**Natural History**

Carcinoma of the prostate is the most common malignancy other than skin cancer in American men. In 1992, some 132,000 men were diagnosed with the disease and 32,000 died of it. More ominously, it is projected that deaths will increase by 37% and new diagnoses by 90% by the year 2000 because of the aging of the population. Unique among malignancies, early-stage prostate cancer presents the clinician with the dilemma of whether or not available curative treatment should be given. For those who do undergo treatment, cure is likely (and treatment justified) if indeed the disease is confined to the gland.

**Staging of Prostate Cancer**

To date, the American Urologic Association staging system, based on that of Whitmore and Jewett, is the one most widely used in North America. Stage A represents inapparent tumors discovered incidental to transurethral resection performed to relieve symptoms of urinary obstruction. Such A1 tumors, seen in three or fewer microscopic foci, are small in volume and usually observed. The larger A2 tumors are considered more aggressive and are often treated. Stage B tumors, like stage A, are confined to the gland but by definition are palpable. Tumors smaller than 1.5 cm and confined to one lobe with normal glandular tissue surrounding on three sides are classified as B1; larger tumors confined to the gland are B2. Stage C represents disease that has traversed the capsule (C1) or involves the seminal vesicles (C2). Stage D disease is metastatic.

The increasing occurrence of prostate cancer diagnosed because of prostate-specific antigen (PSA) elevation without other findings to recommend biopsy has presented the need for a third classification of nonpalpable disease. This need, along with the desire to develop a common classification with the International Union Against Cancer, prompted the AJCC to introduce its TNM clinical staging system in 1992. Stages T1a and T1b correspond to A1 and A2. Stage T1c accommodates prostate cancers for which elevation of PSA was the only finding leading to biopsy. Stage T2a tumor involves half a lobe or less. Stage T2b tumor involves more than one half but no more than one lobe, while T2c involves both lobes. The T2 designation is applied to both palpable tumors and to tumors that, although not palpable, are visible on ultrasound. Stage T3 tumor is extraprostatic; T3a is unilateral and T3b is bilateral extraprostatic disease. Stage T3c tumor invades the seminal vesicles, and stage T4 invades adjacent organs or the pelvic side wall.

Ohori and colleagues reported on the correlation between this AJCC staging system and step-sectioned pathology review of 400 prostatectomy specimens. The aim of the study was to establish whether clinical staging could predict important pathologic differences. Their comparison of clinical and pathologic staging showed clear correlation between the two, with larger mean tumor volume and greater risk of extraprostatic extension for each increase in clinical stage. In particular, a break point occurred between T2a and T2b tumors, with 9% vs 26% having advanced pathologic features. Nonpalpable T2 lesions detected only on ultrasound were disproportionate among the T2a group. Stage T1c tumors fell in sequence by mean tumor volume, but the percentage with poor differentiation was relatively high, and 18% showed pathologic extraprostatic disease. Unlike T1a and T1b tumors, they occurred predominantly in the peripheral zone.

**Zonal Anatomy of Prostate**

McNeal described prostatic zonal anatomy, dividing the gland into peripheral, central, and transitional zones with differing structural and functional characteristics. These glandular zones are best described from their relationship to the urethra and the ejaculatory ducts they surround.

The central zone is a conical region with its base constituting the greater part of the base of the gland and its apex at the urethra at the proximal verumontanum. It constitutes about one quarter of the gland volume. This cone of glandular tissue envelopes the ejaculatory ducts, continuing from the seminal vesicles and vasa deferentia, as well as their accompanying blood vessels and lymphatics, on their route to egress at the verumontanum. Critically, the prostate capsule does not ensheathe these ducts and vascular structures on their course through the surrounding glandular tissue of the central zone. This is referred to as the invaginated prosthetic space (IES). Invasion of the IES is one of the chief modes of extraprostatic spread of prostate cancer.

The peripheral zone accounts for about 70% of prostate glandular tissue and a like percentage of carcinomas. It comprises the posterior, lateral, and distal parts of the prostate gland, bordered at its lower anterior face by the surgical capsule, a muscular barrier separating it from the transition zone anteriorly. At its apex, its ducts empty into the membranous urethra distal to the verumontanum. This is a second critical area where the prostatic capsule is thin or absent. Tumor in this region can readily escape the prostate into the trapezoid area, bounded anteriorly by the urethra, posteriorly by the rectum, proximally by the prostate apex, and distally by the musculature of the pelvic floor (rectourethralis).

