CT Colonography for Radiographers

A Guide to Performance and Image Interpretation

Joel H. Bortz
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Editors

Second Edition

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Editors
Joel H. Bortz
Los Angeles, CA, USA

Leonie Munro
Morningside Durban, South Africa

Aarthi Ramlaul
Buckinghamshire New University
High Wycombe, UK

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The editors collectively dedicate this book to all diagnostic radiographers (radiation technologists/medical radiation technologists) who perform CT colonography or who will be doing so in the future. Your professional approach to service delivery to asymptomatic and symptomatic patients underpins successful imaging of the colon for prevention and management of colorectal cancer.

On a personal note…

Joel Bortz dedicates this to his children and seven grandchildren.

Aarthi Ramlaul dedicates this to her husband and two sons.

Leonie Munro dedicates this to her family and two grandsons.

Joel H. Bortz, Aarthi Ramlaul, and Leonie Munro.

Foreword

I am delighted to introduce this book which is written by leaders in the field of teaching and training of CT colonography. This is now established as a mainstream investigation in all pathways aimed at detecting colorectal cancer and its precursors.

Although colorectal cancer is one of the deadliest cancers, it remains one of the most treatable if detected at an early stage. This requires the expansion of necessary capacity, which is best facilitated by large radiographer provided services. Scrupulous attention to consistent high-quality preparation, distention, and procedural modifications, based on interpretation of the images during the scan, is required. When performed to the highest standards, CTC performance has been validated as equivalent to the previous gold standard of optical colonoscopy and has the potential to save lives with its greater safety profile and patient acceptability. All these facets are comprehensively addressed in this book. The technical and procedural aspects of CTC are discussed in consistent, standardised terms within a methodical framework which will embed best practice in all students of this text.

This publication discusses the role of CTC in colorectal cancer diagnosis, other incidental colorectal diseases, extracolonic findings and screening. Additionally, new chapters on the role of CTC for incomplete and failed colonoscopy, and opportunistic screening broaden the remit of the advanced practice radiographer with an encompassing view of the patient pathway and extracolonic findings. A new chapter on audit appropriately underscores the importance of radiographer involvement in the quality assurance of their service, and new chapters on PET, dual energy CT, photon counting CT, and AI will equip the reader for current and future developments.

Since the last edition radiology practice has evolved: an expanding radiographer scope of practice has increased for those involved in the reporting of CTC scans. The structure of this book should encourage even greater numbers of the profession to take on this important responsibility. By doing so, radiographers ensure one-stop staging with rapid escalation of positive cases to endoscopy and multidisciplinary team meetings for the benefit of patients.

Whether the reader of this book is responsible for delivering high-quality examinations, the whole pathway, is a service lead, or is a healthcare professional within colorectal cancer services curious about the technology, this book provides a comprehensive guide supporting the delivery of quality, early diagnosis, and improved colorectal cancer survival.

Ingrid Britton
Royal Stoke University Hospital
Stoke-On-Trent, UK
Midlands Academy
London, UK

Preface

The increasing use of computed tomography colonography (CTC), also known as virtual colonoscopy, as the preferred imaging modality, coupled with an ongoing shortage of radiologists, adds to an already burdened radiology workload. Hence, diagnostic radiographers, who have a key role within the imaging team in the United Kingdom's National Health Service (NHS) and are skilled in their practice, are becoming increasingly responsible for patient pre-assessment, informed consent, and performing CTC examinations. Those radiographers who have received advanced training are providing a preliminary descriptive report of the images, thus being involved in image interpretation and reporting of CTC images.

Following the success of the first edition of this text, the editors are pleased to offer this new, updated second edition of this textbook aimed at supporting radiographers in this extended role, and once again filling the gap in this market. The aim of this new edition remains to provide radiographers with a platform, on all aspects of CTC, in order to support them in their extended scope of practice. When 'radiographer' is used within the text, we are referring to diagnostic radiographers/radiation technologists/medical radiation technologists who practise within this extended role.

The editors and authors are leaders in the field of radiography practice and education. Dr. Joel H. Bortz, gastrointestinal (GI) radiologist and lead author, has performed more than 10,000 CTC examinations over the past 17 years. Collectively, the editors have put together these chapters, which serve as both a learning package and a toolkit in CTC performance and image interpretation. All chapters have been updated to include current and future projected developments within CTC performance and image interpretation and takes into account the learning derived during the Covid-19 pandemic and the increasing use of artificial intelligence (AI) in radiography.

The text is suited to and aimed at radiographers globally, who wish to train to take on this extended scope of practice, and those who are currently performing CTC examinations in practice. In addition, undergraduate and postgraduate radiography/radiation technology students will benefit from using this as a reference or core text in gastrointestinal imaging. Furthermore, the scope of the text may appeal to trainee radiologists as well as nurses working within medical imaging.

The overall strength of the text lies in the presentation and discussion of a vast range of 2D and 3D images of normal anatomy as well as the most common pathologies seen in CTC. Each chapter includes helpful signposting and

key take away messages that are focused on the essential elements that pertain to CTC. Each chapter includes a list of references which serves as a source for further reading and adds to the learning experience for readers. The text opens with an introduction which sets the scene and acts as a guide for the chapters that follow.

There are two critical components to achieving a successful CTC examination: an adequately prepared bowel and good distension of the colon with carbon dioxide (CO_2). Patients must therefore fully understand their responsibilities for bowel preparation. This requires that oral and written instructions are clear, readable, and easily understood by all patients including those with communication impairments. Communication is therefore pivotal, and the chapter on communication gives guidance on patient-centred communication before, during, and following a CTC examination.

It is the responsibility of a radiographer performing CTC examinations to ensure that patients have been provided with adequate, comprehensive information, including benefits and related risks, to enable informed consent to be established. The chapter on informed consent discusses duty of care and the role and responsibilities of a radiographer in the information-giving and consent-gaining process. The chapter also presents a current dilemma in the consenting process relating to the use of AI in CTC procedures and subsequent decision-making regarding diagnosis and patient management.

A chapter on the principles of computed tomography is included again, but this time there is discussion about the science of CT including hybrid imaging and dual-energy CT. Student radiographers study this subject as part of their undergraduate course of study and need to be familiar with the concepts discussed. Radiographers with years of experience would be gently reminded about the science behind these technologies.

Due to the increasing number of CT examinations being performed, radiation doses associated with CT examinations have become a popular topic of debate. Chapter 5 provides an insight into the principles of radiation dose and explains the concepts of effective dose and diagnostic reference levels in CT and CTC imaging.

Chapter 6 describes various options for dose optimisation in CTC in response to the increased awareness of radiation dose contributed by radiological studies, especially CT examinations. The techniques discussed are not unique to CTC, however, and can be applied for optimisation of various scan protocols.

Chapter 7 reviews the development of CTC as a diagnostic tool, evaluates current guidance, and discusses the future of CTC. As CTC is a minimally invasive procedure, which involves the administration of air, intravenous injections and contrast media, patient safety must be considered first and foremost throughout the examination.

Chapter 8 focuses on the role of contrast media in CTC including the types of contrast media, the usage, allergic reactions, and issues of patient safety. Cathartic bowel preparation and tagging agents are pivotal in CTC. For a successful study, it is important that a clean bowel is well distended and that residual fluid is tagged. Chapter 9 focuses on patient preparation, including bowel preparation, the role of tagging and methods of colonic insufflation.

Over the years, there have been several changes to the technique used in performing CTC examinations, and Chap. 10 is focused towards providing detailed step-by-step guidance on conducting a CTC examination as seen currently as best practice.

Chapter 11 teaches the normal anatomy of the colon as seen on 2D and 3D CTC images to facilitate accurate image interpretation. In order to be able to identify image appearances of pathologies, it is essential to know what normal anatomy looks like first. Similarly, it is important to be knowledgeable of normal image appearances as certain imaging artefacts or pitfalls in imaging may produce images which may mimic a pathology. Commonly encountered traps and artefacts are discussed in Chap. 12.

An extensive range of images demonstrating pathologies can be seen in Chaps. 13–17 which cover internal haemorrhoids and other anorectal lesions; the different types of polyps; the adenoma-carcinoma sequence; management and treatment of colon cancer; diverticular disease and lipomas.

During CTC procedures, intra-abdominal and pelvic organs are visualised and extracolonic lesions may be identified. While the majority of these lesions are not considered to be of clinical importance, the potential benefit of detecting an extracolonic lesion is of high clinical relevance which can benefit the patient through early detection and subsequent intervention. Chapter 18 explains the significance of extracolonic findings in CTC screening.

Chapter 19 is a new chapter which focuses on metabolic-associated fatty liver disease, previously known as non-alcoholic fatty liver disease. This disease is of concern globally and CTC allows for visualisation of the liver, as an extracolonic organ, during CTC imaging.

Chapter 20 is a new chapter which focuses on the role of CTC in incomplete or failed optical colonoscopy and the reasons for incomplete or failed optical colonoscopy procedures are discussed.

Chapter 21 offers good practice guidance in CTC reporting. Reporting of CTC must be undertaken by competently trained practitioners, i.e. either a radiologist or trained radiographer.

With the increasing incidence of colorectal cancer, it is important to be aware of the role of complementary imaging in supporting CTC. Chapters 22 and 23 evaluate, respectively, the role of ultrasound and magnetic resonance imaging, and the role of nuclear medicine, in the management of colorectal pathology.

Chapter 24 explores the responsibility and accountability of radiographers within a practice framework and the possible consequences of failing to provide a duty of care, and practice, at the required standard.

Chapter 25 is a new chapter which focuses on AI and machine learning in cross-sectional imaging. The use of AI in radiography practice is increasing significantly, and this chapter discusses the potential impact of AI in radiography and ethical considerations pertaining to the use of AI. The chapter also provides an overview of AI-enabled image interpretation in cross-sectional imaging, particularly in CTC.

Chapter 26 is a new chapter which focuses on the principles and dose, related to the use of dual-energy CT. The science of dual-energy CT and photon counting, which are relatively recent advances in CT imaging, are

explained. The benefits that these applications offer to CT scanning are described.

Chapter 27 is a new chapter focused on the application of audit principles and offers good practice guidance for planning and conducting CTC audits and using audit data to implement changes in practice.

In keeping with the ethos of learning and applying knowledge and understanding of the information presented within the text, Chap. 28 provides an opportunity for readers to self-assess their knowledge and engage their critical thinking abilities by writing a preliminary report based on case samples. Recommended answers are provided for you to check your responses. Use this exercise as a learning activity to draw comparisons, learn from them and develop a deep approach to learning.

Lastly, a brief glossary is provided at the end for terms that may appear confusing within the text.

We wish you well in your extended scope of practice as a GI radiographer undertaking CTC, and we hope you find this revised edition a helpful and useful resource in your continued learning and practice.

Los Angeles, CA — Joel H. Bortz
Buckinghamshire, UK — Aarthi Ramlaul
Durban, South Africa — Leonie Munro
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About the Authors

Rachel Baldwin-Cleland Rachel has been undertaking CTCs since 2005. She was a GI superintendent and research radiographer at St Mark's Hospital, London. She is currently a clinical research fellow completing a PhD focused on education, training, and sustainability in CTC. She is also involved in setting up the National CTC Training and Accreditation Programme in the UK. She is a faculty tutor for radiographer and radiologist CTC courses, and CTC 'Train the Trainer' courses. She is Chair of the Gastrointestinal Radiographer Specialist Interest Group (GIRSG) and is the radiographer representative on the UK BCSP Quality Assurance Committee. Her other research areas involve small bowel imaging and sarcopenia effects on surgical outcomes in GI patients.

Joel H. Bortz, MBChB, DMRD, FRCR, FFRRCS Joel is a South African trained radiologist with three radiology degrees. He served as an examiner and convenor for the Colleges of Medicine of South Africa and was an examiner at several South African universities. He is based at LSG Imaging in Los Angeles, United States, and has vast experience in CTC. He is the author of numerous peer-reviewed CTC publications and other imaging topics.

Hesta Friedrich-Nel Hesta is the acting Dean of the Faculty of Health and Environmental Sciences at the Central University of Technology, Free State, South Africa. She has a master's degree in Radiography (Therapy), a PhD in Health Professions Education, and a Postgraduate Diploma in Higher Education.

Tracey Gregory Tracey is an associate lecturer in diagnostic imaging at the University of Derby. She is also the business manager and co-owner of a private dental practice in Cumbria and an external speaker in dental radiography. She is currently an SCoR assessor in dental radiography.

Kalpesh Girish Mody Kalpesh is a specialist radiologist/lecturer at Inkosi Albert Luthuli Central Hospital in affiliation with the University of KwaZulu-Natal (UKZN) in Durban, South Africa. At the hospital, he provides a general radiological service to the population of KwaZulu-Natal covering multiple imaging modalities including CT, ultrasound, and MRI. He also has an interest in hepatobiliary and gastrointestinal imaging with a focus on oncologic imaging. He is also involved in the administration and performance of the postgraduate programme in radiology at UKZN, as well as contributing to the undergraduate medical syllabus.

Leonie Munro, ND Rad(D), MA Leonie is a retired diagnostic radiographer. She has a national diploma in diagnostic radiography, a master's degree in communication, a postgraduate diploma in public administration, and a certificate for trainers. She has authored and co-authored several peer-reviewed journal publications, and chapters in books, which focused on radiography and professional communication. She is the co-editor of the peer-reviewed journal *The South African Radiographer*.

Fozy Peer Fozy is the past-president of the ISRRT and retired manager of the Nuclear Medicine Department at the Inkosi Albert Luthuli Central Hospital in KwaZulu-Natal, South Africa. She has published papers in both peer-reviewed and accredited journals. She is now an executive member of the Society of Radiographers of South Africa.

Richard Price Richard is a diagnostic radiographer and Emeritus Professor of Radiography at the University of Hertfordshire, UK. He is the immediate past Dean of the School of Health and Social Work at the University. He is a co-author of the history of *The Society of Radiographers: 100 years 1920–2020*. From 2008 to 2014 he was editor-in-chief of *Radiography*, the peer-reviewed journal of the Society of Radiographers. He is a past president of the Society and College of Radiographers and was awarded the Society's Gold Medal in 1995.

Aarthi Ramlaul, EdD, MA, B.Tech(DRad), ND Rad(D) Aarthi is a diagnostic radiographer and Associate Professor of Diagnostic Radiography at Buckinghamshire New University, UK. Her primary research focused on the development of critical thinking in diagnostic radiography education and its impact on autonomous clinical decision-making. She has a keen interest in the ethico-legal aspects of professional practice and the implementation of artificial intelligence in clinical decision-making. Aarthi has edited and authored numerous publications, including four textbooks in medical imaging.

Christoph J. Trauernicht Christoph is the Director of Medical Physics at Tygerberg Hospital and Associate Professor at Stellenbosch University. He is the current president of the Federation of African Medical Physics Organisations. He has also worked as an IAEA expert on numerous occasions, including international training courses on CT quality assurance and dosimetry, as well as dose optimisation. He serves on the Accreditation Board of the International Organisation for Medical Physics. He has served as examiner and convenor for the Colleges of Medicine of South Africa and has helped evaluate medical physics interns as part of the National Board Assessment for the Health Professions Council of South Africa. Chris was one of the founding members of the South African chapter of AFROSAFE in 2018.

Riaan van de Venter Riaan is a lecturer and research associate in the Department of Radiography at the Nelson Mandela University. They are an associate editor of the Journal of Medical Imaging and Radiation Sciences and the co-editor of *The South African Radiographer*. They are also the current president of the Society of Radiographers of South Africa (SORSA). Riaan's research interests span workforce development, health professions education, role extension, advanced practice, image interpretation, trauma, wellbeing, patient care, image interpretation as well as sexual and gender minorities.

Stephen Wilson Stephen has been undertaking CTC since 2007 and reporting CTC since 2009, with an advanced practice role at Peterborough City Hospital. Stephen obtained his Pg. Cert in CT Colonography in 2015 from Keele University and completed his masters at Salford University in 2017, specialising in upper GI. He is course administrator for the University of Suffolk Pg. Cert in CT Colonography and a clinical lead for the National CTC Training and Accreditation programme.

Abbreviations

2D	2-Dimensional
3D	3-Dimensional
AAA	Abdominal aortic aneurysm
AAC	Abdominal aortic calcification
AC	Adaptive child
ACG	American College of Gastroenterologists
AGA	American Gastroenterological Association
AI	Artificial intelligence
AIDR	Adaptive iterative dose reconstruction
ALARA	As low as reasonably achievable
ANN	Artificial neural network
Apps	Applications (software)
ASIR	Adaptive statistical iterative reconstruction
AUC	Area under curve
BE	Barium enema
BI-RADS	Breast imaging reporting and data system
BLMRC	Bright lumen magnetic resonance colonography
BMD	Bone mineral density
BSCP	Bowel cancer screening programmes
BSGAR	British Society of Gastrointestinal and Abdominal Radiology
CAD	Computer-aided diagnosis
CCE	Colon capsule endoscopy
CCE	Cryptogenic cirrhosis
CEA	Carcinoembryonic antigen
ceCT	Contrast-enhanced computed tomography
CEUS	Contrast-enhanced ultrasonography
CNN	Convolutional neural networks
CO_2	Carbon dioxide
CP	Controlling parent
C-Rads	CT colonography reporting and data system
CRC	Colorectal cancer
CTA	Computed tomography angiography
CTC	Computed tomographic colonography
CTDI	Computed tomography dose index
CVD	Cardiovascular disease
DCBE	Double contrast barium enema
DD	Diverticular disease

DDSS	Diverticular disease severity score
DECT	Dual-energy computed tomography
DL	Deep learning
DLMRC	Dark lumen magnetic resonance colonography
DLP	Dose-length product
DNA	Deoxyribonucleic acid
DNN	Deep Neural Network
DVD	Digital versatile disc
DXA	Dual-energy X-ray absorptiometry
E1	Not of clinical importance
E2	Low clinical importance
E3	Moderate clinical importance
E4	High clinical importance
EBCT	Electron beam computerized tomography
EC	Electronic cleansing
ECF	Extracolonic findings
eGFR	Estimated glomerular filtration rate
ESGAR	The European Society of Gastrointestinal and Abdominal Radiology
ESGE	European Society of Gastrointestinal Endoscopy
EUS	Endoscopic ultrasonography
FAP	Familial adenomatous polyposis
FC	Free child
FDA	Food and Drug Administration
FDG-PET	F-18-Fluoro-deoxy-glucose positron emission tomography
FOV	Field of view
FRAX	Fracture risk assessment tool
GAN	Generative adversarial network
gFOBt	Guaiac faecal occult blood test
GIST	Gastrointestinal stromal tumour
GIT	Gastrointestinal tract
GRE	Gradient echo
HASTE	Half-Fourier acquisition single-shot turbo spin-echo
HCC	Hepatocellular carcinoma
HCP	Healthcare practitioners
HCPC	Health and Care Professions Council
HCV	Hepatitis C virus
HDL	Low high-density lipoprotein
HP	Hyperplastic polyp
HU	Hounsfield units
IV	Intravenous
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
ICV	Ileocaecal valve
IEC	International Electrotechnical Commission
IMA	Inferior mesentery artery

IO	Iterative optimisation
IVC	Inferior vena cava
Kerma	Kinetic energy released in matter
keV	Kiloelectronvolts
L	Level (window)
LDL	Low-density lipoprotein
LLD	Left lateral decubitus
MAFLD	Metabolic-associated fatty liver disease
MASH	Metabolic-associated steatohepatitis
MDCT	Multi-detector computed tomography
MERCURY	Magnetic Resonance Imaging and Rectal Cancer European Equivalence
MinIP	Minimum intensity projection
MIP	Maximum intensity projection
ML	Machine learning
MPR	Multiplanar reformations/reconstructions
MRC	Magnetic resonance colonography
MRE	MR elastography
MRF	Mesorectal fascia
MRI	Magnetic resonance imaging
MRS	MR spectroscopy
MSAD	Multiple scan average dose
MSI	Microsatellite instability
NAFDL	Non-alcoholic fatty liver disease
NASH	Non-alcoholic steatohepatitis
NHS	National Health Service
NHSBCSP	National Health Service Bowel Cancer Screening Programme
NICE	National Institute for Health and Clinical Excellence
NN	Neural network
NP	Nurturing parent
NPSA	National Patient Safety Agency
NSF	Nephrogenic systemic fibrosis
OP	Optical colonoscopy
PACS	Picture archiving and communication system
PET	Positron emission tomography
PGD	Patient Group Directive
PPE	Personal protective equipment
PPV	Positive predictive value
PVR	Perspective volume rendering
QA	Quality assurance
RCR	Royal College of Radiologists
RECIST	Response evaluation criteria in solid tumours
RLD	Right lateral decubitus
RNN	Recurrent neural networks
ROI	Region of interest
SAFIRE	Sinogram-affirmed iterative reconstruction
SCoR	Society and College of Radiographers
SMA	Superior mesentery artery

SSCT	Single-slice computed tomography
SSP	Sessile serrated polyp
TA	Transactional analysis
TBS	Trabecular bone score
TD	Translucent display
TDSN	Tensor deep stack network
TNM	Tumour node metastases
TRUS	Transrectal ultrasound
TSA	Traditional serrated adenoma
UICC	Union for International Cancer Control
UK	United Kingdom
US	Ultrasound
USA	United States of America
USE	Ultrasound elastography
VC	Virtual colonoscopy
VLDL	Very low-density lipoprotein
W	Width (window)
WHO	World Health Organisation

1 Introduction

Joel H. Bortz

Several reasons led to writing this second guide for radiographers on computed tomography colonography (CTC) performance and image interpretation. Since 2005 several studies have been undertaken to evaluate radiographers' competencies in interpreting CTC images [1–5]. Literature reports that the implementation of training and education for role extension and advanced practice for radiographers has reduced backlogs in some countries [6–9]. Artificial intelligence (AI) is used for detection of colon polyps [10]. Machine learning is a subset of AI and is used to differentiate benign and premalignant colorectal polyps at CTC [11]. In 2020, a joint statement was published by the International Society of Radiographers and Radiological Technologists, and European Federation of Radiographer Societies in terms of AI training and protocols for radiographers [12]. Advanced imaging techniques for colorectal cancer (CRC) include dual energy computed tomography (DECT) [13, 14].

In 2014, the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiologists, in their publication on the guidance on the use of CTC for suspected cancer [15], stated that barium enema should be replaced by CTC as the imaging modality of choice for patients with suspected CRC. According to them, the number of CTC examinations has increased, which has added to an already burdened radiology workload. In many United Kingdom (UK) centres, radiographers are responsible for patient pre-assessment, informed consent, and performing CTC examinations; those who have received training make a preliminary reading of the images. The aim of this book is to present a guide which addresses the needs of radiographers. Being a guide, the focus is on the basics of CTC. We have included a range of normal CTC images of the colon. Images of pathology seen at CTC, including extracolonic findings and bone mineral density for osteoporosis screening, are presented. These examples are not exhaustive. In keeping with the basics of CTC we have attempted to cover the most common pathologies seen at CTC examinations.

CTC is used for CRC screening. Literature reports that younger adults are presenting with colon cancer [16–20]. In 2020, the American Cancer Society [21] recommended that CRC screening in average risk people should commence at 45 years and no longer at 50 years; in May 2021 the US Preventive Service Task Force [22] also recommended that the age of CRC screening should start at 45 years and continue until 75 years of age. It may be continued to 85 years if requested by patients who are in good health with a good life expectancy. In the UK, since April 2021 a phased screening model has been adopted to gradually reduce the age from 60 years to 50–59 years in England, Wales and

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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Northern Ireland; screening in Scotland commences from age 50 years [23]. In the UK, Australia, New Zealand, and Denmark, for example, there has been a rapid increase of CRC among young adults [16, 17, 19, 24]. According to Exarchakou et al. [19], such cancers in the UK have been traditionally right-sided, especially in affluent young adults.

