About the book

Pelvic cancers usually require MR imaging and the revised and updated MRI Manual of Pelvic Cancer Second Edition contains chapters covering all the major pelvic cancers. There are also chapters dealing with basic pelvic anatomy, staging, and imaging techniques. The use of novel MR techniques such as diffusion weighted imaging, dynamic contrast enhancement, and magnetic resonance spectroscopy is integrated appropriately.

The extensive use of high quality MR images makes this book an invaluable bench reference for all those required to commission, order, or report MR pelvic cancer examinations.

New to the Second Edition:
- New imaging techniques applicable to a number of pelvic cancers including cervical, endometrial, ovarian, and vaginal cancer
- Imaging findings post chemotherapy for oesophageal, gastric, bladder and anal cancer
- Imaging findings in brachytherapy for prostate cancer
- A dedicated cancer chapter

A highly useful resource, this guide:
- Presents a comprehensive set of high quality images of pelvic cancers
- Reproduces pelvic cancer staging, MRI techniques, and pelvic anatomy
- Provides a short account of each disease and set of images demonstrating the tumor, node, and metastasis stages
- Contains illustrations of recurrent disease and appearances following chemoradiotherapy
- Discusses imaging before exenterative surgery and the imaging of metastatic disease within the pelvis
- Has a consistent format with the extensive use of high quality MR images of pelvic cancer to aid diagnosis.

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MRI Manual of Pelvic Cancer
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MRI Manual of Pelvic Cancer

Second Edition

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This book is dedicated to
Cuong, Joshua, and Alex
Claire, Max, Felix, and Maxi
Paddy, Rachel, and Helen
Contents

Contributors ...........vii
Preface ...............viii
Acknowledgment ..........ix
Abbreviations ..........x

1. Diagnosis, staging, and follow-up of pelvic tumors: The role of MR imaging .......................................................... 1
   Bernadette M. Carrington

2. MR imaging techniques in pelvic cancer .............................. 3
   Andrew P. Jones, Rohit Kochhar, and Alison Kilburn

3. Anatomy of the pelvis ..................................................... 16
   James O'Connor and Paul A. Hulse

4. Cervical cancer ............................................................. 38
   Bernadette M. Carrington

5. Endometrial cancer .......................................................... 77
   Maryna Brochwicz-Lewinski

6. Ovarian cancer ............................................................ 97
   Soo Y. S. K. Mak and Prakash Manoharan

7. Vaginal cancer ............................................................ 118
   M. Ben Taylor

8. Vulval cancer ............................................................. 135
   Maryna Brochwicz-Lewinski and Jane Hawnaur

9. Rectal cancer .............................................................. 152
   Mike Dobson

10. Anal cancer ............................................................ 178
    Rohit Kochhar and Paul A. Hulse

11. Bladder cancer .......................................................... 201
    Suzanne Bonington

12. Prostate cancer .......................................................... 220
    Claire Barker

13. Penile cancer ............................................................ 236
    Rohit Kochhar and M. Ben Taylor

14. Pelvic metastases ....................................................... 259
    Fenella Wong

15. MRI of residual and recurrent tumor before pelvic clearance surgery .... 288
    Bernadette M. Carrington

Index .... 315
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Preface

Magnetic resonance imaging continues to be an invaluable imaging tool in the staging of pelvic malignancy. In the second edition of this book, the chapters have been extensively revised and incorporate the 2010 UICC/AJCC staging system. A new chapter deals with penile cancer. The evidence for and sensible use of advanced MR techniques such as diffusion-weighted imaging, dynamic contrast enhancement, and magnetic resonance spectroscopy are discussed. There are sections which deal with pitfalls in pelvic cancer MR imaging interpretation. Our intention is that this book will remain a useful bench reference for radiographers who image and radiologists who report pelvic MR examinations as well as being of interest to all those involved in the clinical management of pelvic cancer.

Soo Y. S. K. Mak
Paul A. Hulse
Bernadette M. Carrington
Acknowledgment

Once again a tremendous amount of team work has contributed to this book. In particular, we thank our secretaries Kami Ramnarain, Liz Stockton, Angela Squire, and Jackie Nevins for their work in helping us prepare our manuscripts and images, Kath Westwell our CRIS manager for performing many word searches, and our MR radiographers for constant high-quality imaging.

Finally, we should like to acknowledge our contributors for their extremely hard work and patience in both writing and revising their chapters and we also acknowledge contributions of the following from the first edition: Rhidian Bramley, Neelam Dugar, Jeremy Lawrance, Sue Roach and Susan Todd.
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC</td>
<td>Apparent diffusion coefficient</td>
</tr>
<tr>
<td>AFP</td>
<td>Alpha-fetoprotein</td>
</tr>
<tr>
<td>AIN</td>
<td>Anal intraepithelial neoplasia</td>
</tr>
<tr>
<td>AJCC</td>
<td>American Joint Committee on Cancer</td>
</tr>
<tr>
<td>APR</td>
<td>Abdominoperineal resection</td>
</tr>
<tr>
<td>BLADE</td>
<td>Periodically rotated overlapping parallel lines with enhanced reconstruction</td>
</tr>
<tr>
<td>BPH</td>
<td>Benign prostatic hypertrophy</td>
</tr>
<tr>
<td>CA-125</td>
<td>Cancer/carbohydrate antigen-125</td>
</tr>
<tr>
<td>CEA</td>
<td>Carcinoembryonic antigen</td>
</tr>
<tr>
<td>Cho</td>
<td>Choline</td>
</tr>
<tr>
<td>Ci</td>
<td>Citrate</td>
</tr>
<tr>
<td>CIN</td>
<td>Cervical intraepithelial neoplasia</td>
</tr>
<tr>
<td>Cr</td>
<td>Creatine</td>
</tr>
<tr>
<td>CRT</td>
<td>Chemoradiotherapy</td>
</tr>
<tr>
<td>CSI</td>
<td>Chemical shift imaging</td>
</tr>
<tr>
<td>CT</td>
<td>Computed tomography</td>
</tr>
<tr>
<td>DCE</td>
<td>Dynamic contrast enhancement/enhanced</td>
</tr>
<tr>
<td>DRE</td>
<td>Digital rectal examination</td>
</tr>
<tr>
<td>DTPA</td>
<td>Diethylenetriamine pentaacetic acid</td>
</tr>
<tr>
<td>DWI</td>
<td>Diffusion-weighted imaging</td>
</tr>
<tr>
<td>ERC</td>
<td>Endorectal coil</td>
</tr>
<tr>
<td>EBRT</td>
<td>External beam radiotherapy</td>
</tr>
<tr>
<td>EGFR</td>
<td>Extracellular growth factor receptors</td>
</tr>
<tr>
<td>EMVI</td>
<td>Extramural vascular invasion</td>
</tr>
<tr>
<td>EORTC</td>
<td>European Organisation for Research and Treatment of Cancer</td>
</tr>
<tr>
<td>EPI</td>
<td>Echo planar imaging</td>
</tr>
<tr>
<td>EUA</td>
<td>Examination under anesthesia</td>
</tr>
<tr>
<td>FAME</td>
<td>Three-dimensional fast SPGR pulse sequence</td>
</tr>
<tr>
<td>5-FU</td>
<td>5-Fluorouracil</td>
</tr>
<tr>
<td>FDG PET-CT</td>
<td>18-Fluorodeoxyglucose positron emission tomography and computed tomography</td>
</tr>
<tr>
<td>FFE</td>
<td>Fast field echo</td>
</tr>
<tr>
<td>FIESTA</td>
<td>Fast imaging employing steady state acquisition</td>
</tr>
<tr>
<td>FIGO</td>
<td>Federation Internationale Gynecologie et Oncologie</td>
</tr>
<tr>
<td>FISP</td>
<td>Fast imaging steady state precession</td>
</tr>
<tr>
<td>FOV</td>
<td>Field of view</td>
</tr>
<tr>
<td>FS</td>
<td>Fat saturation</td>
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<tr>
<td>FSE</td>
<td>Fast spin echo</td>
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<tr>
<td>Gd</td>
<td>Gadolinium</td>
</tr>
<tr>
<td>GE</td>
<td>Gradient echo</td>
</tr>
<tr>
<td>GEPDI</td>
<td>Gradient echo proton density image</td>
</tr>
<tr>
<td>GI</td>
<td>Gastrointestinal</td>
</tr>
<tr>
<td>HCG</td>
<td>Human chorionic gonadotrophin</td>
</tr>
<tr>
<td>HIV</td>
<td>Human immunodeficiency virus</td>
</tr>
<tr>
<td>HNPCC</td>
<td>Hereditary nonpolyposis colorectal cancer</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
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<tr>
<td>HPV</td>
<td>Human papillomavirus</td>
</tr>
<tr>
<td>HRT</td>
<td>Hormone replacement therapy</td>
</tr>
<tr>
<td>IVC</td>
<td>Inferior vena cava</td>
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<tr>
<td>IAF</td>
<td>Ischioanal fossa</td>
</tr>
<tr>
<td>IOG</td>
<td>Improving outcomes guidance</td>
</tr>
<tr>
<td>JSM</td>
<td>Jewett-Strong-Marshall</td>
</tr>
<tr>
<td>KRAS gene</td>
<td>v-Ki-ras2 Kirsten rat sarcoma viral oncogene homolog</td>
</tr>
<tr>
<td>LAVA</td>
<td>Liver acquisition with volume acceleration</td>
</tr>
<tr>
<td>MIP</td>
<td>Maximum intensity projection</td>
</tr>
<tr>
<td>MR</td>
<td>Magnetic resonance</td>
</tr>
<tr>
<td>MRS</td>
<td>MR spectroscopy</td>
</tr>
<tr>
<td>MSAD</td>
<td>Maximum short axis diameter</td>
</tr>
<tr>
<td>NICE</td>
<td>National Institute for Health and Clinical Excellence</td>
</tr>
<tr>
<td>PACS</td>
<td>Picture archiving and communication system(s)</td>
</tr>
<tr>
<td>PA</td>
<td>Polyamine</td>
</tr>
<tr>
<td>P53</td>
<td>Protein 53 gene</td>
</tr>
<tr>
<td>PIN</td>
<td>Prostatic intraepithelial neoplasia</td>
</tr>
<tr>
<td>PROPELLER</td>
<td>Periodically rotated overlapping parallel lines with enhanced reconstruction (Siemens)</td>
</tr>
<tr>
<td>PSA</td>
<td>Prostate-specific antigen</td>
</tr>
<tr>
<td>Rb</td>
<td>Retinoblastoma tumor suppressor gene</td>
</tr>
<tr>
<td>RF</td>
<td>Radiofrequency</td>
</tr>
<tr>
<td>ROC</td>
<td>Receiver operating characteristics</td>
</tr>
<tr>
<td>ROI</td>
<td>Region of interest</td>
</tr>
<tr>
<td>SCC</td>
<td>Squamous cell carcinoma</td>
</tr>
<tr>
<td>SNP</td>
<td>Single nucleotide polymorphism</td>
</tr>
<tr>
<td>SPAIR</td>
<td>Spectral adiabatic inversion recovery</td>
</tr>
<tr>
<td>SPIO</td>
<td>Super-paramagnetic iron oxide</td>
</tr>
<tr>
<td>SPIR</td>
<td>Spectral presaturation with inversion recovery</td>
</tr>
<tr>
<td>STIR</td>
<td>Short tau inversion recovery</td>
</tr>
<tr>
<td>SV</td>
<td>Seminal vesicle</td>
</tr>
<tr>
<td>T1WI</td>
<td>T1-weighted image(s)</td>
</tr>
<tr>
<td>T2WI</td>
<td>T2-weighted image(s)</td>
</tr>
<tr>
<td>TEs</td>
<td>Echo times</td>
</tr>
<tr>
<td>THRIVE</td>
<td>Ultrafast spoiled gradient echo</td>
</tr>
<tr>
<td>Tis</td>
<td>Carcinoma in situ</td>
</tr>
<tr>
<td>TME</td>
<td>Total mesorectal excision</td>
</tr>
<tr>
<td>TNM</td>
<td>Tumor node metastasis</td>
</tr>
<tr>
<td>TR</td>
<td>Repetition time</td>
</tr>
<tr>
<td>TRUS</td>
<td>Transrectal ultrasound</td>
</tr>
<tr>
<td>TSE</td>
<td>Turbo spin echo</td>
</tr>
<tr>
<td>TURP</td>
<td>Transurethral resection of the prostate</td>
</tr>
<tr>
<td>UICC</td>
<td>Union Internationale Contre le Cancer</td>
</tr>
<tr>
<td>UKCCCR</td>
<td>United Kingdom Coordinating Committee on Cancer Research</td>
</tr>
<tr>
<td>US</td>
<td>Ultrasound</td>
</tr>
<tr>
<td>USPIOs</td>
<td>Ultrasmall paramagnetic iron oxide</td>
</tr>
<tr>
<td>VAIN</td>
<td>Vaginal intraepithelial neoplasia</td>
</tr>
<tr>
<td>VIBE</td>
<td>Modified three-dimensional fast gradient echo sequence</td>
</tr>
<tr>
<td>VIN</td>
<td>Vulval intraepithelial neoplasia</td>
</tr>
</tbody>
</table>
Diagnosis, staging, and follow-up of pelvic tumors: The role of MR imaging