The transition zone makes up only approximately 5% of glandular tissue in younger men. This proportion markedly increases with age as benign prostatic hyperplasia...
Two imaging modalities, ultrasound and magnetic resonance imaging (MRI), have been widely used and intensively studied in the diagnosis and staging of prostate cancer. They have been subject to this attention because of their relative ability to distinguish the internal zonal anatomy of the prostate gland. We will discuss the current use of these evolving technologies.

Ultrasound Identification of Prostatic Cancer

The introduction of the 7-MHz ultrasound probe afforded a major advance in the detail and reproducibility of prostatic imaging. Its superior sensitivity in comparison to that of the long-standard digital rectal examination (DRE) in identifying abnormalities of the prostate gland gave initial hope that it would prove to be the definitive prostatic imaging modality. A major strength of the transrectal ultrasound study (TRUS) is its limited ability to distinguish the zonal anatomy of the prostate gland, most particularly that of the peripheral zone, from which the majority of prostate cancers arise (Figs 1A-B). Many reports have been published comparing ultrasound examination with pathology seen in tissue specimens. In a number of meticulous studies, Shinohara and associates compared preoperative TRUS examinations with sectioned pathology slices corresponding to the imaged ultrasound “slices.” In this fashion, they compared 98 prostatectomy specimens with the corresponding preoperative ultrasounds. Two thirds (66) of the cancers were hypoechoic. One third (31) were not seen on preoperative ultrasound -- i.e., they were isoechogenic. Volume and histologic analysis showed the isoechogenic tumors to be smaller (mean volume, 1.2 cc) and better differentiated. The hypoechoic tumors were larger (mean volume, 3.86 cc) and more poorly differentiated. A systematic underestimation of tumor size was seen with a mean 4.2-mm ultrasound underestimation of the maximum tumor dimension seen on pathology. These authors and others have stressed the interplay among the normal zonal microscopic architecture, the pattern of tumor growth, and the ultrasound findings. The peripheral zone, where most prostate cancers arise, is made up of fairly uniform glands producing a finely stippled ultrasound echo pattern. The presence of tumor with crowded cells and compressed or disrupted acini reduces these microscopic interfaces, producing a relatively hypoechoic region. The more poorly differentiated the tumor (the more cellular and less glandular), the more hypoechoic the ultrasound appearance. The borders of the tumor will be infiltrative, with mixed normal and malignant elements, and relatively isoechogenic. Shinohara speculates that the observed ultrasound underestimation of tumor dimension is predictable on this basis.

A distinctive echo pattern with stippled hyperechoic areas seen within a larger hypoechoic region has been shown to sometimes represent high-grade Gleason pattern 5 comedocarcinoma, defined pathologically as tumor growing within ducts, often necrotic, with occasional calcificatin of the necrotic material producing the relatively fine hyperechoic foci. In describing 11 scans with hyperechoic foci among 160 preoperatively imaged prostatectomy specimens, Hampar and associates noted 7 specimens in which corpora amylacea corresponded to coarse hyperechoic foci situated within benign glandular structures outside of (or surrounded by) tumor. Of the 7 instances where fine hyperechoic foci were seen within the hypoechoic region, 5 represented comedocarcinoma. Two reflected the presence of intraluminal crystalloid material with no comedocarcinoma present.

Screening for Prostate Cancer by Transrectal Ultrasound

Analyses of TRUS as a screening tool for prostate cancer have been disappointing. Sheth and associates have identified the low specificity of the hypoechoic lesion as a major factor in the poor screening performance of TRUS. They reviewed preprostatectomy ultrasounds in light of postoperative pathology in a group of 29 patients in whom prostate cancer had previously been diagnosed by transurethral prostatectomy (TURP). They found a sensitivity of 55% and a specificity of only 37% in this high-prevalence population. Cooner and colleagues, in a large and meticulous study of 1,807 men in a urologic practice, compared the relationships of TRUS, DRE, and PSA as prostate screening methods. Again, the low specificity of hypoechoic findings was seen to impair the usefulness of TRUS as a screening tool. Although 40% of patients had hypoechoic foci on TRUS, the positive predictive value of TRUS when DRE was normal was only 5%. This contrasted with positive predictive values of at least 35% for positive DRE and for elevated PSA. Chang and Friedland have pointed out that the positive predictive value of a screening test depends not only on the characteristics of the test but also on the prevalence of disease within the screened population. When a test of low specificity is used to screen a population with low prevalence of disease, the positive predictive value will be low. In their reanalysis of data presented by Lee and colleagues, they demonstrate that the positive predictive value of DRE alone (62%) was not enhanced by the addition of ultrasound. In an update of his large ongoing screening study, Cooner has restated the matter from a different perspective. Among his patients with normal DRE and PSA, 40.8 sonograms and 8.5 biopsies would be required to detect a single prostate cancer.