Guidelines for CRC screening include those that are of average, increased or high risk of developing CRC in terms of testing frequency [21]. Average risk is defined as having (a) no personal or family history of CRC, (b) no personal history of inflammatory bowel disease such as ulcerative colitis or Crohn's disease, and (c) no previous abdominal or pelvic region radiation treatment. Screening for CRC in increased risk people should start at 40 years and should include persons that have (a) had previous CRC, (b) inflammatory bowel disease, (c) a strong family history of CRC, and (d) had radiation to abdomen and pelvis. People who are at increased risk usually require colonoscopy more frequently. Apart from CTC and optical colonoscopy (OC), there are stool-based screening tests. The UK bowel screening programme uses the FIT test. It is the high sensitivity faecal immunochemical test. According to Pickhardt [25], it is important to consider the sensitivity of available screening tests for detecting relevant lesions. He reports that CTC in general rivals OC, and for advanced adenoma it is higher when compared to various stool and serum-based tests.

In 1993, the first virtual colonoscopy (VC), also known as CTC, was performed by David Vining from Wake Forest University Health Sciences. It took 60 s to scan the patient using a single-slice helical scanner. Data-processing of the fly-through study took 8 h [26]. Today with multi-detector scanners, and powerful computers, it takes a few seconds to acquire data, which are processed in real time. The 10 year period from 1993 to 2003 showed minimal support for CTC, due to poor results compared with OC. A 2003 ground breaking publication by Pickhardt et al. [27] resulted in CTC being brought into mainstream CRC screening [28]. During that timeframe several changes were made to bowel preparation, tagging, air insufflation, and radiation risks, respectively. Magnesium citrate has replaced sodium phosphate. The latter was withdrawn from the market due to reports of phosphate nephropathy. Faecal and residual fluid tagging was introduced. Residual stool is tagged by 2% w/v barium sulphate, and at the same time it lightly tags the surface of polyps as well as flat lesions [29]. Tagging of fluid is accomplished using iohexol (Omnipaque), which is ingested to stain any residual fluid white. This allows for easier observation of any submerged lesions. The amount of iohexol has been reduced from 75 [30, 31] to 50 cc [25]. The use of automated pressure-controlled CO_2 (carbon dioxide) insufflation, instead of room air has resulted in better distension of the colon. Furthermore, CO_2 is more comfortable for patients: there is less post procedure distension and pain compared to the use of room air [32, 33]. CO_2 is rapidly absorbed across the intestinal mucosa, which results in rapid decompression of the colon without the passing of flatus. Supine and prone studies are the two standard views performed; a right lateral decubitus scan (a third view) is also performed when there is poor colon distension, especially of the rectosigmoid region. This may occur in patients with diverticular disease. Which study do most patients prefer? The vast majority prefer CTC over an OC examination; only a minority opt for OC [34].

CRC is the second leading cause of death worldwide. According to the World Health Organisation [35] in 2020, the third most common site of cancer was CRC. It is the third most common cancer diagnosed in both women and men in the USA [36]. The American Cancer Society [36] estimated there would be 104,270 new cases of colon cancer, and 45,230 new cases of rectal cancer in 2021. CRC was expected to cause approximately 53,000 deaths in 2021. There has been an overall decline in the incidence of CRC as well as deaths in the USA; this has been attributed to CRC screening and removal of potentially harmful polyps [37]. However, deaths from CRC among people younger than 55 in the USA have increased 1% per year from 2008 to 2017 [36].

When a new screening test is assessed the following criteria are used: diagnostic performance; procedural risk; patient acceptability; and cost-effectiveness. OC has for many years been considered the gold standard in CRC screening. Recent publications have cast doubt on this statement [25, 38, 39]. For CTC, an argument can be made that in terms of these criteria it meets or exceeds OC as a CRC screening test [25, 39]. CTC has shown high sensitivity for clinically relevant polyps, either comparable to or superior to OC. Its sensitivity may exceed that of OC, possibly due in part to improved detection of right sided lesions [39]. The high specificity of CTC has resulted in high positive predictive value (PPV) [40]. Advanced neoplasia yield is equivalent to primary OC even though less than 10% of cases are referred to polypectomy [41]. CTC is effective for the diagnosis of relevant flat lesions [42]. CTC is also a useful examination in pre- and post-surgical evaluation of patients with CRC [43, 44].

OC is used for screening of CRC, and for diagnostic and therapeutic procedures. Patients may be referred for CTC following a failed or incomplete OC. In view of this a brief discussion of OC-related complications is presented. Since the introduction of OC in the early 1970s, its use expanded to the level of 14 million patients by 2004 [45]. Even though the overall rate of serious OC-related complications remains low, namely 0.1–0.3% (1 in a thousand to 3 in a thousand), the number of individuals affected is considerable [46]. For example, the OC perforation rate for screening CRC is 0.1% which translates into 14,000 cases per year. For diagnostic or therapeutic OC, the complication rate doubles. Direct mechanical trauma may be caused by injury from the end of the endoscope, or from the abrasive effect of the side of the scope as it is advanced or withdrawn. An OC-related complication is shown in Fig. 1.1a, b.

Another mechanism of injury occurs due to traction on areas of colonic attachment. Barotrauma secondary to colonic distension may occur when pressures exceed 140 mmHg. This typically occurs on the right side of the colon, particularly in the caecum [47]. Perforation of the colon may be intraperitoneal and/or extraperitoneal. Perforation is most commonly in the sigmoid colon due to acute angulation at the rectosigmoid junction. Figure 1.1c–e show air in the abdomen. Intraperitoneal air results from perforation of the transverse colon, sigmoid colon, or caecum. Occasionally, the gas leakage may be confined to the mesocolon. Symptoms and signs of free perforation into the peritoneal cavity include persistent abdominal distension, pain, subcutaneous emphysema, and fever. Perforation of the ascending colon, descending colon and rectum will more likely cause extraperitoneal air due to the retroperitoneal location of these colonic segments. Large extraperitoneal gas leaks may spread to the subcutaneous tissues, leading to subcutaneous emphysema, and into the thorax, which may lead to pneumomediastinum, pneumopericardium, and pneumothorax. Figure 1.1f is an example of free air in the abdomen, thorax, and neck. Supine and erect radiographs of the abdomen may be negative if the gas is subtle or loculated within the mesentery or is extraperitoneal [48, 49].

Polypectomy is the most common cause of perforation in the therapeutic side of OC where the rate doubles compared to screening colonoscopy. Perforation is the result of a through-and-through injury related to the act of polyp removal. A vast majority of such perforations result in operative repair. A recent approach is to repair the perforations with endoscopic clips [49]. Polypectomy may cause haemorrhage in 2.7% of patients [50]. Bleeding may result from haematoma in the wall of the colon or haemorrhage into the lumen of the colon.

Polypectomy syndromes may be subdivided into (1) postpolypectomy distension syndrome, and (2) postpolypectomy coagulation syndrome. The former is applied to patients with severe abdominal pain with a rigid abdomen, and where the evaluation for perforation and haemorrhage is negative. The latter occurs after electrocautery of large sessile polyps at colonoscopy. It is caused by a transmural burn extending through the wall of the colon, often into the adjacent mesentery [51]. This syndrome is only seen in 1% of cases. Patients develop severe abdominal pain with

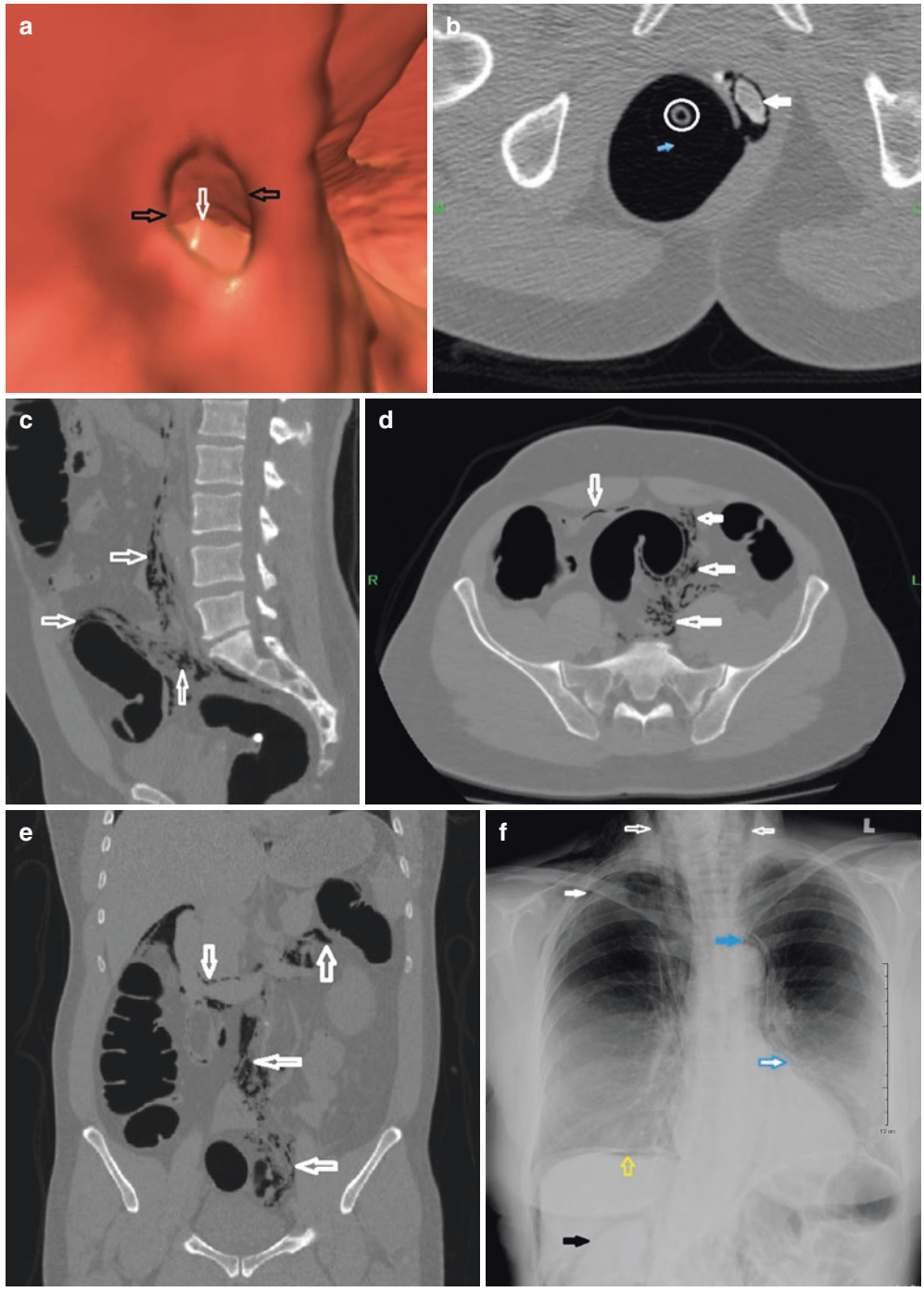

Fig 1.1 (**a**) 3D view of contained perforation of rectum (open black arrows). (**b**) 2D axial view shows contained perforation and calcified faecalith (white arrow) and rectal catheter (white circle). (**c**, **d**) Unsuspected colonic perforation at incomplete optical colonoscopy diagnosed at same-day diagnostic CTC. Extra luminal gas extending along the sigmoid mesentery and superiorly along the retroperitoneal fascial planes: sagittal view (**c**), axial view (**d**), and coronal view (**e**). (**f**) Chest radiograph of a patient post-optical colonoscopy in whom a perforation of the sigmoid colon occurred. Note air in the soft tissues of neck (open white arrows); shallow pneumothorax on the right (closed white arrow); pneumomediastinum (closed blue arrow); pneumopericardium (white and blue arrow); air under the diaphragm (open yellow arrow); air around the right kidney (closed black arrow)

peritoneal signs and fever, usually 1–5 days after the procedure. Abdominal radiographs are usually negative. The syndrome is usually self-limited. It is treated conservatively with bowel rest and antibiotics.

Splenic injury, in the form of laceration or rupture, is a serious complication [52] and is probably a lot more common than has been reported [53]. There may be direct trauma to the spleen leading to capsular avulsion. In patients with an acutely angled splenic flexure, there may be direct pressure on the spleen by the colonoscope. If stretching of the colon occurs during OC, there may be excessive traction or torsion on the phrenicocolic ligament causing a capsular tear.

The presence of diverticular disease is common in older patients. Occasionally, patients may develop acute diverticulitis after colonoscopy. Patients present with left iliac fossa pain and fever a few days post colonoscopy. CT findings are typical with colonic wall thickening, pericolic inflammatory change, and fatty infiltration. Other complications that occur as a result of colonoscopy include bowel obstruction, appendicitis, cathartic and chemical colitis, and thoracic complications following extraperitoneal perforation of the colon. Complications following sedation tend to occur in the older age group where a combination of intravenous (IV) benzodiazepine (Midazolam) and an IV narcotic pain medication (fentanyl) may depress cardio-pulmonary movement. Of fairly recent origin is the transmission of infection via incompletely sterilised colonoscopes. Incomplete cleaning and sterilisation of the colonoscope may cause infection, such as hepatitis B and C, and HIV [54, 55]. A new sterile disposable catheter is used for each patient undergoing a CTC examination.

In May 2020, a joint guidance on performing CTC in the early recovery phase of the Covid-19 pandemic was issued by the British Society of Gastrointestinal and Abdominal Radiology (BSGAR), and the Society and College of Radiographers (SCoR) in order to restart CTC services [56]. According to Moreno et al. [57], CTC is a socially distanced and minimally invasive study with a very low risk of transmission of infection hence is the preferred screening test compared to OC during the Covid-19 pandemic. Peprah et al. [58] reported that none of the 224 patients that had CTC examinations during May and July 2020 acquired Covid-19 infection. None of the 86 staff developed Covid-19. They emphasise that the steps in the BSGAR and SCoR guidelines [56] were adhered to.

CTC is a minimally invasive, fast, safe, and accurate screening examination for CRC [59]. It also allows evaluation of structures outside the colon. When compared with OC, the risk of perforation at CTC is virtually zero. A 168 cm semi-flexible colonoscope is used for OC studies, whereas a sterile small disposable rectal catheter, which is connected to an insufflator, is used in CTC. CTC does not have a bleeding complication. No sedation is required thus there are no complications of sedation-related events. Costs related to CTC are significantly less than for OC, even after costs of investigation of extracolonic findings (ECFs) are factored in [60]. A paper published in September 2015 underscores that CTC is a cost-effective screening test for CRC compared to OC [61]. According to Pyenson et al. [61], CTC was 29% less expensive than OC for the Medicare population in the USA in terms of screening for CRC. The US Preventive Services Task Force recommends screening should be done until the age of 75 years. The American Gastroenterological Association (AGA) and the ACG are silent in terms of maximum screening age, and Medicare sets no upper age limits [62]. In view of CTC meeting screening test criteria, Pickhardt has a mantra which says CTC is ‘better, faster, safer and cheaper than optical colonoscopy for colorectal cancer screening’ [63]. He emphasises a successful CRC screening programme is underpinned by exceptional quality assurance [25]. He underscores that every part and technical component of a CTC examination is interconnected. In other words, any weak link in a CTC examination chain will impact negatively on the final outcome [25].

Literature reports that CTC should include opportunistic screening for osteoporosis [64]. The role of CTC in bone mineral density (BMD) is presented in this book. Screening CTC includes

visualisation of the colon and extracolonic structures. It includes visualisation of the liver as an extracolonic organ, and unenhanced images of both the liver and spleen [65]. The respective CT attenuation values (Hounsfield units) of these two organs can be compared. CT can easily differentiate and quantify visceral and subcutaneous fat; liver fat (steatosis) can also be accurately quantified. Fairly recent literature has underscored the importance of the 25% global prevalence of non-alcoholic fatty liver disease (NAFLD) and its associated risks [66]. The term NAFLD is however controversial. Therefore, in keeping with global stakeholders' endorsement, metabolic-associated fatty liver disease (MAFLD), instead of NAFLD, as an ECF is used in this book [67]. Lambe et al. [68] underscore that colonic findings and ECFs must be reported on.

The bulk of the book comprises performance of a CTC, normal anatomy including extrinsic impressions on the colon lumen, common pathologies, for example, internal haemorrhoids and diverticular disease, ECFs, potential pitfalls, artefacts, and self-assessment questions. As with all imaging examinations, patient compliance is pivotal in CTC. Patients must thus fully understand the bowel preparation instructions and how it should be done. They must furthermore be informed of their role during the examination including the benefits and risks so that an informed decision is reached. For this reason, topics such as patient-centred communication, informed consent, radiation dose, and dose optimisation in CTC are addressed by experts in their fields. Furthermore, experts in their respective fields cover the principles of CT, photon counting CT, and hybrid imaging; the role and types of contrast media as well as allergic reactions; and an overview of CTC in imaging the colon. Since CTC is used as a CRC screening tool, chapters on the adenoma-carcinoma sequence, management and treatment of colon cancer, as well as the role of other modalities in cancer of the colon, such as magnetic resonance imaging (MRI), and F-18-fluoro-deoxy-glucose positron emission tomography (FDG-PET), are included. CTC, with IV contrast media, is discussed in terms of preoperative evaluation of CRC, as well as for tumour, node, and metastases (TNM) staging. There are chapters on the principles of machine learning/AI, dual-energy CT (DECT), and clinical audit.

Barium enema (BE) was the mainstay for investigation of colon pathology from the early 1900s to the mid-1970s. In the 1970s, there was a decline in the number of BE examinations performed; primarily because fibreoptic colonoscopy had gained ground [69, 70]. Literature on this topic shows that BE could not match the sensitivity of colonoscopy for detection of polyps. Two hundred and 76 double contrast barium enema (DCBE) radiology and pathology reports were reviewed in 2006 to determine the number of patients who had polypoid lesions 10 mm or larger, polyps <10 mm, or advanced neoplastic lesions of any size. DCBE performed in average-risk adults older than 50 years had a diagnostic yield of 5.1% for neoplastic lesions 10 mm or larger and 6.2% for advanced neoplastic lesions, regardless of size [71]. Since 2003, CTC has steadily proven to be the preferred imaging modality for the diagnosis of colon cancer. In a multicentre randomised study on symptomatic patients for diagnosis of polyps and CRC, the findings were that CTC detected more polyps and cancer than DCBE [72]. This led the researchers to recommend that CTC should replace DCBE as the preferred radiological test for a patient with symptoms suggestive of CRC. In light of the evidence of a multicentre study [72, 73], BSGAR and the RCR state in their document that BE can no longer be supported as a suitable radiological investigation for patients with symptoms suspicious for CRC [15]. The performance of DCBE is inadequate for the exclusion of CRC. According to Pickhart [25], there are very few radiologists that now have the expertise to report on DCBE. As such it should now be abandoned as a first-line test in patients at risk of CRC and use should be made of CTC [74]. In terms of dose justification, the radiation dose of DCBE is almost double that of CTC [75].

Given an already worldwide burdened radiology workload, it could be argued that there is a need for radiographers to be trained in preliminary reading of CTC images. A chapter on reporting CTC studies, including perti-

nent medico-legal issues should address radiographers' needs in terms of role extension on this topic. It is therefore our wish that this book will contribute in a profound manner to the role extension needs of radiographers

References

1. Bodliy KD, Fletcher JG, Engelby T, et al. Nonradiologists as second reads for intraluminal findings at CT colonography. Acad Radiol. 2005;12(1):67–73.
2. Jensch S, van Gelder RE, Florie J, et al. Performance of radiographers in the evaluation of CT colonographic images. AJR. 2007;188:249–55.
3. Burling D, Wylie P, Gupta A, et al. CT colonography: accuracy of initial interpretation by radiographers in routine clinical practice. Clin Radiol. 2010;65(2):126–32.
4. Lauriden C, Lefere P, Gerke O, Gryspeerdt S. Effect of a tele-training programme on radiographers in the interpretation of CT colonography. Eur J Radiol. 2012;81(6):851–6.
5. Thomas H, Egelund M, Strozik J, Vuurst M. Radiographers are valuable contributors in interpreting computed tomography colonography. Dan Med J. 2016;63(2):A5193.
6. van de Venter R, Friedrich-Nel H. An opinion on role extension, and advanced practice, in the South African radiography context. Where are we heading and what should we aspire to? SAR. 2021;59(1):45–8.
7. Culpan G, Culpan A-M, Doherty P, Denton E. Radiographer reporting: a literature review to support cancer workforce planning in England. Radiography. 2019;25:155–63.
8. Hardy M, Johnson L, Sharples R, Boynes S, Irving D. Does radiography advanced practice improve patient outcomes and health service delivery? A systematic review. Br J Radiol. 2016;89(1062):1–12.
9. Field LJ, Snaith BA. Developing radiographer roles in the context of advanced practice and consultant practice. J Med Radiat Sci. 2013;60(1):11–5.
10. Rasouli P, Moghadam AD, Eslami P, Pasha MA, Aghdaei HA, Mchrvar A, Nezami-Asl A, Iravani S, Sadeghi A, Zali MR. The role of artificial intelligence in colon polyps detection. Gastroenterol Hepatol Bed Bench. 2020;13(3):191–9.
11. Grosu S, Wesp P, Graser A, Maurus S, Schulz C, Knösel T, Cyan CC, Ricke J, Ingrish M, Kazmierczak PM. Machine learning-based differentiation of benign and premalignant colorectal polyps detected with CT colonography in an asymptomatic screening population: a proof-of-concept study. Radiology. 2021;299:326–35.
12. International Society of Radiographers and Radiological Technologists, The European Federation of Radiographer Societies. Artificial intelligence and the radiographer/radiological technologist profession joint statement of the International Society of Radiographers and Radiological Technologists and the European Federation of Radiographer Societies. Radiography. 2020;26:93–5.
13. Garcia-Figueiras R, Baleato-Gonzalez S, Padhami AR, Luna-Alcala A, Marhuenda A, Vilanova JC, Osorio-Vazquez I, Martinez-de-Alegria A, Gomez-Caamño A. Advanced imaging techniques in evaluation of colorectal cancer. Radiographics. 2018;38(3):740–65.
14. Sato K, Morohashi H, Tsushima F, Sakamoto Y, Miura T, Fujita H, Umemura K, Suzuki T, Tsuruta S, Kura R, Ono S, Aoki M, Hakamada K. Dual energy CT is useful for prediction of mesenteric and lateral pelvic lymph node metastasis in rectal cancer. Mol Clin Oncol. 2019;10:625–30.
15. British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiologists. Guidance on the use of CT colonography for suspected cancer (Ref NO: BF CR [14]9), September 2014. www.rcr.ac.uk. Accessed 17 Sept 2022.
16. Rajagopalan A, Antoniou E, Rajagopalan E, Arachchi A, Chouhan H, Nguyen TC, Teoh W. Is colorectal cancer associated with altered bowel habits in young patients? ANZ J Surg. 2021;91:943–6.
17. Kim J, Dobson B, Ng Liet Hing C, Cooper M, Lu CT, Nolan G, Von Papen M. Increasing rate of colorectal cancer in younger patients: a review of colonoscopy findings in patients under 50 at a tertiary institution. ANZ J Surg. 2020;90:2484–9. https://doi.org/10.1111/ans.16060.
18. Cavestro GM, Zuppardo RA, Mannucci A. Early-onset of colorectal cancer: trends and challenges. Lancet Gastroenterol Hepatol. 2019;4(7):F491–2. https://doi.org/10.1016/S2468-1253(19)30146-3.
19. Exarchakou A, Donaldson LJ, Girardi F, Coleman MP. Colorectal cancer incidence among young adults in England: trends by anatomical sub-site and deprivation. PLoS One. 2019;14(12):e0225547. https://doi.org/10.1371/journal.pone.022554.
20. Putland GR. Screening can PREVENT colon (bowel) cancer, says NHS. https://grputland.tumblr.com/post/145198609652/screening-can-prevent-colon-cancer. Accessed 17 Sept 2022.
21. American Cancer Society. Guidelines for colorectal cancer screening. https://www.cancer.org/cancer/colon-rectal-cancer/detection. Accessed 17 Sept 2022.
22. Davidson KW, Barry MJ, Mangione CM, et al. Screening for colorectal cancer US Preventive Services Task Force recommendation statement. JAMA. 2021;325(19):1965–77.
23. Bowel cancer screening UK. https://www.bowelcanceruk.org/about-bowel-cancer/screening. Accessed 17 Sept 2022.
24. Araghi M, Soerjomataram I, Bardot A, Ferlay J, Cabasag CJ, Morrison DS, De P, et al. Changes in colorectal cancer incidence in seven high-income countries: a population-based study. Lancet Gastroenterol Hepatol. 2019;4:511–8.