Bernadette M. Carrington

INTRODUCTION
Cancer is due to an abnormal proliferation of cells which are resistant to normal regulatory mechanisms and which have the propensity to infiltrate the host organ, to invade locally and to activate mechanisms which allow more widespread dissemination through the body via blood vessels or lymphatics.

Critical initial steps in cancer management are tumor confirmation by histological diagnosis and determination of extent by staging. This fundamental information is central to all management decisions and provides prognostic information. Accurate stratification of patients by tumor type and stage is also a prerequisite of cancer research, enabling valid comparison of outcomes between treatment groups. Objective assessment of treatment response is required to facilitate further management decisions and accurately evaluate the efficacy of treatment regimens.

MR imaging plays an important part in pelvic cancer staging and treatment response assessment. Functional MR imaging offers sophisticated tumor analysis and permits more individualized prognostic information, treatment planning and response evaluation.

TUMOR DIAGNOSIS
Tissue confirmation of malignancy is required wherever possible. This may be achieved by cytological analysis of surface accessible lesions, via needle biopsy of deeper masses (often image-guided) or by excision or incision biopsy, which involves resection of all or part of the tumor respectively. Excision biopsy is ideal since it allows accurate histopathological staging of the primary tumor and offers a potential cure. Most pelvic tumors are diagnosed by clinical examination and biopsy at the time of cystoscopy, colposcopy, or rigid sigmoidoscopy. Occasionally, examination under anesthesia is required. MR imaging is then used to locally stage the tumor, and computed tomography (CT) of the thorax and abdomen is performed to look for disseminated metastases. Ultrasound, either transabdominal or transrectal, can be used for primary tumor assessment but is inferior to MRI in depiction of local spread and the detection of regional lymph node metastases.

TUMOR STAGING
Tumor staging requires the accurate identification of local tumor spread and the detection of lymph node or systemic metastases. It can be estimated from the patient’s symptoms, clinical examination findings, and the level of biochemical tumor markers. The histological type and grade of the tumor also correlate with the propensity for extraorgan spread and the early development of metastases.

MR imaging allows multiplanar assessment of tumor extent within and beyond the organ of origin. Two- to three-millimeter thin-section (“high-resolution”) turbo spin echo T2-weighted sequences are needed, usually in the orthogonal planes but occasionally utilizing off-axis imaging perpendicular to the tumor. The intramuscular injection of smooth muscle relaxants such as hyoscine butylbromide (Buscopan®) has been shown to improve image quality and diagnostic confidence in pelvic cancer imaging. In addition to imaging the true pelvis, it is recommended that at least one MR imaging sequence be performed through the abdomen to allow evaluation of the retroperitoneal nodal stations and visualization of the lumbar skeleton and kidneys.

Machine time constraints do not usually permit full MR imaging of the liver, and small volume omental and mesenteric disease may not be identified without increased patient scan time and the use of intravenous contrast media. Moreover, the lungs are suboptimally assessed by MR imaging. Therefore, it is often necessary to image the thorax and abdomen using CT to provide as accurate an imaging tumor stage as possible. Additional need for extrapelvic imaging to stage patients will be included in the chapters dealing with individual malignancies.

The MR examination should be correlated with clinical, biochemical, surgical, and pathological findings to improve image interpretation and provide the patient with as accurate a tumor stage as possible.

TUMOR STAGING SYSTEMS
Tumor staging systems are internationally agreed graduated classifications of tumor spread.

All the tumor staging systems incorporate common principles:

- There is a gradation from “early” confined tumors, which are given low numbers in the classification systems, to “late” more widespread tumors, which are given higher numbers. The presence and number or size of lymph node metastases are treated similarly. Visceral and bone metastases are grouped in a general metastasis category but are not quantified.
- Each primary tumor has an individual staging classification tailored to its pattern of spread. The difference between tumor extent for each step is clearly demarcated.
- The systems must be easily and consistently applicable, forming a shorthand summary of the tumor extent which is understood within the national and international cancer community.
- The precise information supplied must be of relevance to therapeutic decision making.
The exchange of information is facilitated between different cancer organizations. The most commonly used staging system is the Tumor Node Metastasis (TNM) classification, which has common stratification groups for each tumor type. The TNM cancer staging classifications are reviewed regularly by the International Union against Cancer (Union Internationale Contre le Cancer, UICC) with contributions from associated national and international organizations. The American classification is the “AJCC Cancer Staging Manual” produced by the American Joint Committee on Cancer and it correlates exactly with the TNM classification. For gynecological malignancy, there is also the Federation Internationale Gynecologie et Obstetrique (FIGO) classification and for bladder cancer there is the Jewitt–Strong–Marshall classification, which is principally used in the United States. Colorectal cancer may be staged using the Dukes’ classification, principally in the United Kingdom.