Staging of Prostate Cancer by Transrectal Ultrasound

Scardino and associates have reported on an extensive experience correlating preoperative ultrasound with carefully performed pathologic examination. They found that the most reliable sign of extracapsular disease was the proximity of a hypoechoic lesion to the boundary echo. Increasing size of the hypoechoic lesion, especially in proximity to a bulge, increased this likelihood. In their experience, this paired criterion had a sensitivity of 65%, a specificity of 93%, and an accuracy of
Identification of Prostate Cancer by Magnetic Resonance Imaging

It is generally accepted that the direct MRI manifestation of prostate cancer is the presence of low signal intensity (SI) on T2 weighting (Figs 2A-B). This is typically seen as an island of low signal enclosed by high signal from surrounding benign peripheral zone tissue (Figs 3A-D). Schiebler and associates performed *in vitro* MRI studies, correlating them with step-sectioned pathologic examination, of specimens from 24 patients with prostate cancer. They showed a direct correlation between the proportion of glandular space within a tissue type and the T2 SI. Performing a paired *t* test on the mean differences of relative SI, they demonstrated significant differences for cystic benign prostatic hypertrophy (BPH) (<) and peripheral zone (*P*=.0003). There was no significant difference, however, between well-differentiated tumor and mixed BPH. The authors noted that less well-differentiated tumor, diffusely infiltrating the surrounding peripheral zone glands, produced a border signal characteristic of the tissue being infiltrated. In a complementary study, Quint and associates measured tissue optical density (TOD) on whole-mount pathologic slides following prostatectomy in 28 patients subjected to preoperative MRI examination. Of 30 "characteristic" lesions identified on preoperative examination on the basis low T2 SI, 21 proved to be cancer; however, 9 represented benign tissue. Interestingly, of 31 cancers seen on pathology, 10 were not detected by the preoperative MRI. The authors argue that cancers were identified by MRI because, being more cellular, lower water content allowed them to stand out from surrounding normal glandular tissue. False-positive MRI studies were caused by dense fibromuscular stroma. The causes of false-negative studies were thought to be multiple but chiefly reflected similarity in water content with surrounding tissue, particularly adjacent BPH.

Although asymmetry, irregular outline, atrophy, and distension have been considered signs of seminal vesicle invasion, little methodologic pathologic correlation has been produced to support these as criteria. In a clinicopathologic review of 85 patients undergoing prostatectomy, Shihohara and associates described signs that were predictive of seminal vesicle invasion. These were the presence of a hypoechoic lesion, preferably greater than 2 cm in size, in the base of the prostate, which may be associated with a bulge in the boundary echo, and a unilateral hypoechoic zone in the angle between the prostate and the seminal vesicle -- the "adhesion sign." They found a sensitivity of 59%, a specificity of 98%, and an accuracy of 86% using these criteria for seminal vesicle invasion.

Terris and colleagues described a technique for biopsy of the seminal vesicle in suspect cases of seminal vesicle invasion. They obtained postprostatectomy pathologic correlation in a group of 73 patients who underwent biopsies. Biopsies were performed on 145 seminal vesicles, of which 133 returned benign, and 8.3% of these patients were found to have pathologically involved seminal vesicles. Tumor in association with seminal vesicle epithelium was found in 8 biopsies. All 8 of these patients were confirmed to have seminal vesicle invasion. The authors stressed the importance of proper technique in obtaining reliable biopsies.

Andriole and colleagues have reported on an experience of 64 patients with clinically localized prostate cancer staged with TRUS prior to radical prostatectomy. Of the 48 patients with pathologically established localized disease, TRUS correctly staged 90%. The overstaging of 10% was attributable to artifact from recent biopsy or TURP. Unfortunately, of the 16 patients with pathologically established extraprostatic disease, 10 (62%) were understaged by TRUS. Perrapato and colleagues reported a similar experience, with TRUS understaging 23 of 25 instances of microscopic capsular penetration. Additionally, they noted difficulty in identifying A2(T1b) disease within the transition zone. These difficulties are consistent with the experience of Palken and colleagues, who reviewed 30 step-mount prostatectomy pathology specimens in correlation with preoperative ultrasound. They found TRUS to miss 5 of 6 instances of microscopic capsular penetration, yielding a sensitivity of 17% compared with that of DRE. Only 2 of 11 central gland cancers were detected. The correlation coefficient for tumor volume was .14 compared with .82 for serum PSA. These difficulties presage the findings in the landmark Radiological Diagnostic Oncology Group study, in which 194 patients were prospectively staged with TRUS and MRI prior to prostatectomy and step-section pathology correlation. In this trial, TRUS was found to have a specificity for identifying localized disease of only 46% and a sensitivity for recognizing extraprostatic inoperable disease of only 66%. In fact, TRUS did not recognize the true site of extraprostatic disease in 29% of the cases correctly identified. These authors conclude, as do those of the preceding retrospective experiences, that TRUS is not at this time a reliable staging modality for individual patients with prostate cancer.

