Magnetic resonance imaging anatomy of the prostate and periprostatic area: a guide for radiotherapists

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Abstract

Magnetic resonance imaging (MRI) offers superb soft tissue contrast on T2-weighted images and allows direct multiplanar image acquisition. It can show the internal prostatic anatomy, prostatic margins, and the extent of prostatic tumors in much more detail than computed tomography (CT) images. The present article reviews some key prostatic and periprostatic radiologic landmarks that can be helpful for the radiotherapist using T2-weighted MRI as an adjunct to CT in treatment planning for prostate cancer.

Keywords: Prostate anatomy; Prostate cancer; Magnetic resonance imaging.

With the advent of conformal radiotherapy and especially intensity modulated radiotherapy for prostate cancer, it has become increasingly important to delineate the target volume (prostate +/- seminal vesicles) as accurate as possible. With computed tomography (CT), the delineated volume is likely to be imprecise to a certain extent, because of the low organ discriminating power based solely on differences of attenuation coefficients and the restriction to acquire images only in the transverse plane [25,28]. On the other hand, magnetic resonance imaging (MRI) can demonstrate and characterise soft tissues by providing superb soft tissue contrast on T2-weighted images, and by allowing direct multiplanar image acquisition without loss of spatial resolution [14]. MRI can therefore show in much more detail the internal prostatic anatomy and prostatic margins, and the extent of prostatic tumors, leading to more accurate delineations of both prostate and critical structures, with improved target coverage [6,15] and even definition of subtargets within the prostate [18,23]. This article reviews some important prostatic and periprostatic radiologic landmarks that can be helpful for the radiotherapist using MRI in treatment planning for prostate cancer.

Imaging technique

All images in the present study are taken from patients examined in the treatment position, supine on a flat table and legs gently bent on a knee-fix (Sinned Kneefix cushion, Cablon Medical, Leusden, The Netherlands), with the pelvis positioned in the isocenter of the magnet [5]. An ankle-fix (Sinned) is additionally used to prevent rotation of the legs. Immediately before the examination, a spasmyloytic drug (Visceralgine Forte®, Exel Pharma, Brussels, Belgium) is administered intravenously to avoid any bowel movement that could degrade image quality and to enhance patient tolerance for insertion and presence of an endorectal coil during image acquisition. On a 1.5 Tesla MR scanner (Magnetom Symphony, Siemens, Erlangen, Germany) fast-T2-weighted images (TR/TE 4400/139; section thickness 4 mm with no interslice gap; field of view 28 cm; matrix, 512×179; bandwidth 100 Hz) are acquired in the transverse, sagittal and coronal plane. In case an endorectal coil is combined with a pelvic phased-array coil, at least one set of fast-T2-weighted images (preferably three sets and always including the transverse plane) is obtained before insertion of the coil, because the latter may substantially deform the prostate, making endorectal coil images useless for target delineations. Subsequently, a balloon-covered expandable endorectal coil (MRInnervu, Medrad, Pittsburgh, USA) may be inflated with 60 ml of air, in order to obtain higher resolution images and to perform MR-spectroscopy. A volume of 60 ml is well tolerated and does not allow movement of the coil within the rectum (unpublished data). All scans are acquired with a moderately filled bladder (the patient is instructed to drink 750 ml of water within 1 h before, void 15 min before and drink an additional 250 ml immediately before image acquisition) and emptied rectum (the patient is instructed to empty the rectum 15 min before image acquisition using a rectal laxative).
Normal anatomy
Prostate gland