25. Pickhardt PJ. Imaging and screening for colorectal cancer with CT colonography. Radiol Clin N Am. 2017;55:1183–96.
26. Vining DJ. Virtual colonoscopy: a storm is brewing. Appl Radiol. 2008;37(11):12–6.
27. Pickhardt PJ, Choi R, Hwang I, Butler JA, Puckett ML, Hildebrandt A, et al. Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. N Engl J Med. 2003;349(23):2191–200. https://doi.org/10.1056/NEJMoa031618.
28. ACR practice guidelines for the performance of computed tomography (CT) colonography in adults. www.acr.org. Accessed 17 Sept 2022.
29. Kim DH, Hinshaw L, Lubner MG, et al. Contrast coating for the surface of flat polyps at CT colonography: a marker for detection. Eur Radiol. 2014;24(4):940–6. https://doi.org/10.1007/s00330-014-3095-z.
30. Johnson B, Hindshaw JL, Robbins JB, Pickhardt PJ. Objective and subjective intrapatient comparison of iohexol versus diatrizoate for bowel preparation at CT colonography. AJR. 2016;206(2):1202–7.
31. Kim B, Park SH, Hong GS, Lee JH, Lee JS, Kim HJ, Kim AY, Ha HK. Iohexol versus diatrizoate for fecal/fluid tagging during CT colonography performed with cathartic preparation: comparison of examination quality. Eur Radiol. 2015;25(6):1561–9. https://doi.org/10.1007/s00330-014-3568-0.
32. Burling D, Taylor SA, Halligan S, Gartner L, et al. Automated insufflation of carbon dioxide for MDCT colonography: distension and patient experience compared with manual insufflation. AJR. 2006;186:96–103. https://doi.org/10.2214/ajr.04.1506.
33. Shinners TJ, Pickhardt PJ, Taylor AJ, Jones DA, Olsen CH. Patient-controlled room air insufflation versus automated carbon dioxide delivery for CT colonography. AJR. 2006;186:1491–6. https://doi.org/10.2214/ajr.05.0416.
34. Gluecker TM, Johnson CD, Harmsen WS, et al. Colorectal cancer screening with CT colonography, colonoscopy and double-contrast barium enema examination: prospective assessment of patient perceptions and preferences. Radiology. 2003;227(2):378–84. https://doi.org/10.1148/radiol.2272020293.
35. World Health Organisation. 2021. https://www.who.int/news-room/fact-sheets/detail/cancer. Accessed 17 Sept 2022.
36. American Cancer Society. Key statistics for colorectal cancer in 2021. https://www.cancer.org/cancer/colon-rectal-cancer/about/key-statistics.html. Accessed 17 Sept 2022.
37. Johnson DA. Landmark developments in gastroenterology. Medscape. 2015. http://www.medscape.com. Accessed 17 Sept 2022.
38. Atkin W, Dadswell E, Wooldrage K, Kralj-Hans I, von Wagner C, Edwards R, Yao G, Kay C, Burling D, Faiz O, Teare J, Lilford RJ, Morton D, Wardle J, Halligan S, et al. Computed tomographic colonography versus colonoscopy for investigation of patients with symptoms suggestive of colorectal cancer (SIGGAR): a multicenter randomized trial. Lancet. 2013;381(9873):1194–202. https://doi.org/10.1016/S0140-6736(12)62186-2.
39. Pickhardt PJ, Hassan C, Halligan S, et al. Colorectal cancer: CT colonography and colonoscopy for detection—systematic review and meta-analysis. Radiology. 2011;259:393–405.
40. Pickhardt PJ, Wise S, Kim DH. Positive predictive value for polyp detected at screening CT colonography. Eur Radiol. 2010;20:1651–6.
41. Kim DH, Pickhardt PJ, Taylor AJ, et al. CT colonography versus colonoscopy for the detection of advanced neoplasia. N Engl J Med. 2007;357:1403–12.
42. Pickhardt PJ, Kim DH, Robbins JB, et al. Flat (non-polypoid) colorectal lesions identified at CT colonography in a US screening population. Acad Radiol. 2010;17:784–90.
43. Hong N, Park SH. CT colonography in the diagnosis and management of colorectal cancer: emphasis on pre- and post-surgical evaluation. World J Gastroenterol. 2014;20(8):2014–22. https://doi.org/10.3748/wjg.v20.i8.2014.
44. Sali L, Falchini M, Taddei A, Mascalchi M. Role of preoperative CT colonography in patients with colorectal cancer. World J Gastroenterol. 2014;20(14):3795–803. https://doi.org/10.3748/wjg.v20.i14.3795.
45. Seef LC, Richards TB, Shapiro JA, et al. How many endoscopies are performed for colorectal cancer screening? Results from CDC's survey of endoscopic capacity. Gastroenterology. 2004;127:1671–7.
46. Waye JD, Lewis BS, Yessayan S. Optical colonoscopy: a prospective report of complications. Am J Gastroenterol. 1993;15:347–51.
47. Han SY, Tishler JM. Perforation of the colon above the peritoneal reflection during the barium enema examination. Radiology. 1982;144(2):253–5.
48. Kim DH, Pickhardt JP, Taylor AJ, et al. Imaging evaluation of complications at optical colonoscopy. Curr Probl Diagn Radiol. 2008;37:165–77.
49. Daly B, Lu M, Pickhardt JP, et al. Complications of optical colonoscopy: CT findings. Radiol Clin N Am. 2014;52:1087–99.
50. Pignone M, Rich M, Teutsch SM, et al. Screening for colorectal cancer in adults at average risk: a summary of the evidence for the US Preventive Services Task Force. Ann Intern Med. 2002;137:132–41.
51. Waye JD, Kahn O, Auerbach M. Complication of optical colonoscopy and flexible sigmoidoscopy. Gastrointest Endosc Clin N Am. 1996;2:343–77.
52. Fishback SJ, Pickhardt PJ, Bholla S, et al. Delayed presentation of splenic rupture following optical colonoscopy: clinical and CT findings. Emerg Radiol. 2011;18:539–44.
53. Saad A, Rex D. Optical colonoscopy-induced splenic injury: report of 3 cases and literature review. Dig Dis Sci. 2008;53:892–8.
54. The Farber Law Group. Improper sterilization procedures prompts letters to vets who underwent

colonoscopies. 2009. http://www.washingtoninjuryattorneyblog.com. Accessed 17 Sept 2022.
55. Artavia D. Two hundred colonoscopy patients accidentally exposed to HIV. 2013. http://www.hivplusmag.com/case-studies/daily-dose/2013/07/22/two-hundred-colonoscopy-patients-accidentally-exposed-hiv. Accessed 17 Sept 2022.
56. British Society of Gastrointestinal and Abdominal Radiology and Society of Radiographers. Joint guidance on performing CT colonography in the early recovery phase of the Covid-19 pandemic. BSGAR and SCoR. 2020.
57. Moreno CC, Yee Y, Ahmed FS, Barish MA, Brewington C, Dachman AH, Gollup MJ, Kim DH, McFarland E, Pickhardt PJ, Reddy S, Zalis M, Chang KJ. CT colonography's role in the COVID-19 pandemic: a safe(r), socially distanced total colon examination. Abdom Radiol. 2021;46(2):486–90. https://doi.org/10.1007/s00261-020-02674-5.
58. Peprah D, Plumb A, Corr A, Muckian J, Smith K, Sergot A, Kuah JY, Stephenson J. Re-initiation of CT colonography services during the COVID-19 pandemic: preliminary evaluation of safety. Br J Radiol. 2021;94(1121):20201316. https://doi.org/10.1259/bjr.20201316.
59. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Rad. 2014;18(1):607. https://doi.org/10.4102/sajr.v18i1.607.
60. Pickhardt PJ, Hassan C, Laghi A, et al. Cost effectiveness of colorectal cancer screening with computed tomography colonography—the impact of not reporting diminutive lesions. Cancer. 2007;109:2213–21.
61. Pyenson B, Pickhardt PJ, Sawhney TG, Berrios M. Medicare cost of colorectal cancer screening: CT colonography vs. optical colonoscopy. Abdom Imaging. 2015;40:2966–76. https://doi.org/10.1007/s00261-015-0538-1.
62. Medicare.gov. Your Medicare coverage: is my test, item or service covered? Colorectal cancer screenings. 2015. http://www.medicate.gov/coverage/colorectal-cancer-screnningshtml. Accessed 17 Sept 2022.
63. Pickhardt PJ. CT colonography: does it satisfy the necessary criteria for a colorectal screening test? Expert Dev Gatroenterol. 2014;8(3):211–3.
64. Bortz JH, Munro L. Assessment of bone mineral density in male and female patients at screening CT colonography. SAR. 2018;56(1):11–4.
65. Bortz JH. Is non-alcoholic fatty liver disease (NAFLD) seen at CT colonography an important extracolonic finding? SAR. 2017;55(2):7–12.
66. Powell E, Wong V, Rinella M. Non-alcoholic fatty liver disease. Lancet. 2015;397(10290):2212–24. https://doi.org/10.1016/S0140-6736(20)32511-3.
67. Mèndez-Sández N, Bugianesi E, Gish RG, et al. Global multi-stakeholder endorsement of MAFLD definition. Lancet Gastroenterol Hepatol. 2022;7(5):388–90. https://doi.org/10.1016/S2468-1253(22)00062-0.
68. Lambe G, Hughes P, Rice L, McDonnell C, Murphy M, Judge C, Guiney M. The bowel and beyond: extracolonic findings from CT colonography. Ir J Med Sci. 2021;191:909–14. https://doi.org/10.1007/s11845-021-02595-2.
69. Ott DJ, Gelfand DW. The future of barium radiology. BJR. 1997;70:S171–6.
70. Winawer SJ, Stewart ET, Zauber AG, et al. A comparison of colonoscopy and double-contrast barium enema for surveillance after polypectomy. NEJM. 2000;324(24):1766–72.
71. Kung JW, Levine MS, Glick SN, et al. Colorectal cancer: screening double-contrast barium enema examination in average-risk adults older than 50 year. Radiology. 2006;240(3):725–35.
72. Halligan S, Wooldrage K, Dadswell E, et al. Computed tomographic colonography versus barium enema for diagnosis of colorectal cancer of large polyps in symptomatic patients (SIGGAR): a multicenter randomised trial. Lancet. 2013;381:1185–93.
73. van Wagner C, Smith S, Halligan S, et al. Patient acceptability of CT colonography compared with double contrast barium enema: results from a multicenter randomised controlled trial of symptomatic patients. Eur Radiol. 2011;21:2046–55.
74. Shariff MK, Sheikh K, Carroll NR, et al. Colorectal cancer detection: time to abandon barium enema. Frontline Gastroenterol. 2011;2:105–9. https://doi.org/10.1136/fg.2010.003616.
75. Hiofuji Y, Aoyama T, Koyama S, Kawaura C, Fujii K. Evaluation of patient dose for barium enema and CT colonography in Japan. BJR. 2009;82:219–27.

2 Patient-Centred Communication in Imaging

Leonie Munro

2.1 Introduction

There are three stages in CT colonography (CTC): patient preparation; performing the study; and interpretation and reporting of the study [1, 2]. Although all three stages involve patients, it is the first two that are critical because patient compliance is pivotal in CTC [2, 3]. Patients need to be informed of their responsibilities before and during a CTC study. According to the World Health Organisation (WHO) [4], radiographers and radiologists should adhere to ethics in imaging as well as informing patients of the use of ionising radiation (see Chaps. 5 and 6). Patients should also be informed that artificial intelligence (AI) and its subset machine learning [5, 6] may be used for interpretation of CTC data (see Chap. 25).

Each patient needs to fully understand the role of diet and bowel preparation to ensure a clean bowel as described in Chap. 9. Patients should also understand what to do during the study, such as breath hold, as described in Chap. 10. This entails patient-centred communication, [7] which may be defined as ensuring that each patient, regardless of socio-economic environments, cultures, and other differences including disabilities, is communicated with and not at [7–9].

L. Munro (✉)
Formerly King Edward V111 Hospital, Durban, South Africa

Communication is interactive; it should not be a top down model [10]. For example, patients are required to adhere to all steps in the patient preparation stage, and they must understand the importance of breath hold and not to move during the second stage of a CTC study. We have to communicate with patients in both of these stages. This seems straightforward, but according to Munn and Jordan [11] radiographers need to appreciate that patients may experience high levels of anxiety when undergoing high technology imaging, such as CT examinations. The findings of a systematic review of literature pertaining to patients' perceptions of advanced imaging studies were that negative experiences during previous CT examinations can contribute to patients' apprehension when booked for other imaging studies [11]. In many instances, patients were objectified, which in turn resulted in lack of patient-centred communication [11].

Most patients who undergo CTC examinations are 50 years or older; some may therefore be hard of hearing or visually impaired and/or have mobility problems. Each of such patients presents communication challenges. In the United Kingdom (UK), over eight million people aged 60 years and older have hearing loss [12]. In the United States of America (USA) approximately one in three people between the ages of 65 years and 74 years has loss of hearing [13]. Hearing problems are an important communication challenge when performing a CTC study

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because a patient and CTC radiographer cannot participate in face-to-face communication during scanning. There are over two million people in the UK who have loss of vision; the majority are 65 years or older [14]. It is important that patients with loss of vision are able to identify all items in the bowel preparation kit, for example.

Seating may be a barrier that can influence patient perception. Many elderly people experience difficulty rising from a chair. We need to consider the height of seats in waiting rooms. Chairs that are very low are not user-friendly for elderly patients [15]. The same applies to the height of toilets. These could be challenges for patients with mobility problems. Each challenge that a CTC patient encounters could result in an overall negative perception of the study.

Language barriers need to be considered. Some patients may not understand English, for example. Many countries in the developed and developing world have progressed to multicultural societies, mainly due to rapid migration. The result is that there are two communication scenarios. When a common language is shared face-to-face interpersonal exchanges are not problematic as there is a two-way communication between a CTC radiographer and a patient (dyadic exchange). The second scenario is a triadic exchange in which an additional participant, an interpreter, is present because the patient does not share nor understand the language of the CTC radiographer [16]. A point to consider is that there could be ethical issues in terms of a patient's right to confidentiality when an interpreter is used in a triadic exchange [17]. Research shows that it is preferable to use a professional interpreter for interventional studies and contrast-enhanced imaging studies so that the benefits and risks are clearly conveyed to the patient [18]. A recent study reported the successful use of a digital multi-language questionnaire for diagnostic imaging examinations to minimise language barriers and adhere to patient privacy [19].

Healthcare professionals should use different communication media and materials to ensure patient-centred communication is successful. Each patient must be treated in a dignified and respectful manner. To refer to an elderly hard of hearing person as 'the deaf patient' would be totally unprofessional. As pointed out by Munn and Jordan [11], patient perceptions of imaging procedures may be positive or negative. Anecdotal reports in social media may contribute to patients' perceptions of CTC.

It is the responsibility of diagnostic imaging healthcare practitioners to create a positive communication climate to ensure patient compliance. Each challenge encountered by a patient contributes to the overall perception of a CTC experience. The bottom line is that patients should be willing to return for surveillance or screening CTC studies as our aim is to prevent colorectal cancer. In other words, imaging procedures are not limited to the study. All factors that may impact a patient's perception of the entire experience must be taken into account.

The following abbreviations are used in this chapter

- AC: adaptive child
- AI: artificial intelligence
- CP: controlling parent
- CTC: CT colonography
- FC: free child
- NP: nurturing parent
- TA: transactional analysis
- UK: United Kingdom
- USA: United States of America
- WHO: World Health Organisation

2.2 What Is Communication?

There is no agreed universal definition of communication [7]. Some authors define communication within specific contexts [20–22]. Communication frameworks have been presented in terms of communication interaction, people, and the process itself [7]. According to Weissman [23], communication includes 'an interactive process through which there is an exchange of information that may occur verbally, nonverbally, in writing, or through information technology'. Within a medical context Riuz-Moral et al. [24] state communication is being able to grasp a patient's communicative style, and then to adjust

one's own style to improve efficiency and satisfaction for both. It has also been described as the tool of information exchange, which is necessary (1) to solve health problems, and (2) to create a therapeutic relationship, which is necessary to manage health problems and gain a patient's confidence [25].

Several models are used to describe human communication. The simplest is the Shannon and Weaver model: sender → message → channel → noise → receiver [26]. We need to ensure each patient fully understands what is required to achieve a successful CTC study. In other words, it is important that patients follow all bowel preparation instructions, and diet (see Chap. 9). Patients need to fully understand that a clean bowel and well distended colon are necessary in a CTC study. Patients must cooperate with breath hold instructions.

How can we determine whether patients understand what is required of them? Communication should not be unidirectional, but should include feedback. The Shannon and Weaver model does not address feedback, which is essential in patient-centred communication. Lasswell's model moved towards the social process of communication: who communicated; what was communicated; where was it communicated (context); when did the communication happen; and why was there a need for communication [27]. In terms of this model, we need to question how the information was transmitted. This brings us to types of communication: top down or interactive. A top down approach fails to focus on how patients interpret and understand the required information for patient preparation. Effective communication should lead to patient compliance in the first two stages in CTC.

Booth and Manning [28] undertook an exploratory study using transactional analysis (TA) to investigate radiographer communication with patients. TA is a model of psychotherapy underpinned by a theory that each individual's personality comprises three ego-states: the parent, the adult, and the child. There are two divisions in the parent–ego state: controlling parent (CP) and nurturing parent (NP). The 'adult' state does not include subdivisions. There are two subdivisions in the 'child': free child (FC) and adaptive child (AC). How do these ego-states apply to interactions with patients? A CP interaction is judgemental, critical, and prejudicial, for example. A type of top-down interaction with patients. An NP is supportive and nurturing: patients are encouraged during imaging procedures. Adult interactions are reality-orientated, organised, and objective and show adaptability. Child interactions range from rebellious to manipulative. Within a radiography context patients associate styles of communication with professional and interpersonal competence. Good patient-centred competence encompasses informing, explaining, instructing, teaching, and being friendly in all communication with patients.

2.3 Verbal and Nonverbal Communication

We use verbal and nonverbal communication [29] in formal and informal interactions. Our vocal cords produce sound and spoken words. We need to interpret the meaning of words. This requires sharing the same language and internal references as the speaker. A successful CTC study requires that the rectum must be emptied of any residual fluid, and this must be conveyed to a patient before commencing a CTC study. Would all patients understand what a restroom means if instructed to go there? Restrooms are used in America whereas in South Africa a patient would be instructed to go to the toilet or lavatory.

Sign language or written forms of communication could also be used. This is important when dealing with patients who are hard of hearing. It may at times be necessary to use mime to communicate with hard of hearing patients [30], but this may not be feasible during CT scanning. Other communication methods are needed for patients who remove hearing aids during scanning [9]. Prior to commencing a CTC procedure an agreed alternate method needs to be practised with the patient, for example, a raised arm to indicate the patient must not move and must stop breathing during scanning.

Gestures, facial expressions, tone of voice, dress code, and posture are forms of nonverbal communication [31]. Meaning in communication is a combination of verbal and nonverbal information. What is important to realise is that gestures may be interpreted differently. According to literature, there is controversy whether some gestures are truly pancultural [32] or cultural specific [29, 33]; also whether gestures, for example, are learned or innate behaviour [29]. In complex, adult communication, there is much which remains unknown [7]. This is further complicated by any impairment to normal communication, such as deafness, blindness, or mental incapacity [8, 9]. Patients who are deaf reported they encountered communication difficulties and that health professionals should take time to learn more about the sociocultural aspects of deafness [34].

Both verbal and nonverbal communication are in play when communicating with patients. What is significant is that most people use gestures more than spoken language to communicate. Spoken words contribute only a small percentage of the meaning of any communication (7%), alongside tone of voice and nonverbal behaviour [35]. We need to be aware that patients may become anxious if they do not hear a modulated tone and pitch. CTC patients with vision loss present different communication challenges. Use of gestures in communication needs to be adjusted when communicating with patients who have visual impairments. It would be insensitive to point to a chair on which the patient should sit if the patient has a visual impairment. Clear instructions should be given, such as 'the chair is 2 m to your right'. In patient-centred communication, a conscious effort is required by CTC radiographers to use mainly spoken language when communicating with patients with visual impairments. It is important to tell a blind patient of your movements. For example, 'I will adjust your position, and then I will leave the room to work the CT scanner' [9]. The height of a chair should also be considered, as many older people experience difficulties attempting to rise from a soft low seat [15]. We need to ensure that chairs of suitable heights are available for elderly CTC patients in change rooms and the CT suite.

2.4 Sign, Symbols, and Codes

Although some authors do not make a distinction between the meaning of signs and symbols [36], they are usually taken to mean different things [36, 37]. Signs are used in all communication. A sign can be anything: a gesture or punctuation mark, for example. A sign does not have meaning because it stands for something else [36, 38]. Let's consider the colour red, which comprises the alphabet letters of r-e-d. These letters on their own do not signify anything. Red as a sign can stand for many things; as a traffic signal, it is the colour that indicates when a driver must stop; it could be a figure of speech to indicate being angry. According to Danesi [38], semiotics in its oldest usage referred to a medical diagnosis whereas it now means a science that seeks to establish the meaning of a sign. He cites the respective works of de Saussure, a Swiss linguist, and Peirce, an American philosopher, as underpinning the modern-day definition of semiotics. The former described a sign as a binary structure: a physical part (the signifier) and a conceptual part (the signified); the link between them is arbitrary. If we return to 'red' as a sign, then according to him the English names for colours in the visible spectrum is a result of a social process to distinguish each colour. The Peircean model, according to Danesi [38] comprises three relationships: a sign; concepts, things, gestures, etc. which it refers to is the object; and the interpretant is the meaning we get from the sign. Peirce identified three types of signs: icons, indexes, and symbols. A photograph of a CT scanner, for example, is an icon as it resembles the item. An index sign is one that indicates a referent: an index finger pointing to a place on a map or the use of pronouns to refer to specific persons, such as me, you, and them [30, 38]. A sign is an index when there is causal connection between the signifier and signified which means that a radiologist, for example, could on clinical examination of a CT patient, who presents with a right-sided abdominal pain (signifier), interpret this as possible appendicitis (signified). A sign is a symbol when it can be encoded based on agreement or convention. If we consider 'green', then accord-

ing to Peirce's sign classification it is a symbol; its meaning can be encoded in terms of its use in the English language, namely a colour in the visible spectrum, or a figure of speech to represent envy, or it may be used as a symbol for renewal and rebirth. For some it may represent to go (being given the greenlight).