80% for recognizing microscopic extracapsular penetration. Discontinuity of the boundary echo alone had a sensitivity of only 21% for identifying microscopic extracapsular disease. The authors found that recent biopsy could produce a false-positive ultrasound, with postbiopsy hemorrhage producing a hypoechoic zone adjacent to a boundary echo bulge; they therefore recommend against performing a staging ultrasound within one month of biopsy.

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**Identification of Prostate Cancer by Magnetic Resonance Imaging**

It is generally accepted that the direct MRI manifestation of prostate cancer is the presence of low signal intensity (SI) on T2 weighting (Figs 2A-B). This is typically seen as an island of low signal enclosed by high signal from surrounding benign peripheral zone tissue (Figs 3A-D). Schiebler and associates performed *in vitro* MRI studies, correlating them with step-sectioned pathologic examination, of specimens from 24 patients with prostate cancer. They showed a direct correlation between the proportion of glandular space within a tissue type and the T2 SI. Performing a paired *t* test on the mean differences of relative SI, they demonstrated significant differences for cystic benign prostatic hypertrophy (BPH) (<) and peripheral zone (*P*=.0003). There was no significant difference, however, between well-differentiated tumor and mixed BPH. The authors noted that less well-differentiated tumor, diffusely infiltrating the surrounding peripheral zone glands, produced a border signal characteristic of the tissue being infiltrated. In a complementary study, Quint and associates measured tissue optical density (TOD) on whole-mount pathologic slides following prostatectomy in 28 patients subjected to preoperative MRI examination. Of 30 "characteristic" lesions identified on preoperative examination on the basis low T2 SI, 21 proved to be cancer; however, 9 represented benign tissue. Interestingly, of 31 cancers seen on pathology, 10 were not detected by the preoperative MRI. The authors argue that cancers were identified by MRI because, being more cellular, lower water content allowed them to stand out from surrounding normal glandular tissue. False-positive MRI studies were caused by dense fibromuscular stroma. The causes of false-negative studies were thought to be multiple but chiefly reflected similarity in water content with surrounding tissue, particularly adjacent BPH. An intriguing case report of a prostate cancer found on MRI to have high T2 SI lends further credence to this line of thinking in that the tumor was found on pathology to be highly mucinous.
It would be anticipated that the overlap in signal characteristics between BPH and prostate cancer would cause problems in MRI evaluation of the central gland (central and transitional zones). Carter and associates\textsuperscript{43} compared preoperative MRI to seep-section pathologic findings in 53 patients. They were primarily interested in the ability of MRI to detect nonpalpable cancer in patients undergoing surgery for palpable cancer. They found MRI to be highly reliable in identifying palpable tumors, with a sensitivity of 96%. For nonpalpable tumors, the sensitivity was 58%. However, when nonpalpable tumors were divided between posterior and central gland locations, the sensitivity was seen to be 85% in the peripheral zone but only 15% in the central gland. When specificity was considered, it was found to be only 48%, with three quarters of the false-positives seen in the peripheral zone, usually without any corresponding pathologic abnormality, malignant or benign. The authors conclude that a low signal-to-noise ratio on T2 body coil MRI is an inherent limitation on improving the specificity of MRI of the prostate.