STAGE MIGRATION (STAGE SHIFT)
Two factors contribute to the phenomenon of stage migration. The first is the periodic amendments all cancer staging systems undergo, which may lead to tumors being up- or downstaged in the new system. The second is the impact of cross-sectional imaging, which generally upstages more tumors than it downstages when compared to clinical staging. This results in fewer patients categorized as having early stage disease and more patients categorized as having later stage disease, with an overall apparent improvement in survival, stage for stage, compared with nonimaged patients. This is because the patients who are radiologically upstaged usually have a smaller volume of disease than those who are clinically categorized as belonging to the same stage. The upstaged patients are likely to improve the overall survival rate for the higher stage group and may also result in better tumor response rates. In addition, the early stage disease group is less confounded by inaccurate clinical staging of patients with more advanced tumors, and so this group too will appear to have improved tumor response rates and survival.

The stage migration phenomenon should be remembered when interpreting modern clinical trial results and comparing them to historical controls. In this situation, stage migration may contribute to spurious increased efficacy of the new therapies.

FURTHER READING
MR imaging techniques in pelvic cancer

Andrew P. Jones, Rohit Kochhar, and Alison Kilburn

MR IMAGING EQUIPMENT
Superconducting 1.5-T MR scanners have now become the standard for clinical imaging. While there are options for lower-field open systems and a growing trend toward wider bore, shorter-length superconducting magnets, the horizontal bore 1.5-T magnet with the latest multiple-receiver technology generally provides the optimal specification for pelvic MR imaging in oncology.

Higher-field 3-T imaging is emerging as a platform for research and, although some technical barriers still remain, these machines may become the systems of choice for MR body imaging. Three-Tesla systems offer higher signal-to-noise and contrast-to-noise ratios resulting in shorter-image acquisition times or improved resolution for some pelvic applications. Changes in T1 and T2 relaxation times, increased sensitivity to magnetic susceptibility, and radio frequency (RF) energy deposition have required the implementation of sequence and hardware adaptations to realize the full benefits of 3-T imaging. Also, within the abdomen and pelvis, RF field inhomogeneity resulting from dielectric effects within tissues has been a problem when using larger fields of view and can lead to standing wave effects and large local variations in signal intensity. The most recent application of parallel transmission techniques or multitransmit coil designs have addressed these problems with significant improvements in image quality for body imaging at 3 T. Many issues surrounding MR device compatibility and safety have yet to be fully addressed at 3 T mainly due to a lack of information and testing data for many devices. In comparison to a 1.5-T system, 3-T systems are more expensive to buy and operate, which has prevented widespread uptake in the clinical setting.

Recent technical advances in equipment have resulted in a stabilized magnetic field gradient specification, an escalation in the number of independent receive channels and an improved range of multielement receiver coils. Standard magnetic field gradient performance with maximum amplitudes of approximately 30 mT/m and slew rates of 125 T/m/sec provide satisfactory imaging performance for pelvic imaging where very small field of views (FOVs) are not required and appropriate b-values for diffusion-weighted imaging (DWI) can easily be achieved. Higher-level gradients of maximum amplitudes of approximately 45 mT/m and slew rates of 250 T/m/sec can provide advantages for better optimized echo times and echo train lengths. The latest receiver technology utilizing multiple receive channels and multielement receiver coils provides significant benefits for pelvic imaging, which requires maximum signal-to-noise ratio for large FOVs. Systems using 16- to 18-channel receivers offer performance that matches the requirements of the majority of multielement body coils used in pelvic imaging and allow the use of parallel imaging techniques. Increased receiver channels of 32 and greater may establish a role for combined pelvic and abdominal imaging or emerging whole body applications.

Modern MR systems conventionally have multielement body coils for imaging the pelvis. An array or matrix of coil elements positioned anteriorly are matched with a paired matrix positioned posteriorly or with the matrix of coils in the spine coil. Endorectal coils can provide an increase in signal-to-noise ratio for small FOV applications, for instance in prostate imaging, but physical tissue distortion of the wall of the rectum and signal flaring directly adjacent to the coil can impact on image interpretation.

MR IMAGING PROTOCOLS
Patient Preparation and Care
The interaction between the patient and the radiographic/ technological staff is essential in ensuring a successful examination. Most patients with cancer will be motivated to cooperate but could have difficulty complying due to pain, claustrophobia, or psychological stress. With careful explanation and sympathetic handling, patients are often able to cooperate fully. Time spent in making them as comfortable as possible before the examination, assisting them during the examination, and praising their efforts afterwards may ensure that the current examination is satisfactory and, importantly, that the patient is happy to undergo follow-up MR examinations.

For all pelvic cancers, a standardized imaging protocol should be agreed so as to

- ensure that imaging covers all the potential regions of tumor spread within the pelvis;
- keep scan times to the minimum necessary for patient comfort and efficient use of the MR equipment;
- allow comprehensive interpretation of the examination;
- ensure reproducibility of subsequent MRI examinations.

The administration of Buscopan® (hyoscine-N-butylbromide) to reduce bowel peristalsis can provide significant benefits in some pelvic imaging applications where involuntary bowel motion degrades image quality.

Accepted practice involves the use of orthogonal plane T1-weighted (T1W) and T2-weighted (T2W) sequences with off-axis planes or additional sequences being used for well-defined indications.

T1W Sequences (Spin Echo or Gradient Echo)
T1W sequences give an overview of the abdomen and pelvis for detection of lymph node enlargement, bone marrow metastases, and hydronephrosis and hydroureter (Fig. 2.1). They allow
evaluation of tumor bulk, extension into pelvic fat, and provide some tissue-specific information, for example, the presence of hemorrhage and water. They are most commonly performed in the coronal and transaxial planes (Figs. 2.2–2.7).

**T2W Sequences (Fast or Turbo Spin Echo)**

T2W sequences demonstrate the zonal anatomy of the pelvic viscera and nearly always clearly identify the primary tumor and its local extent. They are usually performed in three orthogonal planes.

**Chemical Fat Saturation**

Chemical- or frequency-selective fat saturation techniques rely on the difference in resonant frequencies of water and fat and their resultant chemical shift of 3.5 ppm (220 Hz at 1.5 T). A saturation pulse centered only over the frequency for fat can selectively remove the signal contribution of fat from the image (Fat Sat and SPIR). The fat saturation pulse is normally delivered for each repetition period (TR) which leads to an increased TR and longer acquisition times. The impact of fat saturation varies with sequence type. Nonuniformity of the RF pulse may cause incomplete fat suppression, but this can be improved by SPAIR sequence, particularly in difficult body regions where there are tissue/air/bone boundaries. The sequence requires extended TE’s, so is usually employed in T2-weighted fat suppression. The chemical shift between water and fat can also be exploited by using a frequency-selective excitation pulse at the water frequency (water excitation), resulting in the selective excitation of only water with no contribution from fat in the resulting images. In general, fat saturation techniques can be applied to both T1W and T2W sequences (Fig. 2.8). They are useful to delineate primary tumor extension into fat and to distinguish fat within lesions (e.g., ovarian masses).

**Imaging Protocols for Specific Cancer Types**

DWI and dynamic contrast-enhanced imaging (DCE) are increasingly being applied to a variety of imaging protocols within the pelvis. However, because these techniques are relatively new in terms of routine application, they have not been included in the basic imaging protocol descriptions given below. These techniques are discussed in more detail later in this chapter.

All the following examination protocols will require the T1W overview sequences detailed in Table 2.1 plus the T2W/other sequences specified in Table 2.2.

**ARTIFACTS AND STRATEGIES FOR REDUCTION**

The main artifacts encountered in MR pelvic imaging are motion and flow related. Motion within the pelvis can arise from respiratory movement, although in most patients this is minimal. Bowel peristalsis produces the more significant artifact of ghosting, which is blurring propagated in the phase encoding direction. Pulsatile flow artifacts arising from arterial blood are most noticeable on STIR sequences and postcontrast T1W images where the dominant high-signal structure on the image is blood.

Chemical shift artifacts, arising from the differing resonant frequencies of water and fat, historically caused problems in pelvic imaging. Currently, utilization of higher receiver bandwidths to achieve rapid signal sampling means that chemical shift artifacts are negligible.

