diffusion-weighted MRI. *Magn Reson Med* 2008; 59:1365–1372
32. Siddiqui K, Chopra R, Vedula S, et al. MRI-guided transurethral ultrasound therapy of the prostate gland using real-time thermal mapping: initial studies. *Urology* 2010; 76:1506–1511
33. Häcker A, Köhrmann KU, Back W, et al. Extracorporeal application of high-intensity focused ultrasound for prostatic tissue ablation. *BJU Int* 2005; 96:71–76
34. Nau WH, Diederich CJ, Ross AB, et al. MRI-guided interstitial ultrasound thermal therapy of the prostate: a feasibility study in the canine model. *Med Phys* 2005; 32:733–743
35. Funaki K, Fukunishi H, Sawada K. Clinical outcomes of magnetic resonance-guided focused ultrasound surgery for uterine myomas: 24-month follow-up. *Ultrasound Obstet Gynecol* 2009; 34:584–589
36. Fukunishi H, Funaki K, Yamaguchi K, Sawada K. P11.05: clinical efficacy of MRgFUS in treatment of adenomyosis: 12 month follow-up. *Ultrasound Obstet Gynecol* 2010; 36:209
37. Furusawa H, Namba K, Thomsen S, et al. Magnetic resonance-guided focused ultrasound surgery of breast cancer: reliability and effectiveness. *J Am Coll Surg* 2006; 203:54–63
38. Liberman B, Gianfelice D, Inbar Y, et al. Pain palliation in patients with bone metastases using MR-guided focused ultrasound surgery: a multicenter study. *Ann Surg Oncol* 2009; 16:140–146
39. Kopelman D, Inbar Y, Hanannel A, et al. Magnetic resonance-guided focused ultrasound surgery (MRgFUS): four ablation treatments of a single canine hepatocellular adenoma. *HPB (Oxford)* 2006; 8:292–298
40. Chopra R, Burtynk M, N'djin WA, Bronskill M. MRI-controlled transurethral ultrasound therapy for localised prostate cancer. *Int J Hyperthermia* 2010; 26:804–821
41. Uchida T, Shoji S, Nakano M, et al. Transrectal high-intensity focused ultrasound for the treatment of localized prostate cancer: eight-year experience. *Int J Urol* 2009; 16:881–886
42. Deckers R, Rome C, Moonen CT. The role of ultrasound and magnetic resonance in local drug delivery. *J Magn Reson Imaging* 2008; 27:400–409
43. Brace CL. Radiofrequency and microwave ablation of the liver, lung, kidney, and bone: what are the differences? *Curr Probl Diagn Radiol* 2009; 38:135–143
44. Terraz S, Cernicanu A, Lepetit-Coiffé M, et al. Radiofrequency ablation of small liver malignancies under magnetic resonance guidance: progress in targeting and preliminary observations with temperature monitoring. *Eur Radiol* 2010; 20:886–897
45. Laumonier H, Blanc JF, Quesson B, et al. Real-time monitoring of hepatocellular carcinoma radiofrequency ablation by quantitative temperature MRI. *Semin Liver Dis* 2006; 26:391–397
46. Goldberg SN, Grassi CJ, Cardella JF, et al. Image-guided tumor ablation: standardization of terminology and reporting criteria. *Radiology* 2005; 235:728–739
47. Chen JC, Moriarty JA, Derbyshire JA, et al. Prostate cancer: MR imaging and thermometry during microwave thermal ablation—initial experience. *Radiology* 2000; 214:290–297
48. Zangos S, Eichler K, Thalhammer A, Mack MG, Marquardt F, Vogl TJ. MR-guided interventions of the prostate gland: a literature review [in German]. *Rofo* 2010; 182:947–953
49. D'Amico A, Cormack R, Kumar S, Tempny CM. Real-time magnetic resonance imaging-guided brachytherapy in the treatment of selected patients with clinically localized prostate cancer. *J Endourol* 2000; 14:367–370
50. Van Gellekom MP, Moerland MA, Battermann JJ, Legendijk JJ. MRI-guided prostate brachytherapy

- with single needle method: a planning study. *Radiother Oncol* 2004; 71:327–332
51. Ares C, Popowski Y, Pampallona S, et al. Hypofractionated boost with high-dose-rate brachytherapy and open magnetic resonance imaging-guided implants for locally aggressive prostate cancer: a sequential dose-escalation pilot study. *Int J Radiat Oncol Biol Phys* 2009; 75:656–663
 52. Ménard C, Susil RC, Choyke P, et al. MRI-guided HDR prostate brachytherapy in standard 1.5T scanner. *Int J Radiat Oncol Biol Phys* 2004; 59:1414–1423
 53. Susil RC, Camphausen K, Choyke P, et al. System for prostate brachytherapy and biopsy in a standard 1.5 T MRI scanner. *Magn Reson Med* 2004; 52:683–687
 54. Bahn DK, Silverman P, Lee F Sr, Badalament R, Bahn ED, Rewcastle JC. Focal prostate cryoablation: initial results show cancer control and potency preservation. *J Endourol* 2006; 20:688–692
 55. Lambert EH, Bolte K, Masson P, Katz AE. Focal cryosurgery: encouraging health outcomes for unifocal prostate cancer. *Urology* 2007; 69:1117–1120
 56. Ellis DS, Manny TB Jr, Rewcastle JC. Focal cryosurgery followed by penile rehabilitation as primary treatment for localized prostate cancer: initial results. *Urology* 2007; 70(suppl 6):9–15
 57. Jones JS, Rewcastle JC, Donnelly BJ, Lugnani FM, Pisters LL, Katz AE. Whole gland primary prostate cryoablation: initial results from the cryo on-line data registry. *J Urol* 2008; 180:554–558
 58. Pisters LL, Rewcastle JC, Donnelly BJ, Lugnani FM, Katz AE, Jones JS. Salvage prostate cryoablation: initial results from the cryo on-line data registry. *J Urol* 2008; 180:559–563
 59. Schouten MG, Ansems J, Renema WK, Bosboom D, Scheenen TW, Fütterer JJ. The accuracy and safety aspects of a novel robotic needle guide manipulator to perform transrectal prostate biopsies. *Med Phys* 2010; 37:4744–4750
 60. Tokuda J, Fischer GS, DiMaio SP, et al. Integrated navigation and control software system for MRI-guided robotic prostate interventions. *Comput Med Imaging Graph* 2010; 34:3–8
 61. Muntener M, Patriciu A, Petrisor D, et al. Transperineal prostate intervention: robot for fully automated MR imaging—system description and proof of principle in a canine model. *Radiology* 2008; 247:543–549
 62. van den Bosch MR, Moman MR, van Vulpen M, et al. MRI-guided robotic system for transperineal prostate interventions: proof of principle. *Phys Med Biol* 2010; 55:N133–N140
 63. Roehrborn CG, Pickens GJ, Sanders JS. Diagnostic yield of repeated transrectal ultrasound-guided biopsies stratified by specific histopathologic diagnoses and prostate specific antigen levels. *Urology* 1996; 47:347–352
 64. Taira AV, Merrick GS, Galbreath RW, et al. Performance of transperineal template-guided mapping biopsy in detecting prostate cancer in the initial and repeat biopsy setting. *Prostate Cancer Prostatic Dis* 2010; 13:71–77
 65. Jones JS. Saturation biopsy for detecting and characterizing prostate cancer. *BJU Int* 2007; 99:1340–1344

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