### Staging of Prostate Cancer by Magnetic Resonance Imaging

The critical medical problem presented once the diagnosis of prostate cancer has been made is the ascertainment of resectability. Disease confined to the gland (A-B,T1-2) is resectable for cure. Disease outside the gland (CT3), whether penetrating the capsule or invading the seminal vesicles, is unlikely to be cured by surgery or other means (Figs 4A-B).\textsuperscript{40,41} A number of careful analyses of standard body coil MRI capabilities for distinguishing stage B from stage C disease have been published. Scheiber et al\textsuperscript{42} measured MRI (and radiologist) performance, comparing preoperative MRI readings with postoperative step-section pathology findings in 100 patients. The criterion for extracapsular disease was the presence of a low-signal region on T2 scan transgressing the capsule or periprostatic venous structures adjacent to the peripheral zone. Invasion of the seminal vesicle was likewise considered to be present if low T2 SI was seen. A T1 scan was used as a check to be sure that hemorrhage was not responsible for the low T2 seminal vesicle signal. Extracapsular disease was found on pathology in 61% of patients, with 20% of these having more than 3 mm of penetration. The authors discovered overall agreement among the four radiologists of only 70%. Receiver-operating-characteristic curves showed poor performance even for those patients with more than 3 mm of extracapsular penetration. The overall accuracy of MRI in detecting stage C disease was only 55%; in their words, "only slightly above a chance guess . . ." In a further analysis of this same group of patients,\textsuperscript{43} the authors derived receiver-operating-characteristic curves for two experienced radiologists and for preoperative serum PSA values for determining the presence of early stage C disease. Mean PSA values for organ-confined disease, tumor penetration less than or equal to 1 mm, and tumor penetration greater than 1 mm were 4.7, 6.6, and 12.6 ng/mL, respectively. No statistically significant difference was seen among the areas under the receiver-operating-characteristic curves. PSA is therefore equivalent to expertly interpreted body coil MRI for identifying subtle stage C prostate cancer.

An alternative indirect approach to the prediction of stage C disease has been based on the correlation between tumor volume and disease stage.\textsuperscript{44-46} Quint and associates\textsuperscript{47} have reported on their efforts to adapt body coil MRI to tumor volume determination. They compared preoperative MRI tumor volumes to pathologically outlined tumor volumes using a voxel summation technique. The presence of extracapsular disease, if any, was noted as well by the pathologist. Twenty tumors were found on pathologic examination to correspond with preoperative MRI abnormalities. Tumors were seen in both the peripheral zone and bridging the peripheral and central zones, with volumes in three instances in excess of 10 cc. Analysis showed that MRI predicted the pathologic tumor volume within 10% in only 2 of 20 cases. There was a tendency to overestimate the size of small tumors and to underestimate the size of large ones. Five tumor volumes were underestimated by more than 50%, and seven tumor volumes were overestimated by more than 50%. Not surprisingly, marked overlap was seen between MRI tumor volume ranges and the presence of extracapsular disease. The authors speculate on postbiopsy hemorrhage and the presence of BPH intermingling with tumor as well as the irregular histology and patterns of tumor growth as being responsible for the shortcomings of MRI. Sommer and associates\textsuperscript{48} have attempted to predict prostate cancer volume using external phase-array coils with fast spin-echo technique. The correlation between MRI prediction and pathologic mapping ($r=.81$, $P<.001$) was improved over that obtained with body coils and conventional spin-echo technique. The authors state, however, that the correlation is still not good enough to use as a basis for clinical decisions. They conclude, as did Quint, that the poor specificity of T2-weighted images and the confounding effects of biopsy pose fundamental drawbacks to reliable determination of tumor volume.