Signs do not function in a vacuum: they require a system to be encoded and decoded. Communication requires encoding. Codes are necessary to create and interpret messages, and a code system comprises an agreed on structure. When we converse, we use language as a code which requires the signs to be used in a specific order for encoding and decoding to occur. Patient communication involves codes provided these have shared meaning. Language barriers may present problems thus shared meaning in a CTC context could be a challenge. A patient and a CTC radiographer could be from different cultures. Even if both are from a shared culture, there could be challenges communicating with patients who have hearing or visual disabilities.

2.5 Denotative and Connotative Meanings

Littlejohn and Foss [39] caution that shared meaning is not guaranteed in communication between people with common backgrounds and cultures. Patient-centred communication needs to be unambiguous [40]. Not all messages are understood by all members of a shared social or cultural group even though they share common backgrounds [39] as each person has personal meanings for signs; we all have different life experiences based on denotative and connotative meanings. We attach denotative and connotative meanings to the signs used. A dictionary contains denotative meanings; there is an unambiguous and very conventional relationship between a sign and its referent [38]. When discussing bowel preparation with a patient, we could refer to cathartic agents, instead of using the word 'laxative'. Let's pause and consider whether this is a common word used in everyday communications by laypersons. Could other meanings be attached to cathartic? Cathartic could be interpreted as an emotional 'cleansing' which could confuse a patient. In other words, there may be several denotative meanings of words that we use when communicating with patients. To avoid misunderstanding, simple words, and not medical jargon, should be used to achieve successful patient-centred communication.

We interpret communication subjectively; we ascribe connotative (subjective) meanings, such as feelings, implications, and associations, to a denotative meaning [38]. Each participant when communicating attributes denotative and connotative meanings to messages based on life experiences, etc. Patient-centred communication is a dynamic complex process [7] which must be adapted to meet the needs of each patient. The underlying message is that simple, unambiguous language should underpin patient-centred communication [41].

2.6 Ensuring a Successful CTC Study: Suggested Communication Materials to Inform Patients of Their Responsibilities

We need to cater for the needs of all patients to ensure they fully understand their responsibilities in CTC examinations. Hardcopy brochures are cost-effective provided the font size is not too small. Layout should not be busy as some patients may think they will not be competent to understand all the information. Text should be simple and unambiguous without jargon. Clear diagrams should be included. For example, pictures of the bowel kit with clear legends. Brochures using sign language should also be available.

Audiovisual instructional material could be used. For example, patients could be requested to watch a DVD or video that covers bowel preparation and visuals of a CT suite. Information should be available on the web. There is software that allows one to select a range of languages. The use of Apps could be explored to enhance interactive communication [42, 43]. Most people have access to smartphones or tablets thus information

in a range of software options, such as PowerPoint presentations, could be used to explain each step in bowel preparation. Mobile phone messaging reminders could be used especially for hard of hearing patients [44, 45]. Ventola [46] recommends that professional healthcare organisations, for example, should develop guidelines and policies to minimise potential risks of breach of patients' data and privacy if social media are used to interact with patients.

2.7 CTC Examinations and Patient Feedback

Studies of CTC versus colonoscopy indicate that patients prefer CTC [47]. A semi-structured questionnaire was used in a study in terms of patients' expectations and experiences of barium enema, colonoscopy, and CTC [48]. Patients were interviewed by telephone by health psychologists within 48 h of the procedures; overall patients reported that CTC was the most impersonal test. There was less interaction with the clinical staff. Compared with barium enema and colonoscopy, the patients reported lack of visual feedback during CTC, and inconsistent verbal feedback [48]. Based on the results of this study, patient-centred communication during and immediately after a CTC study may lead to positive patient perceptions. Similar findings were reported by Plumb et al. [49]; they recommended the need for clear communication of risks, benefits, procedural experience, and results of CTC. Patients must be encouraged to ask questions so that they understand what their role will be during a CTC procedure. They should be informed that additional tests may be needed. The patients in their study were well-informed in terms of risks and benefits of colonoscopy. Feedback from patients of their perceptions and experiences of the CTC procedure should be encouraged. The use of an electronic portal and messaging system can be used for feedback from patients [50]. A portal-based e-mail can also be used for dialogue between patients and radiologists/radiographers [50].

Clinical audits of patient communication during all stages of CTC examinations should be conducted as discussed in Chap. 27.

2.8 Readability of Imaging Reports

Patients and their family may access their written imaging reports. It is therefore important not to use complex terms and concepts to ensure achieving the respective goals of patient-centred care and patient-centred communication. In other words, simple language should be used in imaging reports so that the text can be understood by a layperson [51]. A reporting template is presented in Chap. 21.

2.9 Readability of Text of Instructions and Informed Consent for Patients

It is important that the text of CTC instructions for patient preparation, and that of informed consent, is easy to understand. As discussed above, the language used must not include jargon. An average adult should be able to read and understand the text for bowel preparation, and that of informed consent forms, as well as communication by social media, etc. The readability of two-thirds of 75 informed consent forms for research studies in a South African study was found to be difficult hence not appropriate for an average adult with grade 8 level education [52].

As discussed in Chap. 27, the aim of a CTC examination is that the entire process should be underpinned by best practice standards for optimal patient outcomes. Hence, it is important that we should ensure that the content readability of digital and hardcopy material for a CTC study is of a level that would be understood by all patients. There are several methods one could use to determine the readability of text; one of which is the Flesch–Kincaid formula; it was one of the tests used in the informed consent study [52]; reading score = 206.835 − 1.015 × (total words ÷ total

sentences) − 84.6 × (total syllables ÷ total words). The two variables are words and syllables in, for example, a paragraph. The readability score range is 100–0:90–100 = very easy to read by estimated reading grade 5; 60–70 = text would be easy to read by an average adult with grade 8 level education; and 30–0 would be understood by college graduates.

There are several online readability calculators for readability score and grade level. As discussed above simple words and short sentences should be used in patient-centred communication. This chapter is aimed at radiographers hence the readability content should be suitable for readers with at least a college level of education. For example, according to an online Flesch–Kincaid calculator [53] the Abstract of this chapter has 172 words and 10 sentences; the reading score is 16.7 hence is considered very difficult. In other words, it is an academic text for college graduates. The readability content of CTC instructions for patient preparation should have a readability score of between 60 and 70. The readability score of instructions to patients should therefore be included in a CTC clinical audit. The principles of the latter are discussed in Chap. 27.

Key Messages

- Patient-centred communication needs to be unambiguous.
- Each patient must be treated with dignity and respect.
- It is important to speak slowly and to face patients when explaining their responsibilities in a CTC study.
- It is essential to be knowledgeable of 'Do's and Don'ts' when communicating with patients with visual impairments or hearing impairments.
- Patients should be requested to describe in their own words their understanding of CTC bowel preparation and diet.
- Patients should be informed that a CTC study also includes imaging of organs outside the bowel.
- Patients should be informed that there may be a need for additional tests.
- It is important that the results of the CTC study are communicated quickly to patients.
- Patients should be encouraged to provide feedback after their CTC examinations so that gaps can be addressed and rectified.
- Communication material should meet the needs of every patient.
- Clinical audits of CTC examinations include patient communication.

2.10 Summary

Effective communication is the core of successful CTC studies. Patient-centred communication should cover risks, benefits, and procedural experiences. Different communication materials should be used to meet the needs of patients. Patients should be fully informed of their responsibilities to ensure a successful CTC study is achieved.

References

1. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Radiol. 2014;18(1):607. https://doi.org/10.4102/sajr.v18i1.607.
2. Yee J, Weinstein S, Morgan T, et al. Advances in CT colonography for colorectal cancer screening and diagnosis. J Cancer. 2013;4(3):200–9. https://doi.org/10.7150/jca.5858.
3. Mang T, Graser A, Schima W, Maier A. CT colonography: techniques, indications, findings. Eur J Radiol. 2007;61:388–99.
4. World Health Organisation. Ethics and medical radiological imaging: a policy brief for health-care providers. Geneva: World Health Organization; 2022.
5. Balthazar P, Harri P, Prater A, Safdar NM. Protecting your patients' interests in the era of big data, artificial intelligence, and predictive analytics. J Am Coll Radiol. 2018;15:580–6.
6. Mudgal KS, Das N. The ethical adoption of artificial intelligence in radiology. BJR Open. 2020; 2:20190020. https://doi.org/10.1259/bjro.20190020.
7. Henwood SA, Munro L. Principles of communication. In: Ramlaul A, Vosper M, editors. Patient centered care in medical imaging and radiotherapy. London: Churchill Livingstone; 2013. p. 3–6.
8. Reeves PJ. Communication with specific patients. In: Ramlaul A, Vosper M, editors. Patient centered care in medical imaging and radiotherapy. London: Churchill Livingstone; 2013. p. 7–12.

9. Bungay H. Communication with patient groups with disabilities. In: Ramlaul A, Vosper M, editors. Patient centered care in medical imaging and radiotherapy. London: Churchill Livingstone; 2013. p. 13–9.
10. Booth L. The radiographer–patient relationship: enhancing understanding using a transactional analysis approach. Radiography. 2008;14(4):323–31.
11. Munn Z, Jordan Z. The patient experience of high technology medical imaging: a systematic review of the qualitative evidence. Radiography. 2011;17(4):323–31.
12. Hearing Link Services. https://www.hearinglink.org/your-hearing/about-hearing/facts-about-deafness-hearing-loss. Accessed 8 Sept 2022.
13. Hearing Loss Association of America. Basic facts about hearing loss. http://www.hearingloss.org/content/basic-facts-about-hearing-loss. Accessed 8 Sept 2022.
14. John Gill Technology. Blindness and visual impairment. http://www.johngilltech.com/guidelines/visual.htm. Accessed 8 Sept 2022.
15. Alexander NB, Schultz AB, Warwick DN. Rising from a chair: effects of age and functional ability on performance biomechanics. J Gerontol. 1990;46(3):M91–8.
16. Valero-Garcés C. Challenging communication in doctor/non-native patient encounters. Two perspectives, three types of interaction and some proposals. J Spec Transl. 2010;14:229–46.
17. Etheredge H. Rethinking responsibility in radiography: some ethical issues in South Africa. S Afr J Radiol. 2011;15(1):10–3.
18. Fatahi N, Mattsson FN, Lundgren SM, Hellström M. Nurse radiographers' experiences of communication with patients who do not speak the native language. J Adv Nurs. 2010;66(4):774–83.
19. Maizlin NN, Singh NP, Somers S. Utilizing a digital multi-language patient questionnaire for diagnostic imaging examinations. J Digit Imaging. 2019;32(6):1097–102. https://doi.org/10.1007/s10278-019-00240-0.
20. Mowlana H, Wilson LJ. Communication technology and development. Paris: UNESCO; 1988. http://unesdoc.unesco.org/images/0008/000811/081109eo.pdf
21. Ruxandra R, Filimon S. Improving communication between doctors and patients. Ann Fac Econ. 2010;1(2):1137–40. http://anale.steconomiceuoradea.ro/volume/2010/n2/182.pdf
22. Priebe S, Dimic S, Wildgrube C, Jankovic J, Cushing A, McCabe R. Good communication in psychiatry—a conceptual review. Eur Psychiatry. 2011;26(7):403–7. https://doi.org/10.1016/j.eurpsy.2010.07.010.
23. Weissman GV. Evaluating associate degree nursing students' self-efficacy in communication skills and attitudes in caring for the dying patients. Teach Learn Nurs. 2011;6(2):64–72.
24. Ruiz-Moral R, Rodriguez ER, de Torres LAP, de la Torre J. Physician–patient communication: a study on the observed behaviours of specialty physicians and the ways their patients perceive them. Patient Educ Couns. 2006;64(1–3):242–8.
25. Van den Brink-Muinen A, Verhaak PFM, Bensing JM, et al. Doctor–patient communication in different European health care systems: relevance and performance from the patients' perspective. Patient Educ Couns. 2000;39(1):115–27.
26. Shannon C, Weaver W. The mathematical theory of communication. Urbana: University of Illinois Press; 1949.
27. Lasswell H. The structure and function of communication in society. The communication of ideas. New York: Institute for Religious and Social Studies; 1948. p. 11.
28. Booth LA, Manning DJ. Observations of radiographer communication: an exploratory study using transactional analysis. Radiography. 2006;12(4):276–82.
29. Uko I. Verbal and nonverbal communication. Encycl Arts. 2006;3(1):1–5.
30. Watermeyer J, Penn C. Working across language and culture barriers: communication skills for pharmacists. Johannesburg: University of Witwatersrand; 2009.
31. Nash ES. Medical student training in doctor–patient communication. SAMJ. 1979;56:1118–24. http://archive.samj.org.za/1979%20VOL%20LVI%20Jul-Dec/Articles/12%20December/4.6%20MEDICAL%20STUDENT%20TRAINING%20IN%20DOCTOR-PATIENT%20COMMUNICATION,%20Eleanor%20S.Nash.pdf
32. Ekman P, Friesen W. The repertoire of nonverbal behaviour: categories, origins, usage, and coding. Semiotica. 1969;1(1):49–98. https://doi.org/10.1515/semi.1969.1.1.49.
33. Jones SE, LeBaron CD. Research on the relationship between verbal and nonverbal communication: emerging interactions. J Commun. 2002;52:499–521. https://doi.org/10.1111/j.1460-2466.2002.tb02559.x.
34. Steinberg AG, Barnett S, Meador HE, et al. Health care system accessibility. Experiences and perceptions of deaf people. J Gen Intern Med. 2006;21:260–6. https://doi.org/10.1111/j.1525-1497.2006.00340.x.
35. Mehrabian A. Silent messages. 1st ed. Belmont: Wadsworth; 1971.
36. Ozlem AK. A comparison of sign and symbol (their contents and boundaries). Semiotica. 2010;182(4):1–13. https://doi.org/10.1515/semi.2010.048.
37. Wiener M, Devoe S, Rubinow S, Geller J. Nonverbal behaviour and non-verbal communication. Psychol Rev. 1972;79(3):185–214.
38. Danesi M. Messages, signs, and meanings. 3rd ed. Toronto: Canadian Scholars' Press Inc; 2004.
39. Littlejohn SW, Foss KA. Theories of human communication. Belmont: Wadsworth; 2008. p. 2–13. http://www.cengagebrain.com/shop/content/littlejohn95877_0495095877_02.01_chapter01
40. Arora R. Message and framing and credibility: application in dental services. Health Mark Q. 2000;18(10):29–44.
41. Van Sevellen G. Communication skills for the healthcare professional. Concepts, practice and evidence. 2nd ed. Boston: Jones and Bartlett; 2009.

42. Powell AC, Landman AB, Bates DW. In search of a few good apps. JAMA. 2014;311(18):1851–2.
43. West D. How mobile devices are transforming healthcare. Issue Technol Innov. 2012;18:1–14.
44. Gurol-Urganci I, de Jongh T, Vodopivec-Jamsek V, Atun R, Car J. Mobile phone messaging reminders for attendance at healthcare appointments. Cochrane Database Syst Rev. 2013;2013(12):CD007458. https://doi.org/10.1002/14651858.CD007458.pub3.
45. Wilcox D. Wireless technology offers providers new communication options for patients. Hear J. 2002;55(6):57.
46. Ventola CL. Social media and health care professionals: benefits, risks and best practices. PT. 2014;39(7):491–520.
47. Gluecker TM, Johnson CD, Harmsen WS, et al. Colorectal cancer screening with CT colonography, colonoscopy, and double-contrast barium enema examination: prospective assessment of patient perceptions and preferences. Radiology. 2003;227:378–84.
48. Von Wagner C, Knight K, Halligan S, et al. Patient experiences of colonoscopy, barium enema and CT colonography: a qualitative study. BJR. 2009;82:13–9.
49. Plumb AA, Ghanouni A, Rees CJ, et al. PWE-033 comparison of patient experience of colonoscopy and CT colonography in the English Bowel Cancer Screening Programme. Gut. 2014;63:A136–7. https://doi.org/10.1136/gutjnl-2014-307263.293.
50. Gefen R, Bruno MA, Abujudeh HH. Online portals: gateway to patient-centered radiology. Am J Roentgenol. 2017;209(5):987–91. https://doi.org/10.2214/AJR.17.18291.
51. Martin-Carreras T, Cook TS, Kahn CE Jr. Readability of radiology reports: implications for patient-centered care. Clin Imaging. 2019;54:116–20. https://doi.org/10.1016/j.clinimag.2018.12.006.
52. Fischer AE, Venter WDF, Collins S, Lalla-Edward ST. The readability of informed consent forms for research studies conducted in South Africa. S Afr Med J. 2021;111(2):180–3.
53. Flesch Kincaid Calculator—Flesch Reading Ease Score. https://charactercalculator.com/flesch-reading-ease/. Accessed 13 Nov 2022.

Informed Consent

3

Aarthi Ramlaul and Tracey Gregory

3.1 Introduction

Medical ethics go back thousands of years; the learnings we draw today are based on errors of great consequence that were made in the past. Today medical ethics are presented as agreed ethical standards for medicine, research, and public health. An example is *The Declaration of Geneva*, produced by the World Medical Association [1]. This 'modern version' of the Hippocratic Oath spells out ethics obligations for medical doctors and other healthcare providers, including radiographers, to ensure that policy-makers and practitioners keep ethics at the heart of the decision-making [2].

The key ethical perspective underpinning consent is the principle of autonomy. The Department of Health (2009) states that 'patients have a fundamental legal and ethical right to determine what happens to their own bodies' [3]. In other words, this means that patients have a right to decide whether or not to receive treatment, even if the decision that they make would appear to be unwise and has the potential to, or may even result in, harm. In essence, the autonomous decisions given over to patients with regard to consent to treatment respect patient choice and self-determination. Consent occupies a central position within medical law and is essential prior to medical treatment. Valid consent, therefore, must be obtained from the person who is to receive that treatment prior to any such treatment being given. Ensuring that consent is informed plays a pivotal role in enabling patients to exercise their autonomy.

3.2 What Is Consent?

In its broadest sense, consent within the context of medicine means that a patient agrees to undergo some form of examination, treatment, or procedure. However, it is important to be clear about the different types of consent and when consent is considered to be valid or 'real' [4].

Consent can be either express/ed or implied. Express consent requires patients to be given sufficient information about all aspects of an examination or procedure, prior to it taking place, so that they may make an informed decision about whether or not to undergo that examination or treatment. The act of information giving by a healthcare practitioner (e.g., doctor, radiologist, radiographer, nurse), in a way that a patient understands, enables them to make an informed

A. Ramlaul (✉)
Diagnostic Radiography, School of Health and Social Care Professions, Buckinghamshire New University, High Wycombe, UK
e-mail: aarthi.ramlaul@bucks.ac.uk

T. Gregory
Diagnostic Imaging, Department of Health Care Practice, University of Derby, Derby, UK
e-mail: t.gregory1@derby.ac.uk

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decision about whether or not to receive treatment; whether or not to give informed expressed consent. Express/ed consent may be written, whereby a patient signs a consent form following receipt of all necessary information, or oral, whereby a patient verbally confirms their willingness to undergo the examination or procedure.

Implied consent also requires that an explanation of any examination or procedure should be given. However, it differs from express consent in that written or verbal confirmation does not have to be received by a medical or healthcare practitioner prior to proceeding with the examination or procedure. Instead, the voluntary actions of a patient following receipt of the requisite information (e.g., holding out an arm for a blood pressure cuff to be applied or placing a body part on the image receptor when asked to do so for an X-ray examination) implies that such a patient has agreed to go ahead with the procedure.

Consent required for a CT colonography (CTC) examination is expressed by written consent; it must be provided by a patient prior to the imaging examination [5]. This procedure should form part of the pre-procedure checklist. The consent form and pre-procedure check list should be dated with details of the consenter and state the risks of CTC [5]. In addition, the consent process must comply with locally agreed policies; if a patient withdraws consent at any point in the pathway, this must be acted upon and documented [5].

3.2.1 Valid Consent

Consent given by a patient prior to any examination or procedure must be valid [4]. In order for consent to be deemed valid, a number of factors need to be considered.

- The explanation pertaining to the procedure must be given to a patient in clear, non-medical terms. Should a patient fail to fully understand what an examination or procedure entails, including the risks that it involves, then consent is not considered to be valid.
- A patient must be competent to consent to treatment. A patient can only consent to treatment if they have capacity. Within the framework of the Mental Capacity Act, (2005) [6] and the Mental Capacity (Amendment) Act (2019) [7], a patient is assumed to have capacity unless proved otherwise.
- A patient must have made any decision of their own free will, i.e. without coercion or influence from others.

3.3 Why Informed Consent in CTC?

In the United Kingdom (UK), the role of a GI radiographer has expanded considerably over the last two decades: firstly by taking on the double-contrast barium enema (DCBE) examination, and now in CTC examinations. CTC is a minimally invasive procedure. The examination is used as a diagnostic imaging tool as well as a screening tool. Although there are various ways in which to gain consent, written consent may be required for those examinations or treatments that are considered to be invasive and/or involve a significant risk and/or side effects [8].

As radiographers, we cannot assume that our patients know what ionising radiation is and what the risks of it are. A false assumption could negatively affect the healthcare decision a patient makes. By providing information to patients, radiographers will enable them to make better decisions regarding their care. This would translate into more accurate expectations and better experiences. Furthermore, providing information to patients to enable them to make an informed choice is an ethical obligation. No examination may be carried out on patients without their permission or consent. By giving them the necessary information, they are being empowered to make an informed choice of whether to go ahead with the proposed examination or not, with the decision culminating in their informed consent to go ahead with the examination. Although CTC is a minimally invasive, safe study, there could be some potential risks as outlined below. Serious harm can come to patients if the risks are not explained to patients and/or they are not listened to [9].

3.3.1 Informed Consent in Terms of the Use of Artificial Intelligence

The loss of human control by assigning decision-making to AI-guided technologies could affect various aspects of clinical care and the healthcare system, including the communication in the clinician–patient relationship [10]. With the increasing use of algorithmic decision-making seen in AI in healthcare, patients have an ethical right to expect an explanation about how decisions regarding their diagnosis was reached [8, 9]. However, hospitals and healthcare providers are unlikely to inform patients that AI was used as a part of decision-making to guide or validate a diagnosis; there is currently no precedent for seeking the consent of patients to use technologies for diagnosis or treatment [10].

The use of AI in medicine and failure to disclose its use could challenge the core of informed consent and wider public trust in healthcare [10]. It is therefore unsurprising that a current area of debate in the profession lies in what extent a patient needs to be aware of the use of AI technologies in their procedure, treatment, and/or decisions, and whether the decisions informed by AI systems have been adhered to or overruled by the doctor [11]. According to Amann et al. [11], the underlying process and algorithms associated with AI decision-making have to be explained to patients. They need not to know about every technical detail, but certainly about how their data are to be used, how their final diagnosis was revealed and the risks associated with the decision-making.

If using AI recommended diagnosis, the medicolegal question that arises is who is responsible for the diagnosis, especially if it is a wrong diagnosis? Basically, if radiologists are no longer the interpreters of radiological studies such as CTC examinations, who will be accountable for the decision made? Would it still be a radiologist even though they will not have been able to fully understand nor interrogate the precision within the decision-making process? [12]. The use of AI in the decision-making process to confirm a diagnosis following a CTC examination therefore needs to be explained to a patient [13, 14].