The prostate gland extends from the bladder base to the urogenital diaphragm like an inverted pyramid and envelops the prostatic urethra and the ejaculatory ducts. In young men, the prostate can be divided into five zonal components (Fig. 1): the nonglandular anterior fibromuscular stroma and four glandular components: the peripheral zone (about 70% of the glandular prostate), central zone (25%), transition zone (5%) and periurethral glandular tissue (<1%) [20]. With aging, the periurethral glandular tissue and the transition zone may considerably hypertrophy, gradually compressing the central zone and stretching the peripheral zone (Fig. 2). This hyperplasia essentially does not involve the peripheral zone and therefore only two areas are considered from a radiologic point of view: the central gland (consisting of the hyper-trophied periurethral glandular tissue and transition zone and the compressed central zone) and the peripheral zone (Fig. 2) [3]. The central gland usually consists of nodular areas of varying signal intensity, depending on the relative amount of glandular and stromal hyperplasia [13,24]. Glandular hyperplasia contains relatively more ductal and acinar elements and secretions, with resulting high signal intensity on T2-weighted MR-images. Stromal hyperplasia contains more muscular and fibrous elements, resulting in lower signal intensity (Fig. 3). According to the origin of hyperplasia, the terms 'lateral lobe hyperplasia' and 'median lobe hyperplasia' may be used to denote hyperplasia of the transition zone and of the periurethral glands, respectively. The compressed central zone (also called 'surgical pseudocapsule') may be imperceptible or visible as a faint dark rim, separating the central gland from the peripheral zone (Fig. 4). The latter, containing numerous ductal and acinar elements with sparsely interwoven smooth muscle, is normally of high signal intensity and is surrounded by a dark fibromuscular rim representing the prostatic capsule [3]. At the level of the apex, the prostate gland merely consists of high signal intensity peripheral zone tissue (around the distal prostatic urethra). The ratio of peripheral zone to central gland tissue then gradually decreases upward to the prostatic base, at which level the prostate gland almost entirely consists of mixed signal intensity central gland tissue (Figs. 1 and 4).

Urethra

The prostatic urethra traverses the prostate gland from the bladder neck to the apex. The proximal (also called preprostatic) part lies within the central gland and is generally imperceptible on transverse MR-images. At the level of the veru montanum, midway between the prostatic base and apex and at the verge of the central gland and peripheral zone, it curves 35 degrees anterocaudally into the distal (also called prostatic) part (Fig. 5a), that is generally visible as a small black dash surrounded by high signal intensity peripheral zone tissue (Fig. 6). At the prostatic apex, the distal urethra becomes surrounded by a low signal intensity cone of striated muscle (external urethral sphincter) extending downward to the penile bulb (Figs. 5b-6). This area has traditionally been called the 'urogenital diaphragm', although the concept of a true diaphragm (transversely oriented muscle covered by a superior and inferior fascia) has been matter of debate [21,22].

Seminal vesicles and ejaculatory ducts

The seminal vesicles are paired grapelike pouches filled with high signal intensity fluid (Fig. 7). They lay caudolateral to the corresponding deferent duct and are placed between the bladder and the rectum. Their position may be variable, being directed upward to the level of the ureteral termination, or backward along the anterolateral aspect of the rectum. Their size may vary, depending among others on age and postejaculatory condition [9]. The caudal tip of each seminal vesicle joins the corresponding deferent duct to form the ejaculatory duct, which is enveloped in a thick low signal intensity muscular coat and traverses the central zone of the prostate to terminate at the veru montanum (Fig. 8).

Deferent ducts

The deferent ducts traverse the inguinal canal and enter the pelvic cavity between the peritoneum and the lateral wall of the pelvis. They cross the ureter and then bend...
downward to adjoin the medial side of the corresponding seminal vesicles. They are thin tubular structures with low signal intensity and should not be confused as part of the seminal vesicles (Fig. 9).

**Other periprostatic structures**

The prostate is surrounded by a thin and firmly adherent nonglandular fibromuscular band ('prostatic capsule'), that is continuous internally with the stromal septa subdividing the glandular tissue within the peripheral zone and externally with the periprostatic connective tissue [1]. It is usually visible as a sharply demarcated dark rim at the posterolateral aspects of the prostate on T2-weighted MR-images (Figs. 2 and 4). Only at the prostatic apex and base, this demarcation is less distinct. At the apex, the fibromuscular band blends with the adjoining external urethral sphincter and surrounding fibrous tissue (Fig. 5b) and occasionally becomes sparsely intermingled with loose glandular elements from the apical peripheral zone [3]. At the prostatic base, the fibromuscular band blends imperceptibly with the bladder musculature and therefore cannot be differentiated from the low signal intensity bladder wall [3]. In prostatic hyperplasia causing protrusion of hypertrophied tissue at the bladder base, the bladder wall is elongated and hardly visible (Fig. 10). Anteriorly, the prostate is covered by the thick anterior fibromuscular stroma, which contains no glandular elements and has low signal intensity (Figs. 1 and 4). It is separated from the pubic...