A further issue relevant to consideration of curative surgery for patients with clinically localized prostatic cancer concerns the presence of tumor in the vicinity of the neurovascular bundle (NVB). Walsh and Donker\textsuperscript{50} have shown that this structure, located between the prostatic capsule and Denovillier’s fascia, at the 5- and 7-o'clock positions just outside the posterolateral margins of the prostate and at the anterolateral borders of the rectum, carries the pelvic nerves innervating the corpora cavernosa. Interruption of the neurovascular bundles is responsible for the certainty of permanent impotence associated with traditional radical prostatectomy. Preservation of one bundle will usually preserve potency.\textsuperscript{51} Tempony and associates\textsuperscript{51} investigated retrospectively the utility of preoperative MRI for identifying neurovascular bundles not threatened by tumor and for distinguishing minimal adjacent capsular penetration with accompanying desmoplastic reaction from gross invasion of the NVB. In the former instance, preservation of the bundle is often feasible. In the latter instance, the NVB must be sacrificed if curative surgery is to be attempted.\textsuperscript{52} Imaging was performed with T1 weighting to assess the integrity of the periprostatic fat plane and to outline the NVB and with T2 weighting to identify prostatic cancer "directly." Three criteria for NVB invasion were evaluated: obvious tumor mass extension, decreased SI in the angle between the prostate and rectum, and focal contour bulge in the posterolateral prostate adjacent to the NVB. Of 50 patients evaluated, 32 showed pathologic evidence of tumor penetration of the capsule in the vicinity of the NVB. Of these, 28 had substantial (more than 1 mm) penetration. Magnetic resonance imaging identified 19 of these patients (sensitivity, 68%) and also 13 of 22 patients with no cancer in the vicinity of the NVB (specificity, 59%). The accuracy of MRI evaluation of NVB invasion was therefore 64%. These values compare unfavorably with the intraoperative surgical assessment sensitivity of 85%, specificity of 81%, and accuracy of 84%. The authors ascribe the inadequacy of MRI assessment of the NVB to misinterpretation of the periprostatic venous plexus as part of the peripheral zone, biopsy- and flow-related artifacts and, above all, the limited resolution of the MRI technology.
One particularly vexing problem with preoperative MRI interpretation is the alteration in the gland produced by biopsy. The interplay between imaging technique and the structural alterations evolving over weeks, with breakdown in blood cells and heme, the development and regression of edema, and the development of fibrosis is neither well described nor well understood (Figs 5A-B). Aside from the inherent problem of attempting to image a microscopic process of tumor spread, it seems likely that the “biopsy variable” will continue to be a confounding factor despite improvements in MRI technology. Ramchandani and Schnall\(^52\) have published their thinking as to the imaging changes over time following biopsy. They report an initial increase in T1 signal and decrease in T2 signal with a subsequent increase in T2 signal over a period of days to weeks. The problem of hemorrhage occurring within tumor was not discussed. They report their confidence in being able to distinguish blood from tumor but prefer to wait three weeks following biopsy before performing MRI.

As is the case for TRUS, the definitive evaluation of body coil MRI as a staging modality for apparently operable prostate cancer is that of the Radiological Diagnostic Oncology Group (RDOG).\(^34\) This large, prospective, multi-institutional analysis -- with carefully specified inclusion, imaging, pathologic, and interpretive criteria -- presents a realistic picture of what can be achieved with body coil MRI staging. These investigators found MRI to have a specificity of 57% for the prediction of gland-confined disease. The sensitivity for extraglandular disease was 77%; however, in one quarter of these patients, the site of extraglandular disease identified by MRI was not the site found at pathology. The sensitivity for invasion of the seminal vesicle was only 18%. The overall staging accuracy was 69%. Clearly, these results are inadequate as a basis of potentially life-or-death treatment decisions. The authors state the hope that noise reduction,\(^53\) fat suppression,\(^54\) intrarectal surface coil,\(^55\) contrast agents, or MR spectroscopy\(^56\) might improve the accuracy of MRI.

**Newer Techniques of Magnetic Resonance Imaging**

The phased-array coil is one of the enhancements recently introduced in an effort to improve the resolution of pelvic MRI. Kier and colleagues\(^57\) have reported their experience with a combination of fast spin-echo pulse sequences and phase-array coils. This combination affords the opportunity to combine a high signal-to-noise ratio with more signal averages obtained in a shortened imaging period. Among the imaged population in this study, 20 patients underwent prostatectomy, affording the opportunity for pathologic correlation. The MRI accuracy for extracapsular spread was 85% among these 20 patients. The accuracy for invasion of the seminal vesicle was 100%, with 1 true positive and 19 true negatives. These values may be high, however, because step-section whole-mount slices were not obtained. The authors also performed a qualitative “crossover” analysis of fast spin echo and of the phased-array coil, combining fast spin echo with a body coil and the phased-array coil with standard imaging sequences; they found the combination to be superior to either of the two with a standard modality. The authors point out that phased-array coil imaging has the advantages of offering a wider view of the pelvis without the discomfort and distortion produced by the endorectal coil. Further experience with this technology is awaited.