Standard techniques such as the application of saturation bands, choice of phase encoding direction, and the use of multiple signal averages can reduce the impact of artifacts from respiratory motion and blood flow. Parallel imaging techniques allow change of phase encoding direction and include phase oversampling to avoid aliasing with no increase of scan time. Similarly, where signal-to-noise ratio is sufficient, the use of parallel imaging factors of 2 and greater enable multiple signal averages to be included to reduce the impact of flow and respiratory motion with only limited impact on scan times.

Potential problems with motion artifacts in non-breath-hold techniques can be minimized using free-breathing approaches. These new data acquisition strategies are generally either continuous, with retrospective selection and reordering of phase-encoding steps, or prospective using navigator echo techniques to selectively gate the acquisition according to respiratory motion. Nearly all such acquisition techniques, which involve the selective acquisition of data, require an increase in scan time. They are most applicable to imaging the upper abdomen and are not usually required for pelvic MR imaging.

Techniques originally designed for head imaging such as BLADE and PROPELLER have now been very successfully used throughout the body to allow compensation for some motion artifacts. They use an incremented set of radial segments of k-space lines, which produce data filling within k-space with overlapping spokes of a wheel. The effective repeat sampling of the central region of k-space where the “blades” or “propellers” overlap results in a reduction of the effects of primarily in-plane motion. Overall acquisition times can be slightly greater, but good-quality T2W or proton density images are often obtained in uncooperative or difficult patients.

As with all MR imaging, effective preparation of the patient and good positioning, so that he or she is comfortable and relaxed, reduce the likelihood of generalized patient movement.

**CONTRAST ENHANCEMENT TECHNIQUES**

Intravenous injection of a gadolinium-based contrast agent is not routinely employed in pelvic imaging for malignancy. This is largely due to

- the inherent contrast differences between tumors and pelvic organs and tissues on T2W images;
- the enhancement of both tumors and normal pelvic organs, which can decrease tumor conspicuity.

However, a contrast agent injection may be valuable in certain instances:

1. **Nondynamic injection**
   - To clarify the composition of complex ovarian tumors
   - To determine the extent of sarcoma spread
   - To delineate the extent of disease or treatment effect within muscle groups
   - To predict or identify response to treatment

2. **Dynamic injection of a contrast bolus**
   - To identify the tumor site in prostate cancer
   - To assess the depth of myometrial and bladder wall involvement in patients with endometrial or bladder cancer
<table>
<thead>
<tr>
<th>Sequence Weighting Plane</th>
<th>Typical TE (ms), TR (ms), Flip angle</th>
<th>TSE factor (ETL)</th>
<th>Parallel imaging factor</th>
<th>Signal averages</th>
<th>Slice thickness (mm)</th>
<th>Phase encoding direction</th>
<th>Phase oversampling (%)</th>
<th>Field of view, frequency (cm) x phase frequency</th>
<th>Matrix size (phase x frequency)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1W 3 planes (scout)</td>
<td>TR 20, TE 5, 40°</td>
<td>0</td>
<td>None</td>
<td>1</td>
<td>10</td>
<td>A-P</td>
<td>0%</td>
<td>49 x 100%</td>
<td>128 x 256</td>
<td>To plan subsequent slice positions</td>
</tr>
<tr>
<td>T1W Coronal</td>
<td>TR 669, TE 20 90°, 150°</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>R-L</td>
<td>30%</td>
<td>49 x 100%</td>
<td>256 x 512</td>
<td>1 presaturation band to cover anterior abdominal wall</td>
</tr>
<tr>
<td>T1W Transaxial Pelvis</td>
<td>TR 400, TE 12 90°, 180°</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>R-L</td>
<td>25%</td>
<td>38.3 x 100%</td>
<td>256 x 512</td>
<td>Parallel presaturation band superior to slice block</td>
</tr>
<tr>
<td>T1W Transaxial Abdomen</td>
<td>TR 208, TE 476 70°, 180°</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>5.5</td>
<td>A-P</td>
<td>0%</td>
<td>38 x 68.8%</td>
<td>109 x 256</td>
<td>Inferior and superior presaturation bands parallel to slice block</td>
</tr>
<tr>
<td>T2W Sagittal</td>
<td>TR 5390, TE 102 90°, 150°</td>
<td>17</td>
<td>Not used routinely</td>
<td>3</td>
<td>3</td>
<td>A-P</td>
<td>20%</td>
<td>20 x 100%</td>
<td>210 x 256</td>
<td>Presaturation band positioned over anterior pelvic wall fat and superior to slice block</td>
</tr>
<tr>
<td>T2W Transaxial (oblique for cervix and rectum)</td>
<td>TR 5030, TE 102 90°, 150°</td>
<td>17</td>
<td>Not used routinely</td>
<td>2</td>
<td>3</td>
<td>R-L</td>
<td>100%</td>
<td>20 x 100%</td>
<td>210 x 256</td>
<td>Inferior and superior presaturation bands parallel to slice block</td>
</tr>
<tr>
<td>T2W Coronal (oblique for prostate)</td>
<td>TR 5000, TE 102 90°, 150°</td>
<td>17</td>
<td>Not used routinely</td>
<td>2</td>
<td>3</td>
<td>R-L</td>
<td>100%</td>
<td>20 x 100%</td>
<td>210 x 256</td>
<td>Fat Sat used occasionally</td>
</tr>
<tr>
<td>DWI Transaxial</td>
<td>TR 4100, TE 82</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>A-P</td>
<td>0%</td>
<td>38 x 81.3%</td>
<td>156 x 192</td>
<td>b-value = 0(50), 100, 300, 600</td>
</tr>
<tr>
<td>DWI Transaxial</td>
<td>TR 4300, TE 88</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>A-P</td>
<td>0%</td>
<td>38 x 81.3%</td>
<td>156 x 192</td>
<td>b-value = 1000</td>
</tr>
<tr>
<td>T1 3D Gradient echo (VIBE or equivalent) Sagittal</td>
<td>TR 5.98, TE 2.76 10°</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2.5</td>
<td>A-P</td>
<td>8%</td>
<td>38 x 81.3%</td>
<td>146 x 256</td>
<td>Temporal resolution 30 sec x 5 measurements</td>
</tr>
<tr>
<td>T1 3D Gradient echo (VIBE or equivalent) Transaxial</td>
<td>TR 3.5, TE 1.32 25</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>R-L</td>
<td>56%</td>
<td>32 x 75%</td>
<td>101 x 192</td>
<td>Temporal resolution 3 sec x 100 measurements</td>
</tr>
</tbody>
</table>

Abbreviations: ETL, echo train length; DWI, diffusion-weighted imaging. VIBE, volume interpolated breath-hold examination.
To obtain physiological information about tumor perfusion, oxygenation, and angiogenesis
To differentiate tumor from inflammation or posttreatment fibrosis in bladder cancer

Dynamic Contrast Enhancement
Dynamic postcontrast imaging is usually achieved using specialized 3D sequences. These 3D volume fat saturated gradient echo sequences use short TE and TRs, along with k-space interpolation techniques, to minimize acquisition times. Such rapid 3D volume acquisition times enable multiple volume acquisitions during the arterial, venous, and delayed phases of contrast circulation.

Dynamic contrast enhancement (DCE) techniques can be used to assess tumor perfusion, oxygenation, and angiogenesis, employing modifications of methods first developed in cerebral studies usually based on dynamic T1 contrast enhancement. Signal enhancement curves obtained are mathematically fitted using a variety of pharmacokinetic models, and promising