The World Health Organisation (WHO) states that transparency is crucial to promoting trust among all stakeholders, particularly patients; the WHO encourages practitioners to be frank with patients from the onset about the use of AI rather than hiding the technology [10]. This can have a significant impact on their right to exercise their autonomy: the explanation must, therefore, form part of the 'informed' aspect of 'informed consent'. Practitioners should try their best to explain to their patients the purpose of using AI, how it functions, and what value it adds to their treatment and management. They should also be transparent about any weaknesses of the AI technology, such as any biases, data breaches, or privacy concerns [10]. Only with transparency can the deployment of AI for healthcare and health science, including hospital practice, become a long-term success. Trust is key to facilitating the adoption of AI in medicine [10]. The principles of AI are discussed in Chap. 25.

3.4 The Legal Aspects of Consent

There are two distinct aspects to the legalities of consent in medicine, both of which normally reside in tort law, that is, the wrong committed by one person on another being considered a civil wrong rather than a legal matter.

The first aspect to consider is that of patients actually giving their consent to the examination or procedure. Should any examination or procedure go ahead without them giving their consent, they then may sue for trespass to the person. Trespass to the person occurs when a patient has not given their consent and is subject to either the act of assault (whereby a patient apprehends a touching of their person) or battery (whereby a patient was actually touched). A patient who has suffered trespass to their person is able to sue for compensation in the civil courts. In order to do this, they must be able to prove the touching or the apprehension of the touching of their person, and that it was a direct intentional interference or had the potential to be a direct intentional interference with them. There is no legal obligation for a patient to prove that harm has occurred [15, 16].

The second key element is that of negligence. All healthcare practitioners have a duty of care to their patients. As part of this duty of care, practitioners are required to give sufficient information about all aspects of a procedure, including the risks involved. Failure on the part of the practitioner to give sufficient information could result in the bringing of an action for negligence. In order to establish that a practitioner has been negligent, a patient has to prove a number of key elements: that they were owed a duty of care by the healthcare practitioner, that this duty of care was breached by way of failure to give sufficient information; that this breach of duty of care resulted in them agreeing to the examination or procedure, and that in doing so, they suffered harm as a result.

3.5 Patient Information

Adequate information must be provided to all patients. The information must be written in a comprehensive manner to include all the important benefits and risks of an examination and whether the examination is being carried out as a diagnostic test or a screening test. If current information leaflets given to CTC patients at the preparatory stage do not include the information, then those leaflets need to be reassessed and information on benefit and harm added in [17].

Best practice in information giving should consist of the following information as a minimum requirement [18].

Pre-procedure

- Purpose of the procedure to primarily investigate the presence of bowel cancer or precancerous polyps
- Full description of the procedure in detail from start to finish with assurance that dignity will be maintained at all times
- Contra-indications to bowel preparation
- Names and reliable contact details of appropriate persons who can be approached to answer questions or provide advice and guidance
- Bowel preparation instructions and effects on bowel habit

Aftercare advice

- Process for being informed of results
- Possible complications and when to seek medical advice
- Post procedure advice: eating, bowel habit, etc.

In addition, the National Patient Safety Guidelines (NPSA) must be followed during the prescribing of laxatives for bowel preparation. The consent provided by a patient must be recorded in writing, including the date and designation of the person to whom consent was given. This should be recorded electronically. If not a radiographer, then a healthcare professional, in gaining consent from a patient, should be sufficiently knowledgeable and informed to answer routine questions and must be able to call upon the expert advice of either a radiographer or radiologist prior to the appointment or examination. In signing consent, a patient should be satisfied that all questions have been answered sufficiently and that the benefits, risks, and side effects of the examination have been explained to them.

3.6 Risks Associated with CTC Procedures

There are risks associated with a CTC study. It involves a CT examination where there is a risk of ionising radiation damage to tissues. Patients need to be informed of this risk prior to conducting a CTC examination [19]. This could be a verbal explanation or included in the patient preparation leaflet provided prior to the examination.

An explanation of the risks should include the following

- Risk of perforation
- Anaphylactic reaction from the use of contrast agents (see Chap. 8)
- Risk of harm from ionising radiation explained as a dose equivalent of a CT scan (see Chaps. 5 and 6)
- In the case of patients undergoing CTC screening, the risk of psychological harm in incidence of false positives and false negatives

- Risk of harm from an incidental finding when the examination is being carried out. CTC examinations also demonstrate intra-abdominal and pelvic organs; approximately 10% of cases [20] demonstrate significant pathology, e.g. underlying lymphomas or early cancers of the kidney and ovaries may be identified (see Chap. 18)
- Risk of wrong diagnosis, either human or through AI algorithm recommendations as detailed above

In addition, there should be an explanation of the following

- Side effects and discomfort, e.g. bloating arising from the insufflation of air, and dehydration arising from an electrolyte imbalance caused by the contrast agents
- Alternative options, if appropriate

3.7 The Duty of Consent and the Role of a CTC Radiographer

One of the current dilemmas in gaining informed consent lies in the question of 'whose responsibility is it to gain informed consent?' Does this responsibility lie with the referring physician or does the responsibility lie with the practitioner conducting the examination? In the case of radiographer-led CTC, the question is, 'would the radiographer in charge of carrying out the examination be responsible?'

Interestingly, the results of a recent survey conducted to radiographers [21] revealed that radiographers were of the opinion that a patient's referring physician was responsible for obtaining informed consent. When an examination involves the risk of ionising radiation, only trained experts in the field of medical ionising radiation are qualified to inform patients of the risks of the procedure and explain the benefit of having the examination in spite of the risks. If radiographers are of the opinion that it is not their responsibility, then they are of the belief that the referring physician is fully knowledgeable and competent to inform the patient of risks and benefits of ionising radiation.

Radiographers are the experts in their field, and using the lowest radiation dose for the best image quality, i.e. as low as reasonably achievable (ALARA), is the basis of radiography. Radiographers should be able to confidently advise their patients of the dose of radiation they are receiving and how this translates to a risk experienced in their everyday lives (see Chaps. 5 and 6).

The overall responsibility of obtaining informed consent remains with a healthcare practitioner responsible for conducting the medical intervention. In this case, if the procedure is being carried out by a radiographer, then it is their responsibility and not that of the referring physician. If the examination is being carried out by a radiologist the overall responsibility is theirs even though they chose to delegate the responsibility to a radiographer or a radiology department nurse. In the event of delegation, a radiologist should be available to answer questions that may arise or if a patient wishes to speak to them.

A CTC radiographer has a duty in ensuring that a patient has been provided with sufficient information on all aspects of the examination and that they have given their informed consent prior to the examination being carried out. Radiographers must adhere to their respective employer's local policies and procedures in relation to consent and must be aware of and adhere to guidance issued by the appropriate regulatory body (e.g., Health and Care Professions Council) in the country in which they practise [22].

3.8 Good Practice in Information Giving

The incidence of developing further cancer from radiation depends on the radiation dose received. It is therefore important that patients are sufficiently informed of not just the nature of the examination or procedure that they are about to undergo, but also have been provided with adequate information that will enable them to make an informed decision as to whether or not to proceed.

The language used in the information leaflets needs to be comprehensible to a lay person and should avoid the use of medical jargon. Furthermore, the information leaflet is likely to be read by a patient's family and as such its readability (see Sect. 2.9 in Chap. 2) is of utmost importance for maximising understanding of the procedure and its requirements. This ultimately can affect a patient's experience and the overall quality and outcome of the procedure patient-centred communication is discussed in Chap. 2.

In addition, CTC radiographers need to ensure that they do not present an overwhelming amount of information that may affect a patient's decision-making ability [8]. The more complex a medical imaging examination and/or its side effects, the greater the risks involved. It is therefore crucial to have formal records of patient consent.

Information should be given in advance of the day of examination to enable a patient to take time to read and understand the information and ask questions before their examination. This is one of the key areas that enables consent to be informed [8]. The associated risks need to be defined in advance and clearly articulated within patient information leaflets.

In keeping with a patient-centred care approach, the entire process of information giving and gaining consent should be patient focussed taking into account a patient's culture and beliefs and being able to identify when alternate methods of communication may be required, for example, in cases where English may not be their first language or if a patient has special care considerations, for example, dementia (see Chap. 2).

With regard to duty of care, a CTC radiographer must inform a patient of the benefits of the procedure in addition to the risks. Patients must also be informed of what the likely alternative options may be as well as the risk involved in not having the examination at all, i.e. doing nothing [8].

Patients are naturally concerned about the harmful effects of ionising radiation, not only to themselves, but also to their future offspring. Care should be taken to use appropriate language when discussing the risks and benefits of the examination so that they are able to understand the consequences.

In the case of patients undergoing CTC screening, information regarding risks applicable to them must include, in addition to those already mentioned, the risk of psychological harm from over or under diagnosis that may result from false positives or false negatives. In addition, there is a risk of distress from the discovery of extracolonic pathologies or conditions that may present itself as incidental findings during the screening procedure. Extracolonic findings are discussed in detail in Chap. 18.

3.9 Clinical Audit to Include Informed Consent and Patient Information

CTC examinations must be audited against best practice standards for compliance with the standard, to ensure standards of practice are optimal, and to improve patient outcomes and experience. Informed consent is one of several CTC standards. Patient experience of the entire CTC process is an auditable outcome [23]. The principles of a clinical audit are presented in Chap. 27.

Key Messages

- Patients have the fundamental legal and ethical right to determine what happens to their own bodies. Ensuring that consent is informed plays a pivotal role in enabling patients to exercise their autonomy.
- A radiographer has a duty of care to inform each patient of the benefits and risks of the CTC examination. Patients must also be informed of the likely alternative options as well as the risk involved if they do not have the examination at all.
- The responsibility of obtaining informed consent lies with the healthcare practitioner responsible for conducting the medical intervention.
- Written consent is required for invasive procedures, which are considered to involve significant risks or side effects.

- If a patient fails to fully understand the nature of the examination, including the risks that it involves, then the consent given by such a patient is not considered to be valid.
- The language used in information leaflets needs to be devoid of medical jargon and must be written in a comprehensible style that is understood by a layperson.
- When explaining the extent of the risk from radiation to patients, liken the radiation dose to other acceptable risks in society that they can identify with on a daily basis.
- The experience of a CTC patient is an auditable outcome.

3.10 Summary

Informed consent is an important patient right and fundamental within medical law. There are two aspects to the law of informed consent. One is the act of a practitioner giving information to a patient. The other is receiving and processing of information by a patient: asking questions and then signing a consent form thus providing a written gesture of acceptance of the examination. If an examination is conducted in the absence of consent, a patient may sue for compensation on the grounds of 'trespass to the person'. All practitioners have a duty of care to their patients. Part of this duty of care is to provide sufficient information about all aspects of a CTC procedure. Failure to give sufficient information could result in a patient bringing about an action for negligence.

Radiographers must work within their scope of practice and the expectations set by their professional and regulatory bodies in order for high standards in professional practice to be maintained.

References

1. World Medical Association. The physician's pledge. Declaration of Geneva adopted in 1948, amended by the 68th WMA General Assembly, Chicago, United States, October 2017. Ferney-Voltaire: World Medical Association. 2017. https://www.who.int/publications/i/item/9789240047785. Accessed 21 Nov 2022.
2. World Health Organisation. Ethics and medical radiological imaging: a policy brief for health-care providers. 2022. https://www.who.int/publications/i/item/9789240047785. Accessed 21 Nov 2022.
3. Department of Health. Reference guide to consent for examination or treatment. 2nd ed. 2009. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/138296/dh_103653__1_.pdf. Accessed 21 Nov 2022.
4. Shala KK, Patra AP, Das S. The importance of informed consent in medicine. Sch J Appl Med Sci. 2013;1(5):455–63. https://doi.org/10.36347/sjams.2013.v01i05.0025455.
5. NHS Bowel Cancer Screening Programme (BCSP). Bowel cancer screening: guidelines for CTC imaging. 2021. Bowel cancer screening: guidelines for CTC imaging—GOV.UK. www.gov.uk. Accessed 21 Nov 2022.
6. Mental Capacity Act. 2005. https://www.legislation.gov.uk/ukpga/2005/9/contents. Accessed 21 Nov 2022.
7. Mental Capacity (Amendment) Act. 2019. https://www.legislation.gov.uk/ukpga/2019/18/enacted#:~:text=2019%20CHAPTER%2018,consent%3B%20and%20for%20connected%20purposes. Accessed 21 Nov 2022.
8. Society and College of Radiographers (SCoR). Obtaining consent: a clinical guideline for the diagnostic imaging and radiotherapy workforce. 2016. https://www.sor.org/learning-advice/professional-body-guidance-and-publications/documents-and-publications/policy-guidance-document-library/obtaining-consent-a-clinical-guideline-for-the-dia. Accessed 21 Nov 2022.
9. General Medical Council. Decision making and consent. 2020. https://www.gmc-uk.org/ethical-guidance/ethical-guidance-for-doctors/decision-making-and-consent. Accessed 21 Nov 2022.
10. World Health Organization. Ethics and governance of artificial intelligence for health: WHO guidance. 2021. https://www.who.int/publications/i/item/9789240029200. Accessed 21 Nov 2022.
11. Amann J, Blasimme A, Vayena E, Frey D, Madai VI. Explainability for artificial intelligence in healthcare: a multidisciplinary perspective. BMC Med Inform Decis Mak. 2020;20:310. https://doi.org/10.1186/s12911-020-01332-6.
12. European Society of Radiology (ESR). What the radiologist should know about artificial intelligence—an ESR white paper. Insights Imaging. 2019;10(44):44. https://doi.org/10.1186/s13244-019-0738-2.
13. Kim TW, Routledge BR. Why a right to an explanation of algorithmic decision-making should exist: a trust-based approach. Bus Ethics Q. 2022;32(1):75–102. https://doi.org/10.1017/beq.2021.3.
14. Astromskė K, Peičius E, Astromskis P. Ethical and legal challenges of informed consent applying artificial intelligence in medical diagnostic consultations.

AI & Soc. 2021;36:509–20. https://doi.org/10.1007/s00146-020-01008-9.
15. Dimond BC. Legal aspects of radiography and radiology. Oxford: Wiley-Blackwell; 2008.
16. Ramlaul A, Gregory T. Ethical and legal considerations in professional practice. In: Ramlaul A, Vosper M, editors. Patient centred care in medical imaging and radiotherapy. London: Churchill Livingstone; 2013. p. 255–69.
17. Hersch J, Barratt A, Jansen J, et al. Use of a decision aid including information on overdetection to support informed choice about breast cancer screening: a randomised controlled trial. Lancet. 2015;385(9978):1642–52. https://doi.org/10.1016/S0140-6736(15)60123-4.
18. Society and College of Radiographers (SCoR). Guidelines for the provision of a safe and effective CT colonography service. 2018. https://www.sor.org/learning-advice/professional-body-guidance-and-publications/documents-and-publications/policy-guidance-document-library/national-best-practice-guidelines-for-the-ct-colon. Accessed 21 Nov 2022.
19. Doudenkova V, Bélisle Pipon JC. Duty to inform and informed consent in diagnostic radiology: how ethics and law can better guide practice. HEC Forum. 2016;28:75–94. https://doi.org/10.1007/s10730-015-9275-7.
20. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Radiol. 2014;18(1):607. https://doi.org/10.4102/sajr.v18i1.607.
21. Friedrich-Nel H, Munro L. Radiographers' opinions on patients' rights to informed consent: results of an online survey. SAR. 2015;53(1):27–33.
22. Health and Care Professions Council. Standards of conduct, performance and ethics. London: Health and Care Professions Council; 2016.
23. British Society of Gastrointestinal and Abdominal Radiology and Royal College of Radiologists. Standards of practice for computed tomography colonography (CTC). 2021. https://www.rcr.ac.uk/system/files/publication/field_publication_files/bfcr201-standards-of-practice-for-computed-tomography-colonography-ctc.pdf. Accessed 21 Nov 2022.

4 Principles of CT and Hybrid Imaging

Christoph J. Trauernicht

4.1 Introduction

Computed tomography (CT) entered its sixth decade of clinical use and has proved an exceptionally valuable and useful imaging tool. The first head CT scanner was introduced in 1972. Each pair of slices took over 4 min of scan time and over 1 min of reconstruction time. While this would be considered quite terrible by today's standards, it was considered revolutionary at the time and earned Godfrey Hounsfield and Allan Cormack the Nobel Prize in Medicine in 1979.

4.2 Principles of CT

4.2.1 The X-ray Tube

At the heart of a CT scanner is an X-ray tube (Fig. 4.1). A tungsten filament is heated and emits electrons by a process known as thermionic emission. The emitted electrons, having a negative charge, are accelerated across a potential difference towards a copper anode, which sits at a positive potential. All this happens inside an evacuated glass housing. The vacuum is required to prevent electrons from interacting with any materials inside the housing, other than the tungsten target.

When energetic electrons come into the vicinity of an atomic nucleus, the positively charged nucleus attracts the negatively charged electrons, and these are decelerated in the process. The electric field of the nucleus exerts a force on the incoming electron and forces it to change its velocity (i.e., energy) and direction.

The energy difference of the initial electron energy and the deflected electron energy shows up as an X-ray photon. This process is known as bremsstrahlung (Fig. 4.2), which is the German word for "braking radiation". Bremsstrahlung production depends on the square of the number of protons (Z) in the target nucleus; therefore, the target should consist of a material with a high atomic number, like tungsten ($Z = 74$). Bremsstrahlung production is very inefficient, only around 0.9% for 100 keV electrons, the other 99% of energy is lost through other interactions that do not produce X-rays, but that do result in heat. Therefore, there must be a cooling mechanism for the X-ray target, and the target material must have a high melting point.

An electron that is travelling close to a nucleus will experience a larger force of attraction to the nucleus than one that is passing the nucleus at a larger distance. The electron will experience a larger energy loss, resulting in a higher energy X-ray photon. If the potential dif-

C. J. Trauernicht (✉)
Division of Medical Physics, Tygerberg Hospital and Stellenbosch University, Cape Town, South Africa
e-mail: cjt@sun.ac.za

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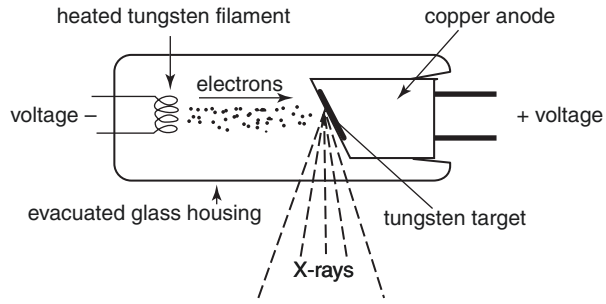


Fig. 4.1 Simplified diagram of an X-ray tube

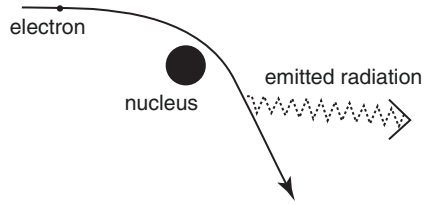


Fig. 4.2 Bremsstrahlung production

ference between the tungsten filament and the target is, for example, 120.000 V (or 120 kVp), then the resultant X-rays will have an energy range from near zero up to 120 kVp. When the operator selects a kVp before the acquisition of an image series, this adjusts the potential difference inside the X-ray tube through the use of a transformer. If the kVp is increased, the energy of the X-rays is increased. This is often referred to as beam quality. In addition, bremsstrahlung production becomes more efficient at higher energies, resulting in more X-rays. This is referred to as the "quantity". Dose to the patient increases with the square of the kVp. It should be noted that the average X-ray energy is only about 1/3–1/2 of the peak kilovoltage. The very low energy X-rays do not contribute to useful image information and are filtered out before the beam enters the patient. Additionally, superimposed on the continuous bremsstrahlung X-ray spectrum are discrete peaks (characteristic radiation) that happen when electrons transition from one energy shell to another one inside the target material after they were knocked out of their shell by the incoming energetic electrons. The manipulation of this spectrum is important in dual-energy CT (DECT). Principles of DECT are presented in Chap. 26.

A direct current (DC) must be used to accelerate the electrons in the tube housing; an alternating current (AC) would result in electrons being accelerated back and forth in the tube, without any useful output. There are additional circuits in an X-ray tube (not indicated in Fig. 4.1), for example, to provide power to focusing cups for the electrons before they are accelerated, so that they travel in a more focused beam towards the anode. The tungsten filament also has its own circuit, and the number of electrons that are emitted can be increased by increasing the filament current, which results in more heat in the filament, and thus more emitted electrons. When an operator adjusts the mA on the control console, this refers to the number of electrons that are accelerated in the X-ray tube, i.e. the beam current. Increasing the mA on the console increases the current to the filament, which means more electrons are emitted and accelerated. Increasing the mA does not affect the beam energy (or beam quality) but does increase the number of X-rays (quantity). Dose is linearly proportional to the beam current or the current-time product (mAs).

CT scanner X-ray tubes have substantially higher requirements than ordinary X-ray tubes because they do not just take a single image, but a series of many projection images. One way in which the additional heat that is generated is dissipated, is by situating the tungsten target inside the X-ray tube on a rotating anode disk, which rotates at a few thousand revolutions per minute. If a rotating anode has a focal track radius of 5 cm and a 1 mm track width, then the annular area that the electrons hit is 314 times ($2\pi r$) larger than that of a fixed anode with a focal spot of 1 mm × 1 mm, resulting in substantially improved heat loading.

Of course, the X-ray tube must be shielded. X-rays are uncharged photons, and it is thus not possible to steer or focus these. The only way to stop them from going where they shouldn't is to either shield or collimate them. An X-ray tube has an exit window that allows X-rays to escape in a particular direction: the rest of the tube is shielded. For a more detailed description of X-ray tubes and computed tomography, the reader is referred to [1–3].

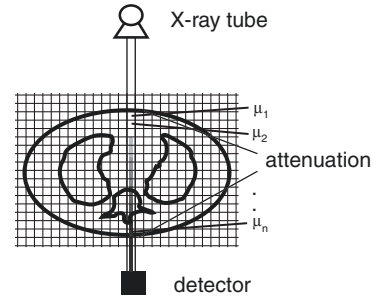


Fig. 4.4 Pixel map

4.2.2 What Are We Imaging?

A planar X-ray of a patient is, in essence, a representation of how the X-ray beam was attenuated through the body of a patient. This is shown visually for a single line of response, also known as a ray, in Fig. 4.3. The initial beam intensity I_0 gets reduced as the beam penetrates through the patient. An attenuated beam intensity I_x arrives at the detector. In mathematical terms, this is given by $I_x = I_0 \times e^{-\mu \times x}$, where x is the thickness of the patient and μ (Greek letter "mu") represents the linear attenuation coefficient.

If we now superimpose a matrix over a patient (Fig. 4.4), then the total attenuation along the line of response will be the sum of each pixel attenuation contribution along the same line of response. This is given by:

$$I_x = I_0 \times e^{-(\mu 1+\mu 2+\mu 3+\cdots+\mu n)\times d},$$

where d is the pixel dimension and μ_1 to μ_n is the linear attenuation coefficient of each pixel in that line of response.

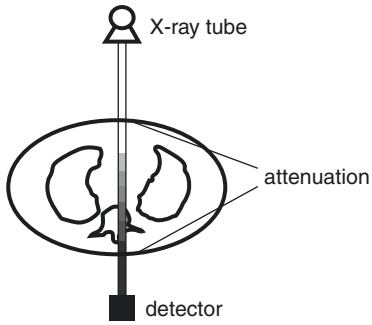


Fig. 4.3 Attenuation

For a CT image a third dimension, the slice thickness, is included as well. Therefore, each pixel on a CT image represents the average attenuation properties of the tissue in this volume element (voxel). A series of rays that pass through the patient at the same orientation is called a view or a projection. A single axial CT image may involve about 800 rays taken at 1000 different projection angles. A typical CT slice has dimensions of 512 × 512 pixels.