The use of the endorectal surface coil has been the subject of much interest for improving the resolution of MRI prostatic imaging (Figs 6A-B and Fig 7). An improvement in staging accuracy of 16% over body coil technology is described in early experience.\(^58\) Chelsky et al\(^59\) described their findings among 47 patients imaged with endorectal MRI prior to prostatectomy. Criteria for capsular stage C disease were infiltration of periprostatic fat, obscuration of periprostatic veins, involvement of the neurovascular bundle, disruption of the capsule, and a bulge in the capsular contour defined as bulging in the glandular surface, making an angle with adjacent peripheral zone. Criteria for invasion of the seminal vesicle were low SI in the seminal vesicle and focal thickening of the tubular walls seen on T2. Sagittal views were obtained to optimally image the base and seminal vesicles and coronal views to optimally image the apex. The authors noted a distinct improvement in the imaging detail over that seen with body coil imaging. In particular, they noted an improvement in visualization of the capsule. Upon comparison with pathology specimens, a notable improvement over the results from the RDOG study was seen for seminal vesicle imaging, with sensitivity of 63%, specificity of 97%, and accuracy of 91%. This improvement was not demonstrated, however, for capsular involvement, with sensitivity of 58%, specificity of 78%, and accuracy of 68%. It was found that the capsular bulge criterion was responsible for a number of false-positive readings. When it was dropped as a criterion for stage C disease as an isolated abnormality, the specificity improved dramatically to 96%, but the sensitivity fell appreciably to 38% and the overall accuracy was virtually unchanged (66%). Outwater and associates\(^60\) have been similarly unsuccessful using fast spin-echo imaging in identifying reliable diagnostic criteria.
Parivar and collaborators combined endorectal surface coil MRI with the inversion recovery (IR) sequence. They preoperatively imaged 26 patients with varying IR and spin-echo sequences. Ex vivo images were also obtained. Preoperative and postoperative images were compared with histologic sections. T2-weighted spin-echo images successfully identified 87% of tumors larger than 4 mm, while IR images identified only 26% of these tumors. The authors felt, however, that the IR sequence offered a qualitative improvement in the visualization of the fascial structures enveloping the prostate, seminal vesicles, and rectum. They describe a "black-line artifact" outlining these organs. In two instances, IR images detected microscopic capsular invasion reaching but not penetrating the periprostatic fat. T2-weighted spin-echo images failed to identify these sites of minimal capsular penetration. Although none of the patients examined exhibited invasion of the seminal vesicle, the resolution obtained by the IR sequence was believed to be superior to that seen with the spin-echo sequence. The authors conclude that including the IR sequence in the endorectal imaging protocol may be helpful to identify early capsular penetration as well as early involvement of the seminal vesicle.

In an effort to improve the results with endorectal coil MRI, Mirowitz and associates imaged 13 patients preoperatively, obtaining gadolinium-enhanced T1 sequences as part of their protocol. Meticulous postoperative pathologic correlation was obtained. They found the central gland to enhance inhomogeneously, which on pathologic correlation was seen to correspond to areas of benign hyperplasia. Enhancement was less pronounced in the peripheral zone and seemed to correlate with biopsy changes and hemorrhage (visible on unenhanced T1 images), BPH, and areas of tumor. The authors concluded that gadolinium-enhanced T1 images were superior to unenhanced T1 images for evaluating zonal anatomy, prostate capsule, surgical capsule, fibromuscular stroma, periprostatic venous plexus, tumor extent, and capsular integrity. T2-weighted images were nevertheless best for all these parameters. The exception to this finding was seen in patients with early involvement of the seminal vesicle in whom the normal pattern of tubular wall enhancement set off by low SI within the lumina is dramatically altered by growth within the lumina of enhancing tumor. The authors conclude that gadolinium might be useful for evaluating cases equivocal for involvement of the seminal vesicle.

A further enhancement of endorectal MRI has been the incorporation of external coils to produce an endorectal/external multicoil arrangement. The advantage of this technique is that it dramatically enlarges the volume of high signal-to-noise ratios obtained by the unpaired endorectal coil. A report by Quinn et al describes their progressing experience with successive enhancements of endorectal coil imaging. They report on 70 patients imaged preoperatively in whom whole-mount pathology specimens of the prostate were obtained for correlation. Initially, an endorectal coil alone was used. Subsequent enhancements included the use of T1 gadolinium enhancement in the latter 40 patients, the introduction of fast spin-echo technique with and without fat suppression, the use of glucagon to diminish artifact from rectal peristalsis, an increase in the volume of air in the endorectal balloon to 100 mL, and the addition of an external multicoil system coupled to the endorectal coil. Initially, the criteria for extraprostatic disease were those usually evaluated. Additional criteria used by these authors include a qualitative assessment of tumor volume, tumor extension to the apex, contour bulging, and broad areas of tumor applied to the prostate capsule. The authors found that motion artifact was reduced by glucagon, fast spin-echo sequences, and balloon inflation. T2 weighting and fast spin-echo IR imaging helped to identify hemorrhage outside of tumors. As reported by Chelsky et al, these authors found bulging capsular margins to be an unreliable indicator for stage C disease. They did not find gadolinium enhancement to be useful. Taking into account the elaborate use of the newest technology described by these authors, their preliminary results are sobering. They report a prospective staging accuracy for all 70 patients of only 51%. Of 27 pathologic stage B patients, 15 were overstaged, and 18 of 42 stage C patients were understaged.