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**Fig. 2.** Central gland changes in prostatic hyperplasia (transverse plane). (a) Normal prostate in 34-year old man: compact central gland (CG) and broad peripheral zone (*); (b) hypertrophied central gland in 62-year old man. R=rectum (with endorectal coil in (a), not in (b)); arrowheads = prostatic capsule; L=levator ani muscle.

**Fig. 3.** Central gland (CG) changes in prostatic hyperplasia (transverse plane). Images at prostatic base from two different patients. (a) Stromal hyperplasia: predominantly low signal intensity; (b) Glandular hyperplasia: predominantly high signal intensity areas (*). BL=bladder; R=rectum (with endorectal coil in (b), not in (a)).
symphysis by Santorini’s venous plexus (draining the dorsal veins of the penis) and some ligamentous and fibroadipose tissue in Retzius’ space (Fig. 6) [21].

The prostate rests within a muscular funnel composed of the anterior aspects of the levator ani (caudally) and obturator internus (cranially) muscles (Figs. 2, 5, 6 and 10) [21]. The levator ani muscle is a broad muscular sheet extending from pubis to coccyx and forming most of the pelvic floor. Its thickest part (inferomedially) embraces the lower half of the prostate (so-called ‘levator prostatae’) and the external urethral sphincter, and the thinner superolateral part attaches to a tendinous arc on the medial surface of the obturator internus muscle, which embraces the upper half of the prostate [21]. The prostatic capsule is separated from this muscular funnel by loose connective and adipose tissue containing the periprostatic venous plexus intermixed with arteries, nerves and lymphatics. At the posterolateral aspects of the prostate, some of these vessels

Fig. 5. Prostatic urethra. (a) Sagittal view of the urethra (arrowheads) traversing the prostate from base to apex. Note the anterocaudal bend at the level of the veru montanum (white arrow); (b) Coronal image through the prostatic apex, the distal urethra becomes surrounded by the low signal intensity external urethral sphincter (*) that extends downward to the penile bulb (PB) and is embraced by the inferomedial aspect of the levator ani muscle (L). BL = bladder.

Fig. 4. Normal prostate from apex to base (transverse plane). (a) The apex consists of the distal part of the prostatic urethra (white arrow) surrounded by high signal intensity peripheral zone tissue (*); (b) At the midprostate, the mixed signal intensity central gland (CG) is posterolaterally surrounded by high signal-intensity peripheral zone tissue (*), subdivided by several stromal septa (horizontal black arrows). The peripheral zone is surrounded by a dark fibromuscular rim representing the prostatic capsule (white arrowheads). Note the anterior fibromuscular stroma (AFS), the compressed central zone (black arrowheads, not to be confused with the true prostatic capsule) and the neurovascular bundles (vertical black arrows); (c) The prostatic base is composed almost entirely of central gland (CG) tissue, with only a narrow posterior band of peripheral zone (*). BL = bladder; R = rectum (with endorectal coil).
are jointly called the neurovascular bundles, containing cavernous nerve fibres that are important to normal erectile function (Fig. 4) [3].

Prostate cancer

Prostate cancer tissue usually has low signal intensity on T2-weighted images. Since 70% of all prostate carcinomas arise in the peripheral zone [19], many of them can be readily detected within the high signal intensity background of normal peripheral zone tissue (Fig. 11a). This sign, however, is by no means specific, since chronic prostatitis, hemorrhage, scar tissue, etc. can produce similar findings [27]. On the other hand, hormonal ablation may decrease the signal intensity of the normal peripheral zone, thus reducing the visibility of low signal-intensity prostate cancer [2]. Tumors arising in the central gland may also be indistinct, especially when low signal intensity stromal hyperplasia predominates (Fig. 3b). Capsular perforation can be suspected in the presence of irregular bulging or disruption of the prostatic capsule, obliteration of the rectoprostatic angle, or asymmetry of the neurovascular bundle [30]. Furthermore, an abnormally low signal intensity within the vesicular lumen or a focal thickening of the seminal vesicle wall is suggestive of seminal vesicle invasion (Fig. 11b) [11]. In a recent meta-analysis, Engelbrecht et al. calculated a joint maximum sensitivity and specificity of 71% for overall tumor staging (cT2 versus cT3 differentiation), 64% for detection of extracapsular extension and 82% for detection of seminal vesicle invasion [8].