---

Table 2.2 Examination Protocols for Pelvic Cancers

<table>
<thead>
<tr>
<th>Examination protocol</th>
<th>Sequences</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vulva</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>T2W sequences in all three orthogonal planes</td>
</tr>
<tr>
<td>Vagina</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>Sequence to cover vagina</td>
</tr>
<tr>
<td>Endometrium</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>Midline to cover endometrium and vagina. Use to plan transaxial sequences</td>
</tr>
<tr>
<td>Cervix uteri</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>To cover whole of the endometrium. One block perpendicular to the endometrium and a second block parallel to the endometrium</td>
</tr>
<tr>
<td>Ovary</td>
<td>T2W transaxial, T2W coronal, T2W sagittal</td>
<td>One block positioned over cervix uteri and angled 90° to the endocervical canal, the second block positioned over the cervix uteri and variably angled perpendicular to the plane that needs to be assessed, e.g., posterior bladder/anterior rectum</td>
</tr>
<tr>
<td>Prostate</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>To include seminal vesicles to apex of prostate from perineum up</td>
</tr>
<tr>
<td>Bladder</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>Oblique sequence to include seminal vesicles, position parallel to prostatic urethra</td>
</tr>
<tr>
<td>Rectum</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>Sequence to include the whole area of interest</td>
</tr>
<tr>
<td>Sigmoid colon</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>T2W sequences in all three orthogonal planes to cover whole bladder. May need to increase slice thickness up to 6 mm depending on distension of the bladder</td>
</tr>
<tr>
<td>Pelvic floor, urethra, and anus</td>
<td>T2W sagittal, T2W transaxial, T2W coronal</td>
<td>T2W sequences in all three orthogonal planes positioned to include disease, ensure FOV is positioned low when scanning the anus</td>
</tr>
<tr>
<td>Penis</td>
<td>T2W sagittal, T2W coronal</td>
<td>Midline to include penis and sacrum. May need a larger FOV for coverage. No anterior saturation band</td>
</tr>
<tr>
<td>Bone metastases</td>
<td>T2W transaxial, STIR coronal, T1W transaxial, T1W coronal</td>
<td>One or two blocks to cover penis and scrotum inferiorly to above the bladder</td>
</tr>
<tr>
<td>Pelvic lymph node metastases</td>
<td>T2W transaxial, T1W coronal</td>
<td>One or two overlapping blocks to cover from bifurcation of the aorta to below symphysis pubis</td>
</tr>
<tr>
<td>Recurrent tumor</td>
<td>T2W sequences, T2W sagittal, T2W transaxial, T2W coronal</td>
<td>Follow site-specific T2W sequences as suggested</td>
</tr>
<tr>
<td>Pelvic clearance</td>
<td>T2W sequences, T2W sagittal, T2W transaxial, T2W coronal</td>
<td>T2W sequences in all three orthogonal planes to include pelvic side walls, and from sacral promontory down to symphysis pubis</td>
</tr>
</tbody>
</table>

T1W (three-plane) scout sequence and T1W coronal and T1W transaxial are performed for all protocols in addition to the specific sequences listed. Abbreviation: FOV, field of view.

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MR IMAGING TECHNIQUES IN PELVIC CANCER

NEW EMERGING TECHNIQUES

Diffusion-Weighted Imaging

DWI is an established technique for body imaging. Improvements in magnetic field homogeneity and sequence optimization using automated phase maps to optimize the magnetic field homogeneity over the imaging volume have resulted in good-quality DWI techniques. Faster imaging sequences, generally using echo planar imaging (EPI) signal readout, permit the use of multiple signal averages (typically 6-10) in combination with parallel imaging to reduce motion effects and permit acquisitions times of two to three minutes. The use of parallel imaging techniques reduces the echo train length of the DWI sequence EPI readout and hence the effective TE, producing a decreased sensitivity to magnetic field inhomogeneities, which can greatly affect image quality within the pelvis.

DWI still remains very sensitive to susceptibility effects that arise from metallic objects or biomedical implants within or close to the imaging volume, as well as hemorrhage where there is a breakdown of blood products containing iron. Both cause signal voids and distortion within the DWI images. In some circumstances, it may be possible to alter image slice positions or orientation to minimize the impact of this susceptibility artifact.

DWI produces an image contrast that results from inherent differences in the restriction of movement of water molecules. Pelvic cancers have been shown to have significantly lower apparent diffusion coefficient (ADC) values compared with normal tissue, with ADC values showing promise as a biomarker for treatment response. In general, DWI is helpful in staging known malignancies, differentiating benign from malignant lesions, and assessing treatment response or identifying disease recurrence (Fig. 2.10).

In clinical practice, DWI normally acquires images at three or more different b-values to allow calculation of the ADC. These b-values always include one or more low b-values (0 or 50 sec/mm²) and a high-b-value (usually about 600-1000 sec/mm²). The choice of the b-values influences both the image appearance of lesions with restricted diffusion on the DWIs and the accuracy of the calculated ADC values and ADC maps. Unfortunately, there is no absolute value of ADC which can be used to identify cancer in the pelvis, as several normal tissues such as lymph nodes, endometrium, and bowel, along with fibrosis, can have low ADC values.

DWI data sets can be combined and fused with conventional MR images to correlate information. High-b-value images showing tumors of high cellularity as high signal can be fused with T2W images to improve the visualization of the depth of tumor invasion, for example, providing enhanced detail compared to T2W images alone.

1H MR Spectroscopy

Multivoxel 1H spectroscopy or chemical shift imaging (CSI) has been applied to the brain for some time. However, CSI techniques have more recently been used for examination of prostate cancer (Fig. 2.11). 1H spectra show changes in creatine (Cr) and choline (Cho) signals in the presence of tumor and a metabolite signal from citrate (Ci), which is present only in normal healthy tissue. In prostate cancer, spectral changes have been reported as being present, despite normal imaging appearances. The spectroscopy provides important information on disease spread in the peripheral zone and in the neurovascular bundle and can be used to guide biopsies, monitor response to treatment, and for the assessment of possible recurrence. Recently, reductions in CSI voxel size have improved the resolution of the CSI data, although best results are reported for endocavity coils rather than pelvic-phased array coils.

A number of studies have produced numerical data for [Cho + Cr]/[Ci] ratios in malignancy versus normal tissue or in benign prostatic hyperplasia (BPH). However, a number of problems still exist with this approach because citrate is a strongly coupled resonance and the spectral shape of this resonance depends on magnetic field strength and pulse sequence timing. Therefore, variations are seen in quantification of the citrate peak between different MR systems. The use of ratios of the metabolites also seems to be more robust in the peripheral zone because of regional variations of citrate within normal prostate. It is now widely recognized that polyamine (PA) resonances, predominantly from spermine, feature in prostate MRS and appear between choline and creatine. Hence, numbers that are quoted as [Cho + Cr]/[Cr] are actually [Cho + PA + Cr]/[Cr]. There is also evidence that polyamine is reduced in malignancy so that at the very least this may be a confounding factor in many earlier published studies. It is important to appreciate that all the other imaging techniques, including DWI, will in the future contribute to the complete examination.
**Figure 2.1** Coronal T1WI of the abdomen and pelvis demonstrating lymph node metastases (arrows).

**Figure 2.2** Transaxial T1WI of the pelvis showing the corpus uteri (intermediate signal intensity, straight arrow) and low signal intensity adnexal cysts (curved arrows).

**Figure 2.3** (A) Transaxial T2WI with phase encoding direction anterior to posterior with ghosting artifact (arrows). (B) Transaxial T2WI with phase encoding direction left to right showing greatly reduced ghosting artifact.
Figure 2.4  (A) Sagittal T2WI of the female pelvis showing image degradation as a result of peristalsis (arrows). (B) Sagittal T2WI of the female pelvis post administration of an antispasmodic agent. The cervical tumor and its relationship with the bladder wall (straight arrow) and rectum (curved arrow) are more clearly visualized.

Figure 2.5  (A) Sagittal T2WI of the female pelvis showing the plane of transaxial oblique slices perpendicular to the endocervical canal (white line). (B) Transaxial oblique T2WI of the female pelvis along the plane illustrated in A. The intact fat plane between the cervix uteri and the bladder is clearly visualized (arrows).
Figure 2.6  (A) Sagittal T2WI showing the plane of transaxial oblique slices parallel to the endocervical canal (white line). (B) Transaxial oblique T2WI of the female pelvis along the plane illustrated in A, showing infiltration of cervical tumor into the rectal wall (arrows).

Figure 2.7  (A) Sagittal T2WI showing the plane of coronal oblique slices through the prostate (white line) and the reduced signal from fat in the abdominopelvic wall due to positioning of a presaturation band (arrows). (B) Coronal oblique T2WI of the male pelvis along the plane illustrated in A, showing disease extending into the bladder from the base of the prostate (arrows).
Figure 2.8 Example of a small field of view transaxial T2W of the male pelvis with fat saturation. Note the loss of signal from fat (arrows) which allows clear visualization of the prostate (curved arrow) and abnormal low signal in the peripheral zone posteriorly (arrowheads) consistent with prostatic cancer.

Figure 2.9 Example images and data from a DCE (dynamic contrast enhanced) MR obtained post treatment for two patients with bladder carcinoma for the assessment of residual tumor and treatment response. Thickening in the bladder wall is seen in both patients on transaxial T2W TSE images. The patient shown in A (T2W) and B (dynamic) was found to have residual tumor post treatment (arrowed). The patient shown in C (T2W) and D (dynamic) was found to have evidence of fibrosis post treatment (arrowed). Graphs in E illustrate an example of DCE concentration-time curves obtained from ROIs defined in residual tumor (triangles), posttreatment fibrosis (circles), and normal bladder wall (crosses) for the two patients. The signal-intensity time curves from areas found to be residual tumor and fibrosis are shown to be quite different. Areas of residual tumor demonstrate a rapid increase in signal intensity due to the increased permeability (leakiness) of tumor capillaries compared to areas of fibrosis which demonstrate intermediate signal increase. (Continued)
Figure 2.9 (Continued)
Figure 2.10  Fifty-eight-year-old female with rectal carcinoma planned for radical pelvic surgery post radiochemotherapy. (A) Sagittal and (B) transaxial T2WI images demonstrating a large lobulated recurrent mass (T) involving the upper and mid rectum (arrows in A). The mass infiltrates the mesorectum and abuts the left levator ani (arrowheads in B). In addition there is possible anterior extension to infiltrate the cervix (curved arrow in B); however, it is difficult to differentiate how much of this is due to post-treatment inflammatory change as opposed to disease. Diffusion-weighted imaging performed using (C) b100, (D) b600, and (E) b1000 demonstrate progressively increasing high signal in the rectal tumor mass (T) and in the nodular anterior extension infiltrating the cervix with corresponding low signal on the ADC map (F) in keeping with restricted diffusion confirming locally infiltrative tumor (curved arrows in C–F). (Continued)
Figure 2.11 $^1$H spectroscopic chemical shift imaging of the prostate. The position of the voxels is shown in the left image and the measured spectrum for each voxel is demonstrated on the right. Citrate occurs only within normal healthy tissue. Areas of malignant tissue are characterized by a decrease in citrate signal and an increase in the choline signal.
FURTHER READING


Elster AD, Burdette JH. Questions and Answers in Magnetic Resonance Imaging. 2nd ed. St Louis, Missouri: Mosby, 2001. Thorough but easy to read physics text providing practical answers on specific topics of benefit to all involved in MRI.


McRobbie DW, Moore EA, Graves MJ, et al. MRI from Picture to Proton. 2nd ed. UK: Cambridge University Press, 2007. Excellent comprehensive MR physics text book that allows the reader to learn about MR at both a practical level and at a more detailed physics level.


Anatomy of the pelvis
James O’Connor and Paul A. Hulse

MUSCULOSKELETAL MORPHOLOGY
The pelvic cavity is divided into the false (greater) pelvis above and the true (lesser) pelvis below by an imaginary plane passing from the sacral promontory posteriorly around the arcuate lines laterally and anteriorly onto the symphysis pubis. The true pelvis is a bowl-shaped structure that contains and protects the lower portions of the urinary and intestinal tracts, and the internal reproductive organs.

The bony pelvis forms an articulated ring consisting of the paired hip bones (composed of the fused iliac, ischial, and pubic bones), the sacrum, and the coccyx.

The pelvic sidewalls are composed of a horseshoe-shaped muscular sling covered with pelvic fascia. The iliohypogastric muscles form the walls of the false pelvis, while the obturator internus and piriformis muscles form the walls of the true pelvis. The pelvic floor is a fibromuscular diaphragm formed from the paired levator ani muscles anteriorly and the paired coccygeal muscles posteriorly. The levator ani muscle arises from the superior and posterior aspects of the pubis, the pubic fascia covering the obturator internus muscle and the inner surface of the ischial bone and ischial spine.

Lying centrally in the pelvic floor is the perineal body, a fibromuscular mass that gives attachment to the anal sphincter, bulbospongiosus, transverse perineal, and levator ani muscles. Lying posteriorly between the anus and coccyx is the anococcygeal body, a fibromuscular mass that gives attachment to levator ani and fibers from the anal sphincter. The pelvic floor divides the pelvic cavity above from the perineum and ischiorectal fossae below.

PELVIC FASCIA, VISCERAL LIGAMENTS, AND PERITONEAL REFLECTIONS
The pelvis has a two-layered covering of fascia. The parietal fascia covers the walls and floor and is continuous superiorly with the iliacus and transversalis fascia. It is thickened over the obturator internus and is more conspicuous on MR imaging. The visceral fascia covers the bladder, uterus, and rectum. Fascial condensations form a bilateral band running from pubis to sacrum. These form supporting ligaments around the urethra and at the bases of the prostate, bladder, rectum, and uterus, attaching each respective organ to the pelvic wall. The urethrovaginal and paravesical ligaments support the urethra. The pubovesical and puboprostatic ligaments support the bladder and prostate. The posterior ligaments support the rectum. The lateral cardinal (cardinal) and paracervical ligaments support the cervix and uterus. The sacrospinous ligaments pass around the side of the rectum to attach to the prostate in the male and the vagina in the female. A fascial condensation anterior to the sacrum forms the presacral fascia.

The uterosacral and sacroprostatic ligaments and presacral fascia are normally demonstrated on MR imaging although the other visceral ligaments are not seen unless pathologically thickened.

The pelvic cavity can be divided into intra- and extraperitoneal compartments. The peritoneum forms a sack, which, in the pelvis, is draped over the pelvic organs to form a number of intraperitoneal recesses. The largest is the rectovesical space. Within the male rectovesical space, the opposing layers of peritoneum between the prostate and rectum fuse to form Denonvilliers fascia. In the female, the rectovesical space is divided by the uterus into the small vesicouterine recess anteriorly and the larger rectouterine space (pouch of Douglas) posteriorly. The apposing peritoneal layers between the vagina and rectum fuse to form the rectovaginal septum. The rectovesical space is continuous laterally with the pararectal fossae. The sigmoid colon usually indents the left pararectal fossa so that the left pararectal fossa is smaller than the right. The pararectal fossae are continuous anteriorly with the paravesical and supravesical spaces. The paravesical spaces are indented by the lateral and medial umbilical ligaments formed from the peritoneal coverings of the inferior epigastric vessels and obliterated umbilical arteries, respectively.

Lying between the transversalis fascia of the anterior abdominal wall anteriorly and the umbilicovesical fascia posteriorly is the extraperitoneal prevesical space. This is limited inferiorly in the male by the puboprostatic ligament and in the female by the pubovesical ligament. The paravesical connective tissues form the lateral border. It extends superiorly to the level of the umbilicus. It is indented anteriorly in the midline by the median umbilical ligament, which contains the urachus; this runs from the apex of the bladder to the umbilicus. The peritoneal reflection and umbilical ligament are consistently demonstrated on MR imaging.

PELVIC VISCERA
Urinary Bladder
The urinary bladder is a muscular organ that has a maximum capacity of around 800 mL when distended with urine. It lies...
below the peritoneal reflection and rests on the pelvic floor. It is 
separated from the pubic bones anteriorly by the retroperitoneal 
space. The vagina in the female and the seminal vesicles and 
vasa deferentia in the male lie posteriorly. The bladder is 
pyramidal in shape when empty with an apex, body, base 
(fundus), and neck. The apex lies anteriorly and points to the 
symphysis pubis. The base forms the posterior wall. The body 
lies between the apex and base and is formed from the infero-
lateral surfaces. These converge with the base at the bladder 
neck. When full, the bladder has an ovoid shape with the 
superior surface rising out of the pelvis and into the lower 
abdomen. The trigone is a smooth triangular area of internal 
mucous membrane lying between the ureteric and internal 
urethral orifices. When fully distended the bladder wall thick-
ness should not exceed 5 mm.

**MR Appearance**

On T1WI, the bladder wall has intermediate signal intensity 
slightly higher than urine in the adjacent lumen. The wall is best 
demonstrated on T2WI because of contrast between its low-
signal muscle layer, high-signal urine, and high/intermediate-
signal perivesical fat. On MR imaging of the bladder wall, the 
advrentitia is variably identified, the deep and superficial muscle 
layers cannot be consistently distinguished, and the mucosa is 
only defined clearly when inflamed. Occasionally, the inner 
mucosal layer can be identified particularly following intrave-
nous gadolinium-diethylenetriamine penta-ecetic acid (DTPA), 
which results in delayed enhancement of the wall (Fig. 3.6B).

**Ureters**

The ureters are retroperitoneal structures, which enter the 
pelvis passing over the pelvic brim close to the bifurcation of 
the common iliac artery. They pass posteriorly to the lateral 
pelvic walls anterior to the internal iliac arteries. Subse-
sequently, they curve anteromedially superior to the levator ani 
to enter the bladder where they describe an oblique course 
through the bladder wall. In the male, the ureter lies postero-
lateral to the ductus deferens and enters the bladder just 
superior to the seminal vesicles. In the female, the ureter passes 
medial to the origin of the uterine artery (a branch of the 
anterior division of the internal iliac artery). At the level of the 
ischial spine, the ureter runs in the broad lamina of the 
uterus and parametrium lateral to the cervix and just above the 
lateral fornices of the vagina, where it is crossed superiorly by 
the uterine artery.