One of the biggest advantages of CT imaging is the reconstruction of many projections into cross-sectional images. Interestingly, the maths for this was developed in 1917 already, when Johann Radon showed that the image of a three-dimensional object can be constructed from an infinite number of two-dimensional images of the object.

4.3 Tomographic Reconstruction: Backprojection

In the previous section, the relationship between the initial and transmitted beam intensity for each ray was given by $I_x = I_0 \times e^{-\mu \times x}$. The initial intensity can be determined by doing a blank scan (as is done every morning), and I_x is measured with the patient in the beam. Therefore, the equation can be rearranged to solve for μ, the linear attenuation coefficient, the only unknown in the equation: $\mu = \frac{1}{x} \times \ln (I_0/I_x)$.

This can ultimately be done for each pixel along each line of response by tomographic reconstruction, the simplest of which is the back-

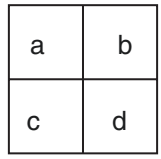
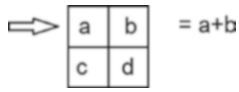


Fig. 4.5 Simple backprojection explained

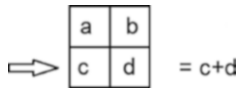
projection algorithm. The following example will explain this algorithm for a 2 × 2 matrix and four projection angles. In this recipe, each pixel has a unique value (*a*, *b*, *c*, or *d*), which represents the linear attenuation coefficient for that pixel as shown in Fig. 4.5. The first part of the recipe requires the acquisition of the four projections.

4.3.1 Backprojection: An Example

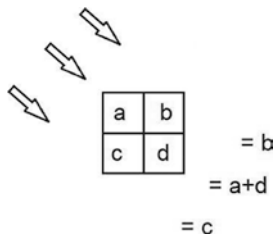
The first ray of the first projection angle is shown in step 1.



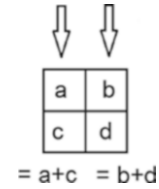
Step 1
The second ray of the first projection angle is shown in step 2.



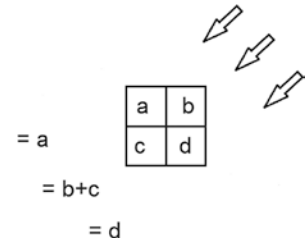
Step 2
This is the first projection angle. The second angle, after a 45° rotation, is shown next in step 3.



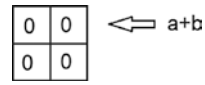
Step 3
Another 45° rotation gives us the third projection angle as shown in step 4.



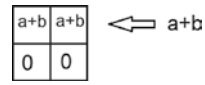
Step 4
Finally, the last projection angle for the backprojection example is shown in step 5.



Step 5
At this point, all projections have been acquired, now the reconstruction begins, the second component of the recipe. This is done as follows: since the attenuation coefficients in each pixel are not known, they are initially all set to zero. Then each line of response must be backprojected (step 6) into the empty matrix, starting with the first line of response from step 1 above.

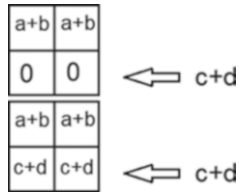


Step 6
Since the values of *a* and *b* are not known at this point and only their sum is known for this particular ray, that value is backprojected into each pixel along that line of response to give step 7—first line of response backprojected.



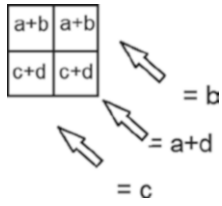
Step 7

The same is done for the next ray (second ray) from step 2, as shown in step 8.



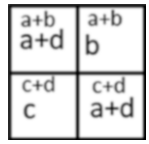
Step 8

Now the second projection from step 3 is backprojected into the result from step 8 for step 9.



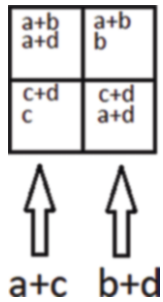
Step 9

At this point, the resultant matrix starts filling up. Step 10 is after the second projection is backprojected.



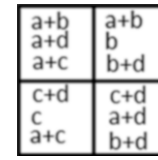
Step 10

In step 11, the third projection from step 4 is now done (backprojected).



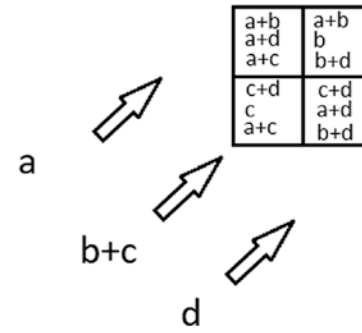
Step 11

Step 12 gives the following after three projections are backprojected.



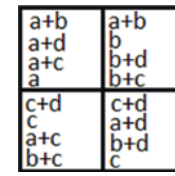
Step 12

Finally, the last projection angle is included as well in step 13 (final projection angle).



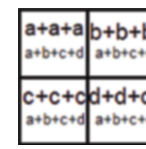
Step 13

After all projections are included in the backprojection algorithm, the following is obtained in step 14: all projections are backprojected.



Step 14

The data in the matrix of step 14 can now be rearranged to result in step 15.



Step 15
Each pixel contains a common $a + b + c + d$. This number is known as it is the sum of all pixels in each projection and can thus be subtracted to give the below in step 16.

3a	3b
3c	3d

Step 16
Now each pixel value can be divided by 3 to give the answer in final step 17.

a	b
c	d

Step 17
This algorithm explains how to do simple backprojection for a 2 × 2 matrix with four projection angles. The reader is encouraged to follow this recipe on a piece of paper with actual numbers substituted for *a*, *b*, *c*, and *d* (say 1, 2, 3, and 4). Obviously, when a 512 × 512 matrix gets reconstructed from a thousand projections, the maths is substantially more challenging.

A simplified solution as the one presented also does not consider things like scatter. Scatter adds counts in a pixel where there should be none, thus altering the linear attenuation coefficient ever so slightly. In a backprojection algorithm, the slight alterations are also backprojected into the image matrix, resulting in noisy images. Projections can be filtered before backprojection to reduce the image noise and to give images a smoother appearance. This is known as filtered backprojection. Unfortunately, smoothing an image also means that fine detail is potentially lost, and therefore the correct filter has to be found for the task at hand. For example, a bony filter used during reconstruction will generally give a higher spatial resolution, but the images also tend to be noisier than images that are reconstructed with a soft tissue filter.

A similar argument can be made for metal artefacts, where the very high CT numbers are also backprojected along the line of response, resulting in streaks across an image (see Figs. 7.4a(i) and 12.12a(ii)). These are not easily filtered out and their removal often requires advanced software solutions.

4.4 Tomographic Reconstruction: Iterative Reconstruction

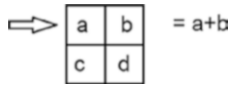
A more advanced family of reconstruction algorithms are the iterative reconstruction algorithms. The principle of iterative reconstruction is to find a solution by successively estimating an image that gave the original projections. Like in the backprojection algorithm, the first step consists of acquiring the projections. However, unlike backprojection, where the projections are backprojected to form the tomographic image, in iterative reconstruction an estimate is made of what the tomographic image could look like, and projections of this image are made at the same angles of the original acquisition. Then the projections of the original image are compared to the projections of the estimate. The result of this comparison is used to modify the current estimate, thereby creating a new estimate. Iterative reconstruction algorithms differ in the way the measured and estimated projections are compared and what kind of correction is applied to the current estimate. The recipe for iterative reconstruction is as follows.

1. Make a first estimate of the slice—this can just be a homogeneous image.
2. Forward-project the estimated slice into projections analogous to those measured by the CT scanner. In this step, physical corrections can be introduced.
3. Compare the projections of the estimate with the measured projections and apply the correction factor.
4. Decide whether to stop or continue. If the difference between iterations is small, or the maximum number of iterations is reached, then stop. Else,

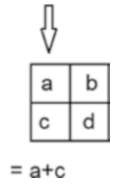
5. Apply the correction to the estimate. A simple correction factor would be to add or subtract half the difference of each pixel value to the first estimate, before forward projecting again.
6. Repeat from step 2.

A simple example analogous to the filtered backprojection example may help to explain this. Consider the same 2 × 2 matrix, but only two projection angles will be used in this example. For the sake of simplicity, only the top left pixel containing "*a*" will be considered in the example.

The first ray will be the same as in the backprojection example above.

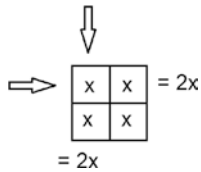


The second ray is shown next:



The first estimate of the solution can consist of a uniform image, denoted by "*x*". Let *x* be the average pixel count $(a + b + c + d)/4$.

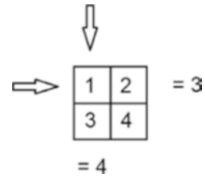
The analogous projections of the first estimate are shown below.



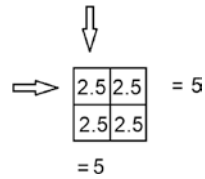
Now $2x$ is compared to $a + b$ for the one ray and to $a + c$ for the other ray. The first correction factor that must be applied to the top left pixel of the estimate can be based on the differences between the original and estimated projections. Since there are two pixels in each row and column, the differences will be halved to prevent additional counts being added into the image. Correction factor = $(a + b - 2x)/2 + (a + c - 2x)/2$.

Therefore, the top left pixel of the updated estimate now becomes x + correction factor = $x + (a + b - 2x)/2 + (a + c - 2x)/2$. A similar argument must be followed for all other pixels, before proceeding to the next iteration. Imagine the original matrix has the following values.

According to this recipe for iterative reconstruction, the following is found for the top left pixel.



Let us assume the first estimate is $(a + b + c + d)/4 = 2.5$ in each pixel. Then the forward projection of the first estimate along the same rays gives the below.



According to the recipe, the first correction factor is then given by: $(a + b - 2x)/2 + (a + c - 2x)/2 = (3–5)/2 + (4–5)/2 = -1 - 0.5 = -1.5$. The top left pixel now becomes $2.5 - 1.5 = 1$ for the next estimate.

Top left pixel done

If one follows this recipe for the other four pixels, then, for this particular example, the solu-

tion converges after a single iteration. Even from this example, it is clear that iterative reconstruction techniques are computationally intensive. However, they offer more versatility than back-projection and allow reconstruction of noisier projections, which means that substantial dose savings are possible.

Since many slices, and not just a single one, are reconstructed, a three-dimensional (3D) data set is obtained. This data set is usually viewed in transverse, sagittal or coronal viewing planes. However, it is also possible to cut the dataset along any viewing plane through software manipulation.

4.5 CT Numbers

CT images that are used clinically are typically displayed in a grayscale, and each pixel's grayscale is a representation of the CT number (or Hounsfield unit) of that voxel. CT numbers are rescaled linear attenuation coefficients to give a CT number of zero for water.

$$\mathrm{CT}(x,y) = 1000 \times \left(\frac{\mu(x,y) - \mu(\mathrm{water})}{\mu(\mathrm{water})} \right).$$

Since the attenuation of X-rays in air is almost zero (μ(air) $\approx$ 0), the CT number for air is very close to −1000.

4.6 Multi-Slice CT

Multiple detector arrays allow for simultaneous data acquisition along several slices, and slice thickness is now determined by the detector size and no longer by the beam collimation. Detectors can be electronically binned to give different slice thicknesses as desired by the operator. Figure 4.6a is an example of a single detector and single slice CT. Figure 4.6b shows a CT with multiple detectors and slices. Multi-slice acquisitions mean that much larger regions can be scanned in a single gantry rotation. The largest number of true slices by a commercial scanner is 320 slices.

The pitch is a parameter that comes into play when helical scan protocols are used. It is defined as the table increment per gantry rotation, divided by the beam collimation width (collimator pitch), or divided by the detector width (detector pitch). A pitch of less than one implies overlapping slices and thus a higher patient dose.

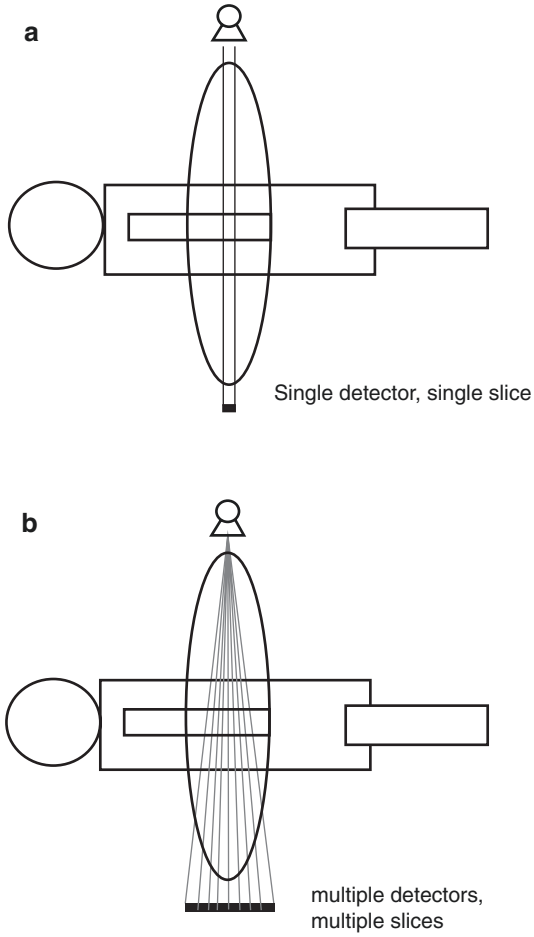


Fig. 4.6 (**a**) Single CT detector and single slice. (**b**) Multiple CT detectors and slices

4.7 Other Considerations

Modern CT scanners typically use a fan-beam geometry, rather than a parallel beam geometry, and reconstruction algorithms are amended accordingly. The introduction of slip-ring technology allowed for continuous gantry rotation without wires getting tangled up around the gantry. This in turn allowed for data acquisition while the CT table was moving, resulting in helical acquisitions patterns.

Surface rendering is a software tool that identifies voxels on the edge of a structure, and then displays these voxels. This approach is useful to examine tubular structures, like the colon.

Dual-energy CT and photon counting CT are covered in Chap. 26.

4.8 Hybrid Imaging

Hybrid imaging refers to the fusion of two or more imaging modalities. The idea behind this is that the second modality will add additional useful diagnostic information, thus making hybrid imaging more powerful than each imaging modality on its own. Existing hybrid imaging modalities include the combination of positron emission tomography (PET) with CT or magnetic resonance imaging (MRI), single photon emission computed tomography (SPECT) with CT or MRI, ultrasound with CT or MRI, or CT and MRI. Of course, not all combinations are useful in all settings.

Most modern PET scanners are integrated with a CT scanner, or, to a lesser degree, with an MRI scanner. These systems can acquire PET images, along with spatially registered CT or MRI images within a short time frame. The nuclear medicine imaging modalities (PET or

SPECT) image radiotracers that are designed for functional imaging, often showing increased (or decreased) metabolic activity, but not necessarily showing the anatomical position of the uptake very well. Additionally, the spatial resolution of nuclear medicine imaging equipment is poor compared to CT or MRI scanners (spatial resolution approaching 1 cm vs sub-millimetre imaging capabilities). However, the correlation of functional images with anatomical images offers a powerful diagnostic tool. The integration of two imaging systems allows for the acquisition of the two scans in quick succession, increasing the probability of the data to be aligned spatially and temporally. Particularly for PET-CT and SPECT-CT, the CT dataset can also be used to do the attenuation correction for the PET or SPECT component of the study. In addition, a single imaging session is logistically more efficient for the patient [4].

PET-CT colonography using fluorine-18-fluoro-deoxyglucose (F-18 FDG) is useful in the accurate anatomic correlation of both malignant and premalignant lesions [5, 6]. Additionally, PET-CTC offers accurate whole-body tumour staging, with integrated morphological and functional images, but at the cost of a higher radiation dose [7].

The integration of PET or SPECT with MRI has also been done. MRI offers better soft tissue contrast than CT, making it more useful in some clinical situations. Although commercial solutions are available, the very strong magnetic field remains a challenge in the integration process with the nuclear medicine imaging modalities. In addition, MRI imaging takes more time than a CT scan (minutes or tens of minutes vs a few seconds), and the systems are very expensive [8]. However, there is a growing field of clinical indications for PET-MRI.

Ultrasound can also be fused with CT data. Stang et al. [9] found that this technique may be useful in staging patients with colorectal cancer, but no literature was found that specifically described ultrasound and CT colonography image fusion.

The value of fusing MRI images was CT data in the diagnosis and staging of colon cancer has been described [10] although this did not specifically refer to CTC.

Generally, the baseline dataset is the higher resolution and anatomically correct CT or MRI dataset. The fusion of two imaging modalities requires the co-registration of the datasets. For a combined imaging modality, like for example a PET-CT scanner, the distance between the imaging planes between the two modalities is known, and fusion can occur by just moving the one dataset that known distance on top of the other one. If the patient did not move and there were no internal organ motions, then co-registration is usually acceptable. Differences in pixel size must be considered.

The co-registration can also be done manually by the operator, who matches points or landmarks that are visible on both datasets, to place the image sets on top of each other. This could include the use of fiducial markers that are visible on both datasets [11, 12]. There are also several automatic or semi-automatic algorithms that can do this using various techniques like edge-detection, gradient methods, voxel similarity, surface matching, intensity differences, standard deviation of voxel differences, or similar [12]. Mutual information methods compare the amount of information that one image contains about the other and when this number if a maximum, then the images are correctly aligned [13]. These techniques work well for “rigid-body” transformations.

Challenges for image fusion include patient movement, tissue deformation, or patient positioning. Deformable image registration allows the re-calibration and modification of images (or parts of images) to allow for better fusion of two datasets where the alignment is not ideal [11]. Deformable algorithms vary significantly in complexity. Affine transformations preserve straight lines and distances between them. Non-affine transformations (image warping) are based on theoretical models that describe tissue properties, like flexibility or rigidity [12].

However, warping techniques can easily hide small features (like for example small polyps) and thus only offer a limited use in medical applications.

Electromagnetic navigation can be used in ultrasound image matching, where sensor coils are tracked in real-time for the orientation and position of the ultrasound probe, and the signal is re-formatted to match previously acquired CT, MRI, or PET-CT data.

Techniques such as a sliding window technique or checkerboard images can be used to view a set of fused images as a single image. The fused image should have more complete information than either of the two input images and help in clinical diagnosis.

Key Messages

- Computed tomography utilises a set of two-dimensional projections taken at many angles around a patient to reconstruct a three-dimensional dataset.
- Tomographic reconstruction is usually done through (filtered) backprojection or iterative reconstruction.
- A CT scan is in essence an attenuation map of the human body. The CT numbers are rescaled attenuation coefficients, relative to water.
- Advances in CT, such as multi-slice CT, helical data acquisition, and many software improvements, have expanded the number of clinical indications for which CT is useful, including CT colonography.
- Hybrid imaging refers to the synergistic fusion of two imaging modalities, with each imaging modality adding unique data for improved clinical decision making.

4.9 Summary

Computed tomography is a powerful imaging modality, allowing the reconstruction of a three-dimensional dataset from two-dimensional image data. This solves the issues of overlying or underlying structures that are present in planar radiography. One of the fields where CT advances have enabled the expansion of clinical indications is CT colonography, which allows the visualisation of the colon in a minimally non-invasive manner.

References

1. Bushberg J, Seibert A, Leidholdt E, Boone J. The essential physics of medical imaging. 2nd ed. Philadelphia: Lippincott Williams & Wilkins; 2002.
2. Mahesh M. MDCT physics: the basics: technology, image quality and radiation dose. Philadelphia: Lippincott Williams & Wilkins; 2009.
3. Dance D, Christofides S, Maidment A, McLean I, Ng K. Diagnostic radiology physics: a handbook for teachers and students. Vienna: International Atomic Energy Agency; 2014.
4. Cherry S, Sorensen J, Phelps M. Physics in nuclear medicine. 4th ed. Philadelphia: Saunders; 2012.
5. Gollub M, Akhurst T, Markowitz A, Weiser M, Guillem J, Smith L, Larson S, Margulis A. Combined CT colonography and 18F-FDG PET for colon polyps: potential technique for selective detection of cancer and precancerous lesions. Am J Roentgenol. 2007;188(1):130–8. https://doi.org/10.2214/AJR.05.1458.
6. Quon A, Napel S, Beaulieu C, Gambhir S. "Flying through" and "flying around" a PET/CT scan: pilot study and development of 3D integrated 18F-FDG PET/CT for virtual bronchoscopy and colonoscopy. J Nucl Med. 2006;47:1081–7.
7. Sun L, Wu H, Guan Y. Colonography by CT, MRI and PET/CT combined with conventional colonoscopy in colorectal cancer screening and staging. World J Gastroenterol. 2008;14(6):853–63.
8. Cal-Gonzalez J, Rausch I, Sunda L, Lassen M, Muzi O, Moser E, Papp L, Beyer T. Hybrid imaging: instrumentation and data processing. Front Phys. 2018;6:47. https://doi.org/10.3389/fphy.2018.00047.
9. Stang A, Keles H, Hentschke S, Seydewitz C, Keuchel M, Pohland C, Dahlke J, Weilert H, Wessling J, Malzfeld E. Real-time ultrasonography-computed tomography fusion imaging for staging of hepatic metastatic involvement in patients with colorectal cancer. Investig Radiol. 2010;45(8):491–501. https://doi.org/10.1097/RLI.0b013e3181ddd3da.
10. Zhao Z, Shou Y, Jiang M, Dang L. Application value of MRI combined with MSCT in diagnosis and staging of colon carcinoma. Comput Math Methods Med. 2022;2022:2593844. https://doi.org/10.1155/2022/2593844.

11. Singh B, Cazacu I, Deza C, Rigaud B, Saftiou A, Gruionu G, Guionu L, Brock K, Koay E, Herman J, Bhutani M. Image fusion involving real-time transabdominal or endoscopic ultrasound for gastrointestinal malignancies: review of current and future applications. Diagnostics. 2022;12:3218. https://doi.org/10.3390/diagnostics12123218.
12. Ewertsen C, Saftiou A, Gruionu L, Karstrup S, Nielsen M. Real-time image fusion involving diagnostic ultrasound. Am J Roentgenol. 2013;200(3):W249–55. https://doi.org/10.2214/AJR.12.8904.
13. Maes F, Loeckx D, Vandermeulen D, Suetens P. Image registration using mutual information. In: Paragios N, Duncan J, Ayache N, editors. Handbook of biomedical imaging. Boston: Springer; 2015. https://doi.org/10.1007/978-0-387-09749-7_16.

5 Principles of Radiation Dose in CT and CT Colonography

Christoph J. Trauernicht

5.1 Introduction

Different X-ray modalities address radiation dose in different ways, for example, in planar radiography the entrance exposure, incident air kerma or entrance surface air kerma, are the commonly quoted figures; in fluoroscopy, it is the air kerma-area product; and in mammography, it is the average glandular dose [1].

When the X-ray tube of CT scanner is switched on the dose is deposited from all directions. The dose is deposited more evenly in tissue when compared to planar radiography, where the entrance dose will be substantially higher than the exit dose because of the attenuation of radiation in the body. The scanning procedure uses narrow beams along the longitudinal axis of the patient, with a significant dose deposited outside of the nominal beam width. In addition, the volume to be imaged is not irradiated simultaneously which can lead to confusion when the dose from a complete series is compared to that of a single slice. As a consequence, dedicated dose quantities that account for these peculiarities in computed tomography are needed: currently, the computed tomography dose index (CTDI), which is a measure of the local dose, and the dose-length product (DLP), which represents the integral radiation exposure associated with a CT examination, are used.

5.2 Radiation Units

As an X-ray beam passes through matter, it deposits energy in the medium in a two-step process: In the first step, the energy carried by the X-rays is transformed into kinetic energy of charged particles like electrons. For the X-rays energies used in CT scanners, the energy is transferred by photoelectric absorption or Compton scattering. In the second step, the released charged particles deposit their energy in the medium by excitation and ionisation. In some cases, the range of the charged particles is large enough that the energy is deposited some distance away from the initial interactions [2].

- Kerma (*k*inetic *e*nergy *r*eleased in *ma*tter) is defined as the kinetic energy transferred to charged particles by indirectly ionising radiation (such as X-rays) per unit mass. The unit of kerma is the grey [Gy], with 1 Gy = 1 J/kg.
- The absorbed dose is defined as the energy imparted by ionising radiation per unit mass of irradiated material. Unlike kerma, absorbed dose is defined for all types of ionising radiation, i.e. both directly (charged) and indirectly

C. J. Trauernicht (✉)
Division of Medical Physics, Tygerberg Hospital and Stellenbosch University, Cape Town, South Africa
e-mail: cjt@sun.ac.za

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(uncharged) ionising radiation. However, the unit for absorbed dose is the same as for kerma, with 1 Gy = 1 J/kg [3].
- The older unit for absorbed dose is the rad, with 1 Gy = 100 rad.

In diagnostic radiology, the production of bremsstrahlung within low atomic number materials is negligible. For a given material and radiation field, absorbed dose and kerma are then numerically equal [1]. The notable exception where they are not equal is close to an interface between different materials.

For dosimetry in CT, both free-in-air and in-phantom measurements are expressed in terms of a computed tomography dose index (CTDI) [4, 5]. The CTDI is measured in a polymethyl methacrylate (PMMA) phantom, but in reality the measured quantity is the air kerma to a cavity within a phantom, not the absorbed dose. The absorbed dose to an air cavity within a phantom arises in a situation close to an interface between materials where the kerma is not equal to the absorbed dose. For this reason, the IAEA introduced the CT air kerma index for both free-in-air and in-phantom measurements in their international code of practice for dosimetry in diagnostic radiology (TRS 457) [1]; however, while this is technically the more correct term, all CT air kerma-related quantities used in the TRS 457 protocol correspond directly with the CTDI-related quantities and without a change in measurement methods. Therefore, in this chapter the better known and worldwide accepted CTDI is used throughout [6]. In the past, the Röntgen, the old unit of quantity exposure, was used instead of air kerma.

5.3 CT-Specific Radiation Dose Measures

CT is unique in that the exposure is essentially continuous around the patient and done in slices of varying thicknesses [7]. CT also often uses multiple exposures along some length of the patient to cover a volume of anatomy (if pitch <1).

In addition, the radiation profile within a single slice of a scan is not limited to that slice only, but there are tails of radiation from the scatter of photons in the object being imaged. The penumbra of the X-ray beam will also add dose to those tails [8]. Figure 5.1(i) shows a typical slice pro-

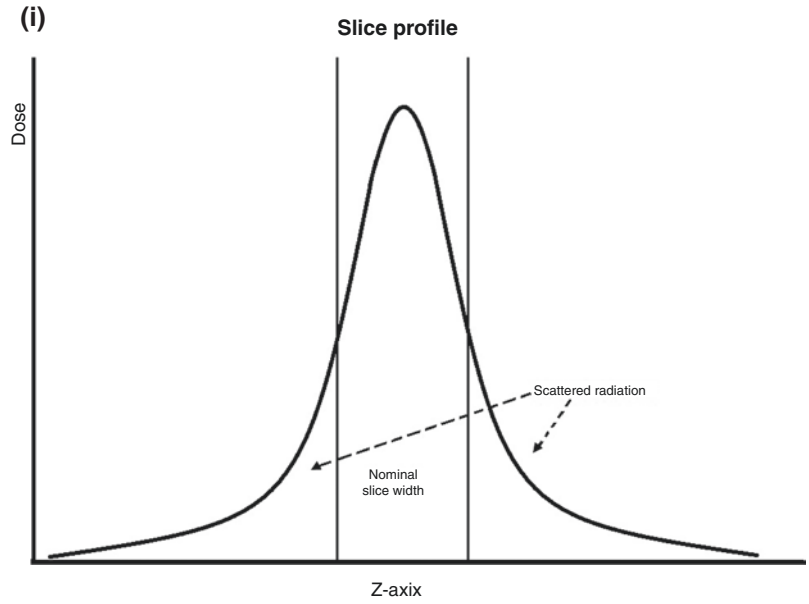

Fig. 5.1 (**i**) Image of a slice profile.

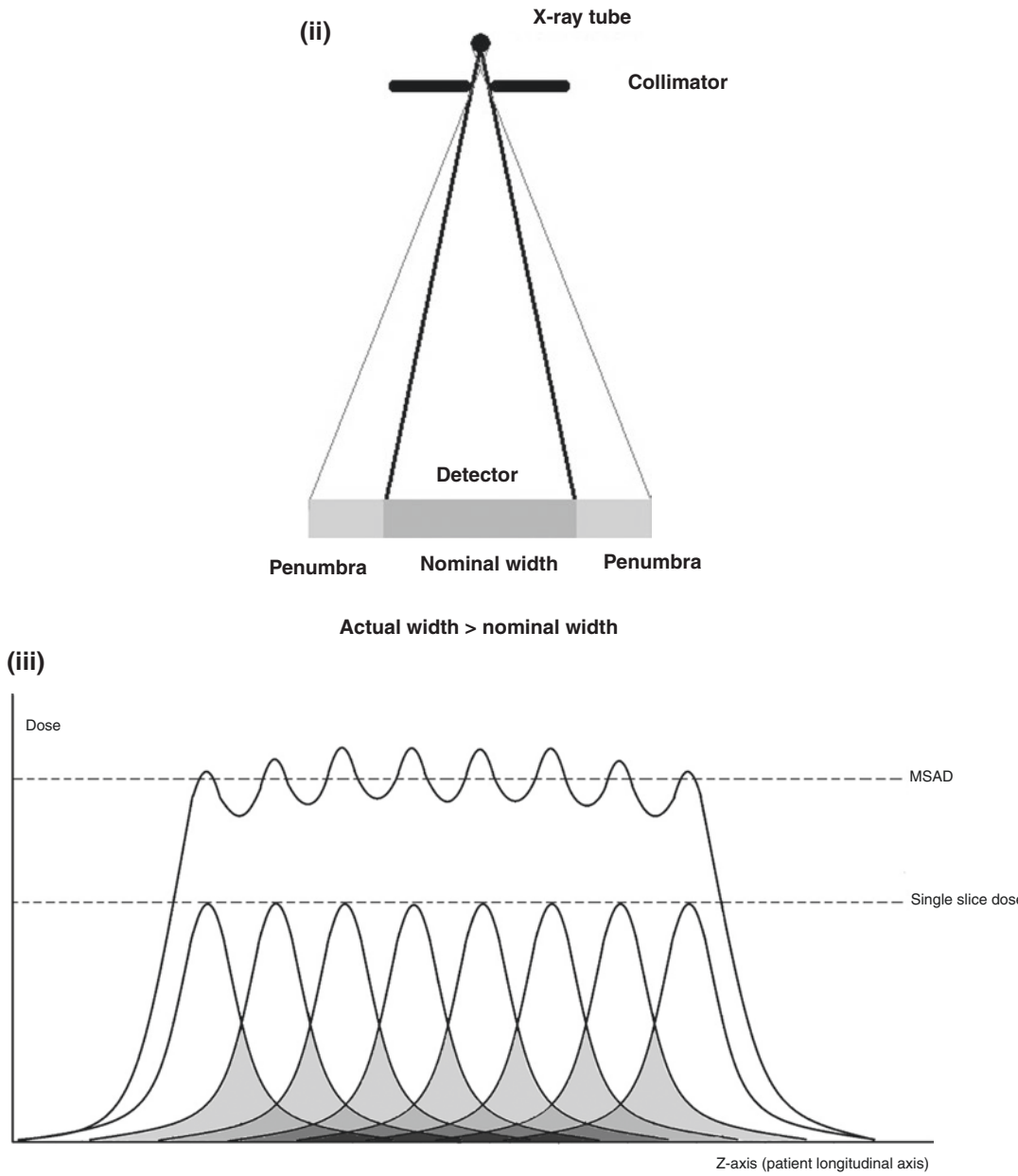

Fig. 5.1 (**ii**) Image of the X-ray penumbra. (**iii**) Summation of 8 slice profiles and the resultant MSAD

file indicating the scattered dose deposited outside of the nominal slice width. The penumbra of an X-ray beam is shown in Fig. 5.1(ii), and it depends on the size of the X-ray source focal spot, the source-to-collimator distance and the collimator-to-detector distance.

When multiple adjacent scans are performed, the tails of the radiation profiles from adjacent scans will contribute to the absorbed dose in the current slice. One of the first dose descriptors, the multiple scan average dose (MSAD) was developed to take this effect into account. It is defined as the average dose resulting from a series of scans over a length interval [7]. By definition, the MSAD is the dose from all slices in a particular procedure, no matter how many slices are done and what scan length is covered [9]. Figure 5.1(iii) shows how the radiation tails from

adjacent slices overlap and get added up to form the MSAD.

The next dose descriptor was the computed tomography dose index (CTDI). It was originally designed as an index [2], not as a direct dosimetry method for patient dose assessment. However, the CTDI is the current worldwide standard for patient dose estimation in CT, even though it has a number of limitations, which will be discussed later.

5.3.1 The CTDI Measurement

The basic CTDI measurement is done with a 100 mm long cylindrical 'pencil' type chamber with a diameter of about 9 mm. In Fig. 5.2(i), the ionisation chamber is centred in the CT gantry and a single axial CT scan without table translation is done. The dose estimate will only be accurate if the entire sensitive volume of the chamber is irradiated. For most CT scanners, this will not

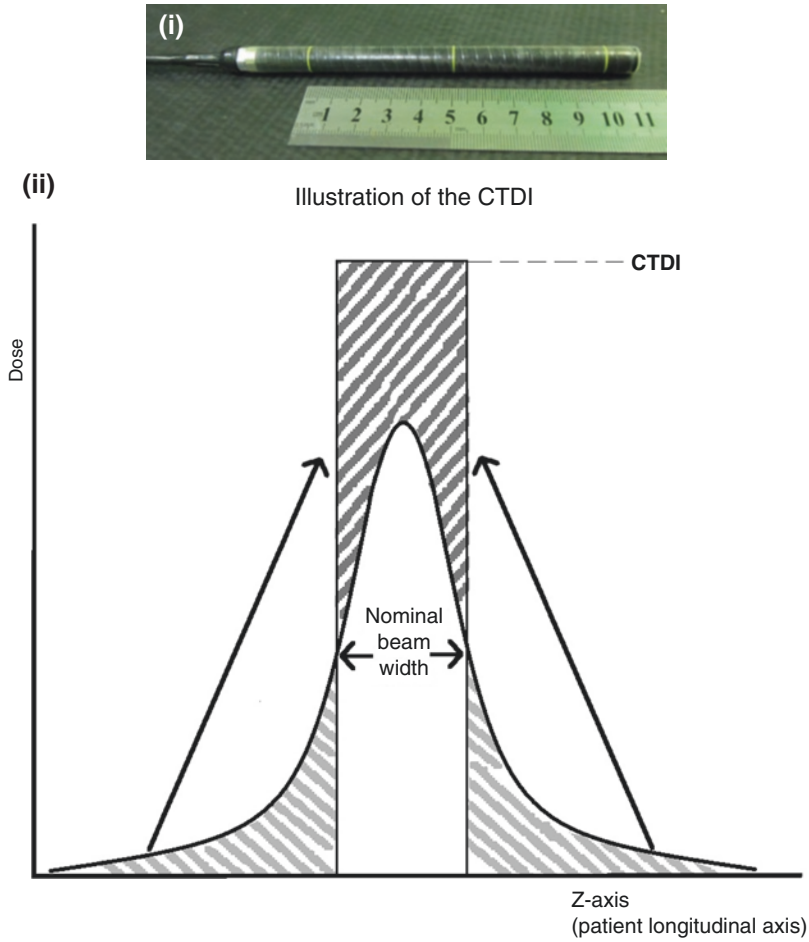

Fig. 5.2 (**i**) A typical CT ionisation chamber. (**ii**) Illustration of the CTDI.

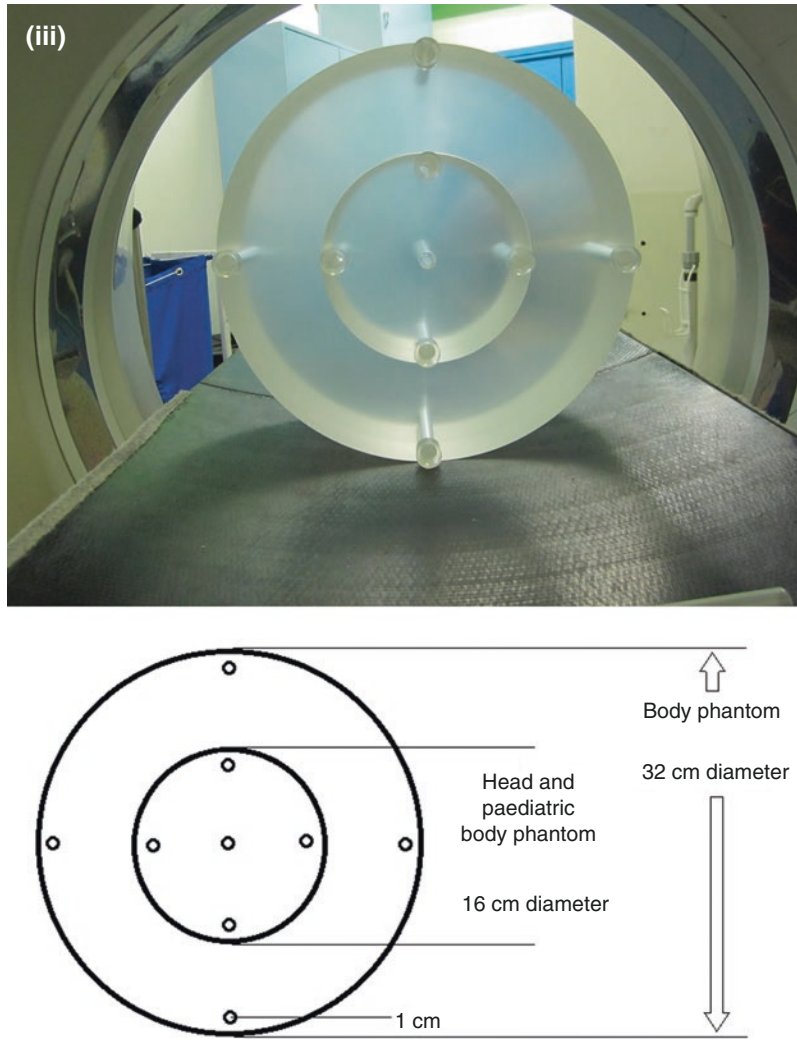

Fig. 5.2 (**iii**) Photo of a PMMA CTDI phantom (**a**) and sketch of the phantom with dimensions (**b**)

happen in a single gantry rotation because the nominal beam width for most scanners is less than 100 mm. Therefore the nominal beam width, as shown in Fig. 5.2(ii), is used to correct the chamber reading for the partial exposure, so that the corrected reading is given by the obtained reading multiplied by the length of the ionisation chamber (100 mm) and divided by the nominal beam width [2]. The nominal beam width is given by the number of non-overlapping slices × slice width [8] or by the width of an individual CT detector × number of active detectors [2].

The process of scattering partially redistributes the dose from the primary beam to outside the collimated beam, which means that adjacent slices, which were not scanned in this setup, will also get some dose. While only a single beam width was done, the ionisation chamber will pick up the scattered dose and add it to the primary dose. This means that the CTDI is the equivalent of the dose value inside the irradiated beam width that would result if the absorbed dose profile were entirely concentrated to a rectangular profile of width equal to the nominal beam width [8].

In practice, the dose profile is accumulated in a range of −50 mm to +50 mm relative to the beam centre (i.e. total length of 100 mm), which will

result in the $CTDI_{100}$. This is equivalent to the IAEA TRS 457's CT air kerma index $C_{a,100}$ [1].

In order to obtain estimates of the doses to organs in the scan range, the CTDI generally refers to standard dosimetry phantoms with diameters similar to the average patient [8]. There are currently two CTDI dosimetry phantoms in common use. The head (and paediatric body) phantom consists of a 16 cm diameter clear acrylic cylinder 15 cm in length. The body phantom consists of a 32 cm diameter clear acrylic cylinder 15 cm in length [4]. In many examples of these phantoms, there are eight measuring holes equally spaced around the periphery, but only four equally spaced holes are required [1]. See Fig. 5.2(iii)a, b.

$CTDI_{100}$ measurements are done for both the centre ($CTDI_{100,center}$) and the periphery ($CTDI_{100,periphery}$) for the chosen phantom. The four peripheral readings will not all be equal because of the presence of the patient couch which attenuates the beam from below, and the effect of any over-ranging. The latter is discussed in dose optimisation in Sect. 6.4.6 in Chap. 6. The peripheral readings are thus averaged for the $CTDI_{100,periphery}$.

The central and peripheral readings are added using a 1/3 and 2/3 weighting, respectively, to give the weighted CTDI, $CTDI_w$. This provides a good estimate of the average dose to the phantom at the central slice [2].

In helical CT scanning, the dose is inversely proportional to the pitch, where the pitch is defined as the table movement during a full rotation of the gantry, divided by the nominal beam width. A pitch of greater or less than unity will result in a decrease or increase in dose, respectively, which is taken into account by the $CTDI_{vol}$. The $CTDI_{vol}$ is given by:

$$CTDI_{vol} = CTDI_w / \text{pitch},$$

and is thus the pitch-corrected $CTDI_w$. The $CTDI_{vol}$ represents the average dose for a given scan volume and is typically displayed on the CT scanner console, sometimes even prior to the actual scan.

The CTDI concept allows for comparison of the output of different CT scanners.

The dose-length product (DLP) in units of mGy cm is defined as the product of the $CTDI_{vol}$ and the length of the CT scan. This means that the DLP will increase with scan distance; the $CTDI_{vol}$ however remains the same, regardless of the number of slices. The DLP serves as a surrogate for patient dose, which is very useful when comparing dose levels, and this became accepted through the establishment of diagnostic reference levels [6, 10, 11].

5.3.2 Limitations of CTDI

The most important limitation of the CTDI is that it is a dose index, but not a measurement of patient dose. The $CTDI_{vol}$ is a dose index that is calculated from air-kerma measurements at five different locations in a PMMA phantom at the centre of a 100 mm long scan. It describes the dose to a phantom and not a real patient. PMMA phantoms will generally underestimate the absorbed dose in clinical situations because actual scan lengths are generally longer than 100 mm and the human body is not homogeneous or made of 16 cm or 32 cm diameter PMMA [12].

Another limitation is that the nominal scan widths of modern CT scanners often approach or exceed 100 mm, which means that not all scattered radiation is accounted for in the CTDI and it thus becomes an inaccurate dose measure [13, 14].

An official regulation was issued by the IEC which confirmed the validity of the existing CTDI for collimation widths of up to 40 mm and introduced a correction factor based on measurements in air made with a 300 mm ionisation chamber [15] or with a set of contiguous measurements with a smaller ionisation chamber [14].

5.4 Effective Dose

The CTDI and the DLP are CT-specific dose descriptors. They do not allow for direct comparison with radiation exposures from other modalities. The way to allow for such comparison is the effective dose. There are a few steps along the way to get to the effective dose.

- The organ dose is defined by the ICRU report 51 as the ratio of the energy imparted to an organ divided by its mass [3].
- The equivalent dose to an organ is defined in ICRP 60 [16] and ICRU 51 [3] as the product of the radiation weighting factor and the organ dose. The radiation weighting factor allows for differences in the relative biological effectiveness between different radiation modalities and is unity for X-rays.

The effective dose is defined as the sum over all the organs and tissues of the body of the product of the equivalent dose and a tissue weighting factor. The tissue weighting factor takes into account the radio-sensitivity of the various organs and represents the relative contribution of that organ to the total detriment arising from stochastic effects for uniform irradiation of the whole body. The sum of all the tissue weighting factors is one. As new evidence became available, they have been adjusted over time [16, 17].

The measurement of effective doses in or on a patient is not practical. For a rough estimate of the effective dose, it is sufficient to multiply the DLP with a conversion factor, depending on which body region was scanned and whether that scan was made in the head or body scanning mode. The concept of DLP-to-effective dose conversion factors is a useful one and widely used; it does have limitations [6]. Organ doses can also be estimated based on pre-tabulated phantom data or on Monte Carlo calculations, mostly using anthropomorphic phantoms [6]. A number of free or commercially available computer programmes exist that do a conversion calculation from DLP to effective dose. A simple web search will find the respective websites. The programmes differ significantly in performance, specification, and price.

The assessment and interpretation of the effective dose is very problematic when organs and tissues receive only a partial exposure or a very heterogeneous exposure [17]. The effective dose should not be used as a risk estimation to an individual patient [17]. The tissue weighting factors are calculated for a generic person, not an individual, whose age and sex have a significant influence on the risk. Organ or tissue doses, not effective doses, are required for assessing the probability of cancer induction in exposed individuals [17]. However, the effective dose is useful to compare various radiological imaging procedures.

5.5 Low-Dose CTC

One of the initial areas of concern with CTC was the risk of radiation [18]. Low-dose CT protocols have been introduced that have allowed a vast reduction of effective doses. A study from Japan reported an average effective dose of 23.5 mSv for routine CTC, but only 5.7 mSv for low-dose CTC using a decreased effective mAs [19].

Typical effective doses for CTC reported in literature range from 7.5 mSv for men and 10.2 mSv for women [20], 5.0 mSv for men and 7.8 mSv for women [21], 2.2 mSv for both prone and supine positions for low-dose CTC [22], 1.8 mSv for men and 2.3 mSv for women [23], to a median effective dose of 5.1 mSv (range 1.2–11.7 mSv) per scanning position in a paper covering the CTC scan parameters of 36 institutions [24]. The effective dose is higher for female patients, as some gender-specific organs are irradiated during virtual colonoscopy (CTC) [20].

It is quite evident that there is a considerable variance in effective doses. With the right dose optimisation techniques effective doses of less than 5 mSv can be achieved for CTC examinations. Various dose optimisation options are discussed in Chap. 6.

5.6 Dosimetric Considerations of Dual-Energy CT (DECT)

The principles of DECT are discussed in Chap. 26. However, the dose aspects are covered here. Similar to conventional single-energy CT, the acquisition and reconstruction parameters should be optimised for the imaging task, while considering the As Low As Reasonably Achievable (ALARA) principle [25]. This may mean that a slight increase in dose may be justified, provided that an increased value in useful information is obtained.

Multi-energy CT faces the same challenges as conventional CT when using an ionisation chamber. Other radiation measurement devices, such as thermoluminescent dosimeters, metal-oxide-semiconductor field-effect transistors (MOSFET detectors), or optically stimulated luminescence dosimeters have known energy dependencies, which can be quite problematic for DECT and thus require careful characterization and calibration.

The American Association of Physicists in Medicine put together a task group in 2010 to evaluate radiation dose in CT, results of which were published in AAPM Report No. 111 [26]. The report introduces a concept of 'equilibrium dose' and related parameters, particularly in response to wider beam collimators where the CTDI concept fails, but does not offer a consensus on the phantoms required to measure this quantity. However, they recommend using a chamber with a flat energy response (~1.5% variation) that is calibrated for ranges of beam quality and kVp from 80 to 140 kVp, associated with those of CT scanner spectra. If the ionisation chamber has a uniform energy response over a range of energies that are used for imaging, then the signal of both energies can be integrated in a single reading.