Newer techniques that aim at improving this accuracy are currently under investigation. Magnetic resonance spectroscopy (MRS) at 1.5 Tesla provides metabolic information...
in addition to morphologic data and can draw the attention to areas that seem less important morphologically [16]. Metabolites of importance are citrate (produced in normal epithelial cells and secreted into the prostatic ducts), choline and related compounds (important precursors in the phospholipid cell membrane synthesis and more prevalent in tumor tissue) and creatine (involved in the cellular energy metabolism and also more prevalent in tumor tissue). A (choline + creatine)/citrate ratio > 1 is considered suggestive of malignancy, and a correlation between the magnitude of this ratio and Gleason grade has been suggested [29, 31]. This may be an interesting issue for further investigation, because a strong correlation between Gleason grade and probability of local relapse after radiation therapy has already been demonstrated [10]. So far, accuracies of up to 88% have been reported for tumor lateralization (presence of tumor in the right or left prostate half) and a more accurate prostate cancer tumor volume measurement is possible with combined MRI and MRS [4, 26, 29]. MRS on higher field strength machines (3 Tesla) is an exciting new opportunity that is currently under investigation.

Another imaging modality that aims at achieving a higher accuracy for tumor detection is dynamic contrast-enhanced T1-weighted MR-imaging (dMRI). After intravenous bolus injection of a gadolinium-containing contrast agent, tumor areas in the prostate enhance earlier and faster on the basis of tumor neoangiogenesis and thus increased microvascular density as compared to normal prostate tissue or benign prostatic hyperplasia [7, 12]. Preliminary studies have shown promising results, but further research is needed to clarify the exact role of dMRI and to assess its accuracy in prostate cancer detection and staging [8].

Fig. 8. Ejaculatory ducts (transverse views). (a) At the midprostate, the ejaculatory ducts join the prostatic urethra at the veru montanum, which is usually visible as a high signal intensity structure (arrowhead). (b) At the prostatic base, the ejaculatory ducts (arrows) traverse the central zone and are enveloped by a low signal intensity muscular ring. BL = bladder; R = rectum (with endorectal coil).

Fig. 9. Deferent ducts. (a) Coronal view of the low signal-intensity deferent ducts (arrowheads) proceeding along the craniomedial side of the corresponding seminal vesicles (SV). (b) Transverse view of the deferent ducts at the medial side of the seminal vesicle, between the bladder and the rectum. BL = bladder; R = rectum.
Use of MRI in radiotherapy planning

MRI can be used to improve treatment planning for prostate carcinoma by providing information that not only helps to more accurately delineate the prostate and seminal vesicles, but also to define a subtarget within the prostate that can be treated to a higher dose.

As opposed to CT, MRI can identify superb anatomical landmarks for clinical target volume (CTV) delineations by offering a clear-cut depiction of the prostatic capsule posterolaterally (separating the CTV from the rectum and levator ani muscle), the fibromuscular stroma anteriorly (separating the CTV from Retzius’ space) and the transition from high signal-intensity normal peripheral zone to low signal-intensity fibromuscular tissue caudally (separating the CTV from the urogenital diaphragm). These boundaries can be employed indirectly by using MRI-derived information (on hardcopy) to improve the delineation accuracy on CT-images (on the workstation) or by direct delineation on the MR-images (on the workstation), using image segmentation and image registration or correlation to account for the lack of tissue electron density values on MRI [14,17].
Furthermore, intraprostatic lesions detected with MRI, with combined MRI and MRS, or with combined MRI and dMRI can additionally be delineated as a subtarget, potentially benefiting from the administration of a focused higher radiation dose.

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