**Prostate**

The prostate is a pyramidal structure approximately 3.0 to 4.5 
cm long composed of glandular and fibromuscular tissue. It is 
enclosed by a 2- to 3-mm band of concentrically oriented 
fibromuscular stromal tissue, inseparable from the prostate 
gland that forms a false capsule. This is deficient at the apex 
allowing a route of extracapsular tumor spread. A fibrous 
prostatic sheath that is continuous with the puboprostatic lig-
ments surrounds the capsule. Between the prostatic capsule 
and sheath is the prostatic venous plexus. The prostate is broader 
superiorly with a base closely related to bladder neck. Inferi-
orly, the apex rests on the urogenital diaphragm in contact with 
fascia of the urethral sphincter and deep perineal muscles. Its 
anterior surface is separated from the symphysis pubis by loose 
areolar tissue in the retropubic space, which contains the 
puboprostatic ligament and part of the prostatic venous plexus. 
Inferolaterally, the prostate rests on the levator ani muscles. 
The seminal vesicles and ejaculatory ducts lie posterosuperi-
orly. Posteriorly, the surface of the prostate is separated from the 
adjacent rectum by Denonvillier’s fascia. The non glandular 
ameter fibromuscular band extends over the anterolateral surface 
of the prostate. Above the level of the ejaculatory ducts the small
transitional zone surrounds the urethra. This is covered posterolaterally by the horseshoe-shaped central zone through which the ejaculatory ducts pass. This in turn is surrounded on its posterior, inferior, and lateral surfaces by the peripheral zone.

**MR Appearance**

On T1WI, the prostate, seminal vesicles, and periprostatic veins are of uniform intermediate to low signal. On T2WI, the zonal anatomy is clearly demonstrated. The central zone and transitional zone, commonly termed the central gland, have low signal compared to the high-signal intensity peripheral zone. The anterior fibromuscular band has low signal on T1WI and T2WI and is contrasted with the relatively high signal from fat in the retropubic space. The verumontanum is often visualized on T2WI as a high-signal intensity structure. The prostatic capsule is consistently identified as a low-signal intensity structure on T1WI.

Following intravenous gadolinium-DTPA, gland enhancement is variable. The periurethral region enhances during the early phase and subsequently the whole gland enhances homogeneously (Figs. 3.8 and 3.26).

Zonal anatomy changes with increasing age. The central zone shrinks as the transitional zone enlarges due to benign prostatic hypertrophy. This causes compression of the peripheral zone and creates a low-signal intensity band (surgical pseudocapsule) between it and the hypertrophied transitional zone (Figs. 3.22 and 3.25).

**Seminal Vesicles, Vas Deferens, and Ejaculatory Ducts**

The seminal vesicles are lobulated sacks 5 cm long with a terminal duct positioned interiorly within the retroperitoneum. They lie obliquely behind the bladder and converge toward the midline. The superior parts of the seminal vesicles lie posterior to the ureters and extend above the level of the peritoneal reflection within the rectovesical space, separated from the rectum by a double layer of peritoneum. The inferior part of each seminal vesicle lies below the peritoneal reflection and is separated from the rectum by Denovilliers’ fascia. The duct of the seminal vesicle joins the vas deferens to form the ejaculatory ducts.

The vas deferens originates in the tail of the epididymis, ascends in the spermatic cord, and passes through the inguinal canal to enter the pelvis crossing the external iliac vessels. It traverses the pelvic sidewall lying external to the peritoneum and then passes medially behind the bladder anterior to and above the ureter and medial to the seminal vesicles where it is dilated to form an ampulla.

The paired ejaculatory ducts arise adjacent to the neck of the bladder and run in close proximity passing anteroinferiorly through the prostate where they converge and open onto the prostatic utricles.

**MR Appearance**

On T1WI, the seminal vesicles are of intermediate signal intensity similar to muscle contrasted with the high signal intensity present within pelvic fat. On T2WI, the walls appear of low signal intensity and the contents return high signal intensity. A clear fat plane should be present in the angle between the anterior surface of the seminal vesicle and the posterior surface of the bladder (Figs. 3.22-3.24).

**Vagina**

This is a musculomembranous tube, which extends from the vulva posterosuperiorly to surround the cervix of the uterus. It is normally collapsed, with its anterior and posterior walls apposed. It broadens superio rly to form a continuous recess around the cervix divided into the shallow anterior fornix and the deeper posterior and lateral fornices. The anterior wall is approximately 1.5 cm shorter than the posterior wall. The vagina is arbitrarily divided into thirds, the important division being between the upper two-thirds and the lower third, demarcated anteriorly by the junction of the bladder and urethra at the bladder neck. Anteriorly, the vagina is closely related to the base of the bladder and the urethra. Posteriorly, the upper third of the vagina at the level of the vaginal fornices is related to the peritoneal reflection in the pouch of Douglas, the middle third is related to the ampulla of the rectum, and the lower third to the perineal body and anal canal. In postmenopausal women, the vagina shrinks and the cervix is less prominent so that the vaginal fornices are virtually effaced.

**MR Appearance**

Layered anatomy of the vagina can be recognized on MR imaging. Mucus secretions within the lumen and the inner mucosal layer may be seen as low signal on T1WI and high signal on T2WI. The surrounding layers of submucosa, collagen, longitudinal, and circular smooth muscle have low signal on T1WI and T2WI. The surrounding adventitia that contains the vaginal venous plexus appears of high signal intensity on T2WI (Figs. 3.17 and 3.18).

Following intravenous gadolinium-DTPA the vaginal muscle wall and submucosa enhance. A central low-signal intensity line, which probably represents the vaginal lumen, is occasionally identified (Figs. 3.6 and 3.7). The vaginal appearances vary with the phase of the menstrual cycle. The wall is thicker in the proliferative phase than the secretory phase. Vaginal secretions are most prominent in the late proliferative and early to mid secretory phase. In the postmenopausal woman, the vaginal wall is thin and of low signal intensity on T1WI and T2WI.

**Uterus and Uterine Tubes**

The uterus is a pear-shaped muscular organ lying centrally in the pelvis between the bladder anteriorly and the rectum posteriorly. It is divided into the fundus, which lies above the level of the uterine tube orifices, the body, and the isthmus, which constricts inferiorly to form the cervix. The cervix is divided into supravaginal and infravaginal parts. The fundus, body, and isthmus of the uterus are predominantly muscular, whereas the cervix is predominantly fibrous in composition. The uterine cavity communicates superolaterally with the uterine (fallopian) tubes and inferiorly with the cervical canal at the internal os. The cervical canal communicates with the vagina via the external os.

Anterior and posterior reflections of the peritoneum pass over the uterine tubes to form the broad ligaments. These also enclose the round ligaments of the uterus, the ovarian ligament, and the uterine vessels. The round ligament arises anteroinferiorly to the origin of the uterine tube from the body of the uterus and passes through the inguinal canal to insert into the labia majora. The ovarian ligament arises posterosuperiorly to the origin of the uterine tube and passes in the mesovarium to attach to the ovary.
The uterine tubes extend from the uterine cornua to open into the peritoneal cavity close to the ovaries. They run in the mesosalpinx formed by the free edges of the broad ligament. They have an infundibulum, a funnel-shaped distal end, which extends beyond the broad ligament to overhang the ovary with its fimbriae; an ampulla forming the widest and longest parts of the uterine tube and an isthmus that is continuous with the interstitial portion lying within the uterine wall.

**MR Appearance**

On MRI, the demarcation between the uterine body and cervix is denoted by a waist in the uterine contour and the entrance of the uterine blood vessels at the level of the internal os.

On T1WI, the uterus appears of low to intermediate signal intensity. On T2WI, three separate layers are distinguished—the endometrium, junctional zone, and myometrium. The endometrium lies centrally and appears of high signal. Its thickness varies with the phase of the menstrual cycle, being thinnest after menstruation and thickest during the mid-secretory phase. The outer layer of myometrium is of intermediate signal intensity that increases through the menstrual cycle to a maximum intensity in the mid-secretory phase. Between the endometrium and myometrium, the functional zone that appears of low signal intensity. Uterine appearances also vary under the influence of oral contraceptives with the myometrium appearing of high signal intensity on T1WI and T2WI.

The cervix is of variable composition consisting of an outer zone of smooth muscle, which appears of intermediate signal on T2WI; an inner zone of fibrous stroma, which appears of low signal on T2WI; and a central area of high signal intensity due to epithelium and mucus in the cervical canal (Fig. 3.15).

In the shrunken uterus of the postmenopausal woman, the zonal anatomy is not well distinguished, the endometrium is thin, and the myometrium is of lower signal intensity.

Following intravenous gadolinium-DTPA, zonal anatomy can be displayed on T1WI. The myometrium and endometrium enhance, but the junctional zone remains of low signal intensity. The paracervical tissues (paracolpos) and inner cervical epithelium enhance, but the cervical stroma remains of low signal intensity.

**Parametrium**

The parametrium is the extraperitoneal connective tissue that lies adjacent to the uterine body (parametrium), the cervix (para-cervix), and vagina (paracolpos), which together are termed the parametrium clinically. The parametrium is rich in vascular and lymphatic tissue and contains the ureters, which pass lateral to the supravaginal part of the cervix. The floor of the parametrium is formed from the lateral cervical (cardinal) ligaments and divides the paracervical parametria from the paracolpos. The uterovesical ligaments demarcate the lateral margin of the parametrial tissues.

**MR Appearance**

The parametrium appears of heterogeneous intermediate signal intensity on T1WI and heterogeneous high signal intensity on T2WI (Fig. 3.16). The parametrial tissues enhance following intravenous gadolinium-DTPA (Fig. 3.6).

**Ovary**

The ovaries are almond-shaped structures usually located in the ovarian fossae close to the lateral pelvic sidewall. Their size varies with age. In the adult, the ovary measures up to 3.0 cm in its longest dimension, but atrophies following the menopause to a dimension of less than 2.0 cm. Considerable variation is seen in their anatomical position.

The ovary is attached to the posterior surface of the broad ligament by a double fold of peritoneum, the mesovarium. Further support is given by the ovarian ligament proper and the suspensory ligament of the ovary that is continuous with the broad ligament attaching to the pelvic sidewall and in which the ovarian vessels and lymphatics run.

Each adult ovary contains approximately 70,000 follicles. With each menstrual cycle some of these develop into Graafian follicles, one of which matures and releases an ovum at ovulation, leaving the corpus luteum. Therefore, the ovarian cortex contains immature follicles, Graafian follicles, and corpora lutea.

**MR Appearance**

On T2WI, the central stroma is of low signal intensity with hyperintense follicles identified in the high-signal intensity peripheral cortex (Fig. 3.16). Following intravenous gadolinium-DTPA, the central ovarian stroma enhances and contrasts with the low-signal ovarian follicles.

Sometimes the ovaries can be difficult to locate on MR imaging. If the round ligament is identified and traced posteriorly, the ovaries lie in close proximity to it, attached to it by the ovarian ligament. Peripherally located follicular cysts and surrounding small vessels help to differentiate the ovaries from adjacent bowel. Occasionally, the ovaries are transposed from the pelvis, using the ovarian vessels as a pedicle, to an intraperitoneal paracolic or retrocecal location in order to remove them from a pelvic radiation field. Knowledge of this is important to avoid confusion with metastatic disease.

**Rectum**

The rectum describes an S-shape in the sagittal plane formed by the rectosigmoid junction superiorly and the indentation of the puborectalis muscle of the pelvic floor (the anorectal flexure) inferiorly. In the coronal plane, there are three lateral flexures caused by internal mucosal folds, which overlie thickenings of the circular muscle layer of the rectal wall (walls of Houston). The terminal part of the rectum is dilated to form an ampulla that is supported by the pelvic floor and anococcygeal ligaments.

The rectum has no mesentery and is only partially invested by peritoneum. In its upper third, peritoneum covers the anterior and lateral surfaces; in the middle third, only the anterior surface; and in the lower third, there is no peritoneal covering.

Above the level of the levator ani and below the peritoneal reflection, a loose layer of connective tissue comprising the perirectal fat, blood vessels, nerves, and lymphatics encloses the rectum. The visceral and parietal layers of perirectal fascia surround this. The rectum and tissues enclosed by the visceral layer of perirectal fascia, also termed the mesorectal fascia, form a distinct anatomical entity, the mesorectum. This is important because radical removal of the rectum is achieved at total mesorectal excision surgery by dissecting along the plane that
separates the visceral (mesopectal) from the parietal layers of perirectal pelvic fascia.

**MR Appearance**
The bowel wall appears of low signal on T1WI and intermediate signal on T2WI. When distended, the wall thickness of the rectosigmoid and anal canal should not exceed 5 mm and 10 mm, respectively. As the bowel wall thickens in the lower rectum, four concentric layers can be discerned. An outside low-signal intensity ring represents the outer muscular layer (muscularis propria), within this a layer of higher signal intensity represents the submucosa; this encloses a layer of low signal intensity corresponding to the muscularis mucosae and lamina propria, and centrally lies a high-signal intensity layer representing the mucosa. On postcontrast T1WI, the submucosal and mucosal layers enhance, but the intervening layer of muscularis mucosae and outer muscular layer do not, permitting differentiation between the layers.

**Anal Canal**
The anal canal begins at the narrowing of the rectal ampulla formed by the indentation of the puborectalis portion of the levator ani and ends at the anal verge, a term that describes the transitional zone between the mucosa of the anal canal and the perianal skin. The upper part of the anal canal is lined with transitional (urothelial type) or rectal glandular mucosa. The lower part of the anal canal is lined with squamous mucosa. The line of demarcation (pectinate line, dentate line) between the two parts lies 2.5 to 3.0 cm proximal to the anal verge and is visible macroscopically but not on MR imaging. It forms a transitional area of squamous and nonsquamous mucosa and indicates the watershed for arterial supply and venous and lymphatic drainage.

Above the pectinate line the anal canal is supplied by the superior rectal artery a branch of the inferior mesenteric artery and drained by the superior rectal vein into the portal venous systems. Below the pectinate line, blood supply is from the inferior rectal artery, a branch of the internal iliac artery, and venous drainage is via the inferior rectal veins to the systemic venous system. At the level of the pectinate line, arterial supply and venous drainage passes on in both directions via anastomoses formed by the middle rectal arteries and veins. Lymphatic drainage above the level of the pectinate line is to the internal iliac lymph nodes and below the level of the pectinate line to the superficial inguinal lymph nodes.

The anal canal has a larger voluntary external sphincter formed from striated muscle, which blends superiorly with the puborectalis muscle. The internal anal sphincter is involuntary and is formed from a thickening of the circular smooth muscle layer, which invests the upper two-thirds of the anal canal. Between the internal and external sphincters lies a continuation of the longitudinal muscle layer of the rectum, which inserts via a fascial extension into the pectinate line.

**MR Appearance**
On MRI the upper and lower parts of the anal canal are identified and appear different. The upper part contains the internal anal sphincter, the longitudinal muscle layer, and the puborectalis muscle. The lower part contains the internal anal sphincter, the longitudinal muscle layer, and the external anal sphincter. The longitudinal muscle layer lies in a slit-like space between the internal anal sphincter, the external anal sphincter, and puborectalis muscle—the intersphincteric space.

On T2WI, all the muscles except the internal sphincter, which has intermediate signal intensity, have low signal intensity (Fig. 3.28).

**PERINEUM**
The perineum lies below the pelvic diaphragm. It is a diamond-shaped space, which is bounded anterolaterally by the ischiopubic rami, laterally by the ischiatic tuberosities and posterolaterally by the lower borders of the sacrotuberous ligaments. A line drawn between the ischiatic tuberosities passes just anterior to the anus and divides the perineum into the urogenital triangle anteriorly and the anal triangle posteriorly.

**Urogenital Triangle**
This compartment contains the urogenital diaphragm, which is a triangular double layer of fascia, which spans the pubic arch and attaches to the ischiopubic rami. The inferior fascial layer of the urogenital diaphragm forms the perineal membrane, which gives attachment to the bulb and crura of the penis or clitoris. It is pierced by the urethra in both sexes and the vagina in the female.

Below the urogenital diaphragm lies the superficial perineal pouch. The muscles of the superficial perineal pouch are analogous in both sexes but smaller in the female.

In the male, the bulbospongiosus muscles cover the corpus spongiosum, which encloses the urethra, to form the bulb of the penis. The corpus spongiosum extends anteriorly to form the glans penis. The ischiocavernosus muscles arise from the ischiial rami to cover the corpora cavernosa and fuse anteriorly together and with the bulb of the penis to form the body of the penis. Thus, the penis is composed of three cylindrical structures: the paired dorsolateral corpora cavernosa and the single, ventral midline corpus spongiosum. Three layers of connective tissue cover the penile corpora. The innermost fibrous tissue layer is the tunica albuginea, surrounding the corpora cavernosa and the corpus spongiosum. The intermediate layer is the deep fascia of the penis (known as Buck’s fascia) which surrounds the corpora cavernosa and separates them from the corpus spongiosum. The outermost layer is a loose layer of subcutaneous connective tissue separated from the overlying skin by the dartos fascia.

In the female, the bulbospongiosus muscles cover the vestibular bulbs. The bulbs arise from the perineal membrane, are united anteriorly by a median commissure, and lie each side of the vestibule. The vestibule contains the openings of the vagina, urethra, and ducts of the greater vestibular (Bartholin) glands, which lie at the posterior border of each vestibular bulb. The glans clitoris is a small round tubercle of spongy tissue analogous to the glans penis often covered by a prepuce. Two corpora or crura lie laterally formed by the paired ischiocavernosus muscles. The vulva is the collective term for the external female genitalia that includes the labia majora and minora, clitoris, bulb of the vestibule, vestibule of the vagina, greater and lesser vestibular glands, and the opening of the vagina.

The superficial transverse perineal muscle is a slender muscle that runs along the posterior border of the perineal membrane and attaches to the perineal body and ischial rami. Deep to the perineal membrane lies the deep perineal pouch, bounded superiorly by the superior layer of the urogenital diaphragm. This principally consists of the deep transverse perineal...