In its early days, DECT was associated with a significant increase in radiation dose because a patient was really just scanned twice at different energies [27]. However, improvements in detectors, filters, X-ray source technology, and software have allowed for good image quality at a lower dose. Recent studies have shown that DECT radiation dose is comparable to, or even less than, conventional CT doses [28, 29]. One of the potential ways in which dual-energy CT can reduce dose is by obviating the need for unenhanced images in certain studies, which can be extracted from contrast-enhanced examinations by subtracting the iodine from the images [30].

Literature reports that a study of 28 patients [31] evaluated the effective doses of DECT to be 4.26 ± 1.05 mSv, which is very much in line with doses reported for conventional CTC. In the same study, the average DLP was reported as 283.7 ± 69.8 mGy cm.

Finally, care should be taken when comparing radiation doses of different imaging techniques without taking image quality or signal-to-noise ratio into account [32].

5.7 Dose for Clinical Audits

CTC dose to a patient is part of the entire process of a study hence should be recorded in every CTC report (see Table 21.2). As discussed in Chap. 27, dose is part of standards of practice of CTC and hence should be subject to a clinical audit as part of a quality improvement process that focuses on patient care and management, for example.

Key Messages

- Dose assessments with phantoms, as is the case for the CTDI, cannot provide a direct estimate of the average dose for a given patient population.
- The DLP is not the same as patient dose but is a reasonable indicator of the dose to a patient.
- The effective dose is the common denominator between different imaging modalities using ionising radiation. Comparing the DLP with, for example, an entrance skin exposure or an average glandular dose is like comparing apples and peaches.
- The introduction of low-dose CTC has brought about a significant dose reduction to the patient.
- Dual-energy CTC does not necessarily involve an increased patient dose.

5.8 Summary

All through the 1980s and 1990s, there were no major debates or controversies regarding the topic of dose in CT [6]. There have, however, been some discussions and debates on the continued appropriateness of the CTDI [33, 34]. There have been some modifications to the CTDI over time, and there are a number of methods for computing dose in CT, for the purpose of technique optimisation and monitoring patient dose levels.

The effective dose or absorbed organ doses are generally estimated using the DLP multiplied with empirical factors or calculations using anthropomorphic phantoms. Various dose optimisation techniques have allowed for the introduction of low-dose CTC. This allows for diagnostic quality images with a significant reduction in radiation dose. Dual-energy CT shows promise for added diagnostic information without an additional dose penalty.

References

1. Pernička F, McLean ID. Dosimetry in diagnostic radiology: an international code of practice. Vienna: International Atomic Energy Agency; 2007.
2. Bushberg JT, Boone JM. The essential physics of medical imaging. Philadelphia: Lippincott Williams & Wilkins; 2011.
3. ICRU. Quantities and units in radiation protection dosimetry. ICRU Report 51. Bethesda: ICRU Publications; 1993.
4. Chu RY, Fisher J, Archer BR, Conway BJ, Goodsit M. AAPM Report No. 31: standardized methods for measuring diagnostic X-ray exposures. American Association of Physicists in Medicine by the American Institute of Physics: New York; 1990.
5. Dixon R, Anderson J, Bakalyar D, Boedeker K, Boone J, Cody D, et al. Comprehensive methodology for the evaluation of radiation dose in X-ray computed tomography. Report AAPM Task Group. 2010;111:20740–3846.
6. Kalender WA. Dose in X-ray computed tomography. PMB. 2014;59(3):R129.
7. McNitt-Gray MF. AAPM/RSNA physics tutorial for residents: topics in CT: radiation dose in CT. Radiographics. 2002;22(6):1541–53.
8. Tack D, Gevenois PA, Abada HT. Radiation dose from adult and pediatric multidetector computed tomography. Berlin: Springer; 2007.
9. Goldman LW. Principles of CT: radiation dose and image quality. J Nucl Med Technol. 2007;35(4):213–25.
10. European Commission. Radiation Protection 109: guidance on diagnostic reference levels (DRLs) for medical exposures. Vienna: Nuclear Safety and Civil Protection; 1999.
11. Menzel H, Schibilla H, Teunen D. European guidelines on quality criteria for computed tomography. Luxembourg: European Commission; 2000. p. 16262.
12. Platten D, Castellano I, Chapple C, Edyvean S, Jansen J, Johnson B, et al. Radiation dosimetry for wide-beam CT scanners: recommendations of a working party of the Institute of Physics and Engineering in Medicine. BJR. 2013;86(1027):20130089.
13. Mori S, Endo M, Nishizawa K, Tsunoo T, Aoyama T, Fujiwara H, et al. Enlarged longitudinal dose profiles in cone-beam CT and the need for modified dosimetry. Med Phys. 2005;32(4):1061–9.
14. IAEA. Status of computed tomography dosimetry for wide cone beam scanners. Vienna: IAEA; 2011.
15. Commission IE. Medical electrical equipment—part 2–44: particular requirements for the basic safety and essential performance of X-ray equipment for computed tomography—Edition 3.1. Geneva: IEC; 2012.
16. ICRP. Recommendations of the international commission on radiological protection. Ottawa: ICRP Publication 103; 1990.
17. ICRP. The 2007 Recommendations of the International Commission on Radiological Protection. Ottawa: ICRP Publication 103; 2007.
18. Chang KJ, Yee J. Dose reduction methods for CT colonography. Abdom Imaging. 2013;38(2):224–32.
19. Hirofuji Y, Aoyama T, Koyama S, Kawaura C, Fujii K. Evaluation of patient dose for barium enemas and CT colonography in Japan. BJR. 2009;82:219–27.
20. Schopphoven S, Faulkner K, Busch H. Assessment of patient organ dose in CT virtual colonoscopy for bowel cancer screening. Radiat Prot Dosim. 2008;129(1–3):179–83.
21. Macari M, Bini EJ, Xue X, Milano A, Katz SS, Resnick D, et al. Colorectal neoplasms: prospective comparison of thin-section low-dose multi-detector row CT colonography and conventional colonoscopy for detection. Radiology. 2002;224(2):383–92.
22. Neri E, Faggioni L, Cerri F, Turini F, Angeli S, Cini L, et al. CT colonography versus double-contrast barium enema for screening of colorectal cancer: comparison of radiation burden. Abdom Imaging. 2010;35(5):596–601.
23. Iannaccone R, Laghi A, Catalano C, Brink JA, Mangiapane F, Trenna S, et al. Detection of colorectal lesions: lower-dose multi-detector row helical CT colonography compared with conventional colonoscopy. Radiology. 2003;229:775–81.
24. Jensch S, van Gelder RE, Venema HW, Reitsma JB, Bossuyt PM, Laméris JS, et al. Effective radiation doses in CT colonography: results of an inventory among research institutions. Eur Radiol. 2006;16(5):981–7.
25. McCollough C, Boedeker K, Cody D, Duan X, Flohr T, Halliburton S, Hsieh J, Layman R, Pelc N. Principles and applications of multienergy CT: report of AAPM Task Group 291. Med Phys. 2020;47(7):e881–912. https://doi.org/10.1002/mp.14157.
26. AAPM Report No. 111. Comprehensive methodology for the evaluation of radiation dose in X-ray computed tomography. Alexandria: AAPM; 2010.
27. Odedra D, Narayanasamy S, Sabongui S, Priya S, Krishna S, Sheikh A. Dual-energy CT physics—a primer for the emergency radiologist. Front Radiol. 2022;2:820430. https://doi.org/10.3389/fradi.2022.820430.
28. Uhrig M, Simons D, Schlemmer H. Advanced abdominal imaging with dual energy CT is feasible

without increasing radiation dose. Cancer Imaging. 2015;15(Suppl1):P1.
29. Grajo J, Sahani D. Dual-energy CT of the abdomen and pelvis: radiation dose considerations. J Am Coll Radiol. 2018;15(8):1128–32. https://doi.org/10.1016/j.jacr.2017.08.012.
30. Ho L, Yoshizumi T, Hurwitz L, Nelson R, Marin D, Toncheva G, Schindera S. Dual energy versus single energy MDCT: measurement of radiation dose using adult abdominal imaging protocols. Acad Radiol. 2009;16(11):1400–7. https://doi.org/10.1016/j.acra.2009.05.002.
31. Sun K, Han R, Han Y, Shi X, Hu J, Iu B. Accuracy of combined computed tomography colonography and dual energy iodine map imaging for detecting colorectal masses using high-pitch dual-source CT. Sci Rep. 2018;8:3790. https://doi.org/10.1038/s41598-018-22188-x.
32. Henzler T, Fink C, Schoenberg S, Schoepf J. Dual-energy CT: radiation dose aspects. Am J Roentgenol. 2012;199(5):S16–25. https://doi.org/10.2214/AJR.12.9210.
33. Brenner DJ. Is it time to retire the CTDI for CT quality assurance and dose optimization? Med Phys. 2005;32(10):3225–6.
34. Brenner DJ, McCollough CH, Orton CG. It is time to retire the computed tomography dose index (CTDI) for CT quality assurance and dose optimization? Med Phys. 2006;33(5):1189–91.

6 Dose Optimisation in CT Colonography

Christoph J. Trauernicht

6.1 Introduction

The publications 103 and 105 of the International Commission on Radiological Protection (ICRP) clearly identify two key elements in radiation protection in medicine: justification and optimisation [1, 2]. In one sentence, these principles could be summarised as 'doing the right procedure' and 'doing the procedure right', respectively.

In 2012, the International Atomic Energy Agency (IAEA) held a conference on radiation protection in medicine in Bonn, Germany. The conference was co-sponsored by the World Health Organisation (WHO): the specific outcome of the conference was the Bonn Call-For-Action [3]. The aims of the Bonn Call-For-Action include: to strengthen the radiation protection of patients and health workers; to attain the highest possible benefit with the least possible risk by the safe and appropriate use of ionising radiation in medicine; and to enhance the safety and quality of radiological procedures in medicine. Ten main actions were identified as being essential. They include enhancing the principle of justification; the implementation of the principle of optimisation; strengthening radiation protection education and training of health professionals; increase access to information on medical exposure globally; and foster an improved radiation-risk-dialogue.

6.2 Justification

There are three levels of justification for a procedure in medicine [1]. The use of radiation in medicine, at the most general level, is accepted as doing more good than harm. At the second level, a specified procedure with a specified objective is defined and justified; for example, a CTC study to detect polyps. The aim of this generic justification is to determine whether the procedure will improve the diagnosis or treatment. At the third level, the application of the procedure to an individual must be justified and judged to do more good than harm to that particular patient.

6.3 Optimisation

Optimisation is the process of determining how to obtain the required diagnostic outcome for a patient from a procedure while minimising factors that cause patient detriment, with economic and societal factors being taken into account. Optimisation is intended for those situations that have been deemed to be justified [1]. Optimisation involves input from a radiologist,

C. J. Trauernicht (✉)
Division of Medical Physics, Tygerberg Hospital and Stellenbosch University, Cape Town, South Africa
e-mail: cjt@sun.ac.za

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radiographer, and medical physicist. It also includes the concept of maximising the benefit of the use of radiation while minimising the risk of detriment. Therefore, a knowledge of risk estimation may be important in optimisation in clinical practice. The concept of ALARA (as low as reasonably achievable) should be applied whenever possible.

6.3.1 Risk

Radiation exposure from CT is associated with an increase in risk for fatal cancer, especially in paediatric CT scanning [4–6]. The lifetime cancer mortality risk for a 1-year-old patient attributable to the radiation exposure from an abdominal CT is estimated to be 0.18%, which is about an order of magnitude higher than for adults [7]. An estimate for the absolute lifetime cancer risk associated with the radiation exposure from CTC is about 0.14% for paired CTC scans for a 50-year-old, and about half of that for a 70-year-old [8]. Most of the quantitative data regarding the risk of radiation-induced cancer comes from studies of the atomic bomb survivors from Japan [9]. According to the BEIR VII Phase 2 report [9] approximately 42 of 100 people will be diagnosed with cancer from causes unrelated to radiation; a single exposure of 100 mSv of X-ray radiation could result in approximately one additional cancer in 100 people. The risk depends on age and sex, with a higher risk for females and those exposed at younger ages. Typical CT exposures result in doses substantially smaller than that; nonetheless, some argue that the risks of medical radiation should form part of an informed consent process [10] (see Chaps. 2 and 3). While the increased risk of a radiation-induced cancer is small for any one individual, the risk to the population as a whole is considerable, given the large number of CT scans performed worldwide [5]. A risk-benefit analysis to estimate the ratio of cancers prevented to induced for CTC screening every 5 years from age 50 to 80 showed that the benefits from such screening outweighs the risk substantially; the estimated number of radiation-related cancers from CTC screening every 5 years in that age bracket was 150 cases/100,000 individuals, while the estimated number of colorectal cancers prevented ranged from 3580 to 5190/100,000, yielding a benefit-risk ratio that varied from 24:1 to 35:1 [11].

Increasing concerns about radiation dose have led CT manufacturers to develop dose reduction tools for their CT scanners [12]. It was shown that specifically for CTC large dose reductions are possible without losing diagnostic quality [13]. Effective doses from low-dose CTC are lower than those from a double-contrast barium enema [14, 15].

6.4 Patient Dose in CT: Controllable and Built-in Factors

A number of controllable and built-in factors influencing patient dose in CT are discussed below.

6.4.1 Tube Current

The most straightforward way to reduce radiation dose is to reduce the tube current (mAs). There is a linear relationship between dose and mAs; decreasing mAs will however result in increased image noise and thus decreased image quality. There is a wide tolerance for image noise in CTC [16]. A number of studies [17–20] have shown that decreases in the tube current can still maintain accuracy for the purposes of polyp detection in CTC.

6.4.2 Automatic Tube Current Modulation

For most patients, the anterior–posterior (AP) dimension is smaller than the lateral dimension. This means there is a larger attenuation of radiation in the lateral projections when compared to the AP projections. Less radiation will reach the detectors to produce an image for the lateral projections. The tube current can therefore be

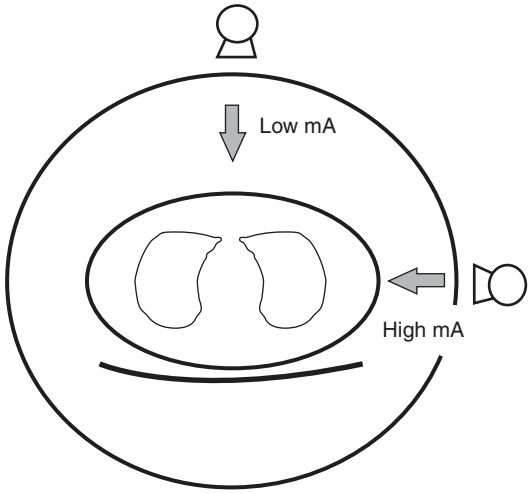

Fig. 6.1 Tube current modulation

reduced for the AP projections while still maintaining the same noise level as the lateral projections [21]. The tube current may be modulated according to patient attenuation or using a sinusoidal-type function. The modulation may be fully pre-programmed, implemented in near-real time using a feedback mechanism, or achieved using a combination of pre-programming with a feedback loop [22]. As shown in Fig. 6.1, the smaller patient thickness in the AP direction (and thus less attenuation of the X-ray beam) allows for a reduction in tube current for those projections.

Automatic dose modulation can occur in the *X*–*Y* axis as described above, and also along the *Z*-axis [23] where the dose can be reduced in more radiolucent parts of the body (e.g. over the lungs). Both approaches are now also commonly combined resulting in an *X*–*Y*–*Z* axis dose modulation [16]. These approaches typically use the AP and lateral CT scout images to predict the amount of dose modulation in the scan. In a CTC screening population, the dose to patients was significantly lower (at least 33%) when tube current modulation was applied with *X*-, *Y*-, and *Z*-axis tube modulation, when compared to *X*- and *Y*-axis tube current modulation only [24].

Another approach for dose reduction is an organ-based tube-current modulation [25] to reduce the radiation dose to superficial radiosensitive organs: the lens of the eye, thyroid, and breast, for example. This is done by decreasing the tube current when the tube passes closest to these organs: to maintain the same noise level, the dose is increased for the opposing projections.

It has been shown in CTC [26] that the amount of stool and fluid tagging, using tagging agents such as iodine and barium, does not significantly affect the radiation exposure when using automatic exposure control.

6.4.3 Tube Voltage

Decreasing the X-ray tube voltage from 140 to 80 kVp decreases the $CTDI_{vol}$ (computed tomography dose index) by about a factor of 4 [27], while a tube voltage reduction in CTC from 120 to 100 kVp resulted in a 20% decrease in $CTDI_{vol}$ in one study, but with only a minimal decrease in 3D image quality at all patient sizes [28]. The CTDI is measured in a phantom and not in a patient, but the dose reduction potential remains with a reduction in tube voltage. A reduction in kVp will result in a less penetrative beam and an increase in image noise. Therefore, reducing the kVp for large patients should be done with caution because conventional dose modulation approaches will increase the tube current to make up for the increased noise in the image, which in turn can reverse any dose savings. It has been shown that at a constant kVp, increasing the patient weight from 10 kg (kilogram) to 120 kg reduces the transmission of X-ray intensity for abdominal CT scanning by about a factor of 100 [29]. One approach is to set the kVp according to patient weight [16], whereas another approach takes into account the patient size and diagnostic task [30].

The ability to automatically select the tube potential can also be an effective approach for dose reduction [31]. This has been implemented on some CT scanners using the topogram, which provides information about the attenuation in the patient along the patient length axis and, on the basis of that information, the required tube current is calculated for the different kVs to obtain a

specified image quality. An overall dose reduction of over 25% was reported for 40 patients undergoing abdominal CT angiography (CTA) compared with a standard protocol using 120 kVp [32].

6.4.4 Iterative Reconstruction

Iterative reconstruction is well established in nuclear medicine. It is becoming more popular for CT image reconstruction. The concept of iterative reconstruction was used in the first transmission CT efforts in the early 1970s, but was not practical for fast high-resolution CT [33]. The increase in computing power, and the ongoing efforts for lower doses in CT, have changed the situation: the first CT vendor introduced iterative reconstruction in 2008 [33]. Familiar vendor names include iDose (Philips Healthcare), IRIS and SAFIRE (Siemens), AIDR 3D or ADMIRE (Toshiba/Canon), and ASIR or VEO MBIR (GE Healthcare).

All iterative reconstruction methods consist of three major steps, which are repeated iteratively (i.e., repeatedly). In the first step, a set of projections from an estimated volumetric object is generated to create artificial raw data. This data is then compared to the real measured raw data in the second step and a correction term is computed, which is then applied to the volumetric object in the third step. This becomes the new estimate and the process is repeated until a fixed number of iterations is reached or until the updates/correction terms between the various projections are considered small enough. The initial guess for the volumetric object can be an empty image, or an image estimate that uses prior information; a standard filtered back-projection image, for example. The iterative reconstruction methods differ mainly in how the actual and estimated projections are compared and how the correction term is computed [33].

Projections might be examined for points likely to result from noisy projections. Noisy data are penalised and edges are preserved during reconstruction. An added benefit of iterative reconstruction is that beam hardening artefacts can potentially be reduced [34] and that incomplete or noisy data can still be reconstructed [35–37].

Iterative reconstruction techniques can allow scanner-specific models and statistical noise models to be included in the reconstruction to help eliminate noise and so bring the dose down [38]. Iterative reconstruction has allowed large dose reductions (32% or more) when compared to filtered back projection without the loss of diagnostic information [39, 40]. Iterative reconstruction allowed for a dose reduction of 10–24% in abdominopelvic multidetector CT examinations in one study and an average abdominal CT radiation dose decrease of 25.1% in another study [41] when compared to filtered backprojection image reconstruction [42]. Another pilot study [43] showed that the radiation dose during CTC can be reduced 50% below currently accepted low-dose techniques without significantly affecting image quality when an adaptive statistical iterative reconstruction technique was used for image reconstruction. While there is some variation in the amount of dose saving, there is a significant dose reduction in all cases.

6.4.4.1 Use of Artificial Intelligence in CT Image Reconstruction

Artificial intelligence (AI) is an emerging technique in CT image reconstruction [44]. These types of techniques can be used to improve image quality, or conversely reduce patient dose, in computed tomography [45]. The first commercial algorithms are already FDA approved in the United States. Image denoising is often the first step in CT image processing, and several deep learning methods are available for this step [46] and show promise in reducing image noise, without a loss of spatial resolution [47, 48]. Alternatively, deep learning (a subset of AI) can be used to aid the iterative reconstruction process by producing high-dose images from lower dose data, or by "learning" how to differentiate noise from signal.

Deep learning will also have a significant role to play in sparse-sampling CT, where the number of acquired image projections are reduced and

dose reductions of over 50% are reported [46]. Deep learning-based reconstruction algorithms have certain limitations: large and applicable training datasets are required, as well as ground-truth data. The reduced noise or improved contrast-to-noise ratio may make for pretty viewing, but there is limited data on direct comparisons of diagnostic accuracy between different reconstruction methods [44]. The principles of AI are presented in Chap. 25.

6.4.5 Pre-patient Beam Filter

Since the cross-section of patients is well approximated by an oval shape, special bowtie filters are nowadays common in CT systems for attenuating the beam at the periphery, while keeping the intensity in the central portion of the beam [31]. Different filters can be used for different fields-of-view (FOV) or patient sizes [49] to reduce the radiation dose to the patient, especially the skin dose [50].

6.4.6 Active Collimators: Over-Ranging

In helical scanning exposure is needed before the start and after the end of the planned scan range in order to reconstruct images at these positions [51]. This over-ranging requires at least one extra gantry rotation, even though only a small portion of this data is utilised for image reconstruction.

For a given beam collimation, the observed Z-over-ranging depends on slice width and pitch [52]. Z-over-ranging increases with increasing cone angle of large Z-axis coverage multidetector CT scanners [53]. Active collimation synchronises the width of the X-ray beam at the ends of the scan range to the clinically useful area needed for image reconstruction. The pre-patient collimator asymmetrically opens and closes at the beginning and end of each spiral scan, temporarily blocking those parts of the X-ray beam that are not used for image reconstruction. Percentage dose reductions, when using active collimation, are larger for short scan lengths and greater pitch values [54]. Figure 6.2(i) shows the concept of over-ranging, with the first and last full rotation of the gantry shown in a darker shade of grey. Figure 6.2(ii) explains how dose is deposited outside of the planned scan length because of over-ranging. Active collimation (Fig. 6.2(iii)) reduces the dose outside of the planned scan length by opening and closing the collimator asymmetrically.

6.4.7 Detector Material

The X-ray detector is a very important determinant of the dose performance of a CT system [49]. Two dose-relevant characteristics of a detector are quantum detection efficiency and geometrical efficiency, which together describe the effectiveness of the detector in converting X-rays to a signal. Solid state or ceramic scintillators with a fast response, low electronic noise, and a high light output are preferred over and more efficient than the xenon gas detectors that were common in the 1980s [55]. To improve radiation dose efficiency, advances in the detector material and system electronics are needed. For example, integrating detector components to reduce electronic noise or minimising detector to detector cross-talk [31]. In one study, CTC images acquired using an integrated circuit detector had significantly lower noise than images acquired using the conventional detector, which allowed for a dose reduction of approximately 20% to result in similar levels of image noise [56]. Some advances in detector materials are also described in Chap. 26.

6.4.8 Shielding

External shielding may be useful in reducing radiation exposure to parts of the body that are not in the examination field [57]. Use of shielding for radiation-sensitive tissues and organs in the examination field is generally not recommended [58] because of an increase in noise and beam-hardening artefacts.