The RDOG has published a three-way comparison of (1) body coil MRI alone, (2) body coil MRI and fat suppression, and (3) endorectal coil MRI. The staging accuracy was 61%, 64%, and 54%, respectively. The authors point out that staging accuracy was improved by reading body coil images in conjunction with endorectal coil images, but this was variable among readers, with the best result -- only 79% -- obtained by the most experienced reader in the group. Hricak and associates have reported improved staging accuracy with an integrated endorectal coil–pelvic phased-array technique when compared to results with pelvic phased array only. They stress, however, the importance of patient preparation and the need to establish standardized techniques. Clearly, further systematic evaluations of these new technologies are needed and will be forthcoming.

**Computed Tomography in the Staging of Prostatic Cancer**

Hricak et al have compared the accuracy of computed tomography (CT) staging of clinically localized prostatic cancer to that of a series of body coil MRI protocols. They found a statistically significant advantage for MRI utilizing multiplanar imaging and both T1 and T2 weighting. In their analysis, MRI derived its advantage from the ability to image structures in a multiplanar fashion and from its superior soft-tissue contrast. These characteristics were particularly helpful in evaluating the pelvic floor, bladder base, and seminal vesicles. In addition, MRI was better able to distinguish periprostatic blood vessels from the adjacent prostatic capsule. In a contemporaneous report, Platt and colleagues evaluated CT performance among 32 patients, also with postprostatectomy pathology correlation. Local invasion into prostatic capsule was suggested on CT by marked asymmetry of the periprostatic fat, presence of distinct focal masses, or involvement of adjacent structures. Local invasion of the seminal vesicles was suggested by marked asymmetry or by obliteration of the angle of the seminal vesicle. They found CT to have a sensitivity of 50% for extraprostatic disease. Of particular concern was the low accuracy in evaluation of the seminal vesicle, with 2 of 3 instances of invasion missed and, more seriously, with 23 false-positive diagnoses of invasion. These patients would be incorrectly upstaged and deprived of potentially curative surgery.
In an attempt to determine whether optimal conceivable CT imaging could improve on these disappointing results, Rorvik and colleagues19 imaged 19 patients prior to prostatectomy with a "refined" CT procedure. They used a 3-mm slice thickness with a 5-mm slice space. The field of view was 12 cm. A reconstruction algorithm with 0.4-mm spatial resolution and a 512 × 512 scan matrix was used. In this fashion, the pixel size was reduced to 0.23 mm. A 3-s scan time and high-dose technique were used along with intravenous and gastrointestinal contrast in all patients. All examinations were performed on a GE 9800 Quick Scanner. Each CT was read independently by two radiologists using the widely accepted criteria suggested by Hricak and colleagues.68 Despite this elaborate effort, the diagnostic accuracy for detecting extraprostatic disease was only 42%, no better than with standard techniques. In addition, interobserver agreement between the two radiologists was no better than chance, calling into question the usefulness of the CT staging criteria. Acknowledging the inadequacies of both TRUS and MRI staging, the authors conclude that CT cannot be made equivalent. The same conclusions have been offered by the authors of the RDOG multi-institutional cooperative trial in explanation of their not including CT in the study protocol.71

Current Role of Imaging in Screening and Staging of Prostatic Cancer

Both DRE and PSA determination are the basis of screening for prostatic cancer, while TRUS is useful as a second-tier screening tool and an aid to biopsy.72,73 As reflected in the preceding discussions, neither MRI nor TRUS, although providing better accuracy than CT, is a reliable tool for staging prostatic cancer. This is highlighted by the RDOG multi-institutional trial results, with MRI having an overall staging accuracy of 69% and TRUS 58% (P value not significant).34 Preoperative staging can reliably identify only the most blatant examples of extraprostatic disease. With regard to lymph node disease, CT and MRI are able to identify only the occasional patient with nodal enlargement, which is per se a nonspecific finding, requiring biopsy to justify a clinical decision. These limitations must always be kept in mind when these modalities are used. It is hoped but by no means proven that newer technology will improve on these results. Bone scanning is the "gold standard" for identifying bone metastasis, but the prevalence of abnormal findings is so low in patients with low PSA values that it is questionable whether this would be useful for patients with PSA values below 15 to 20 ng/mL except in those with highly aggressive histology.

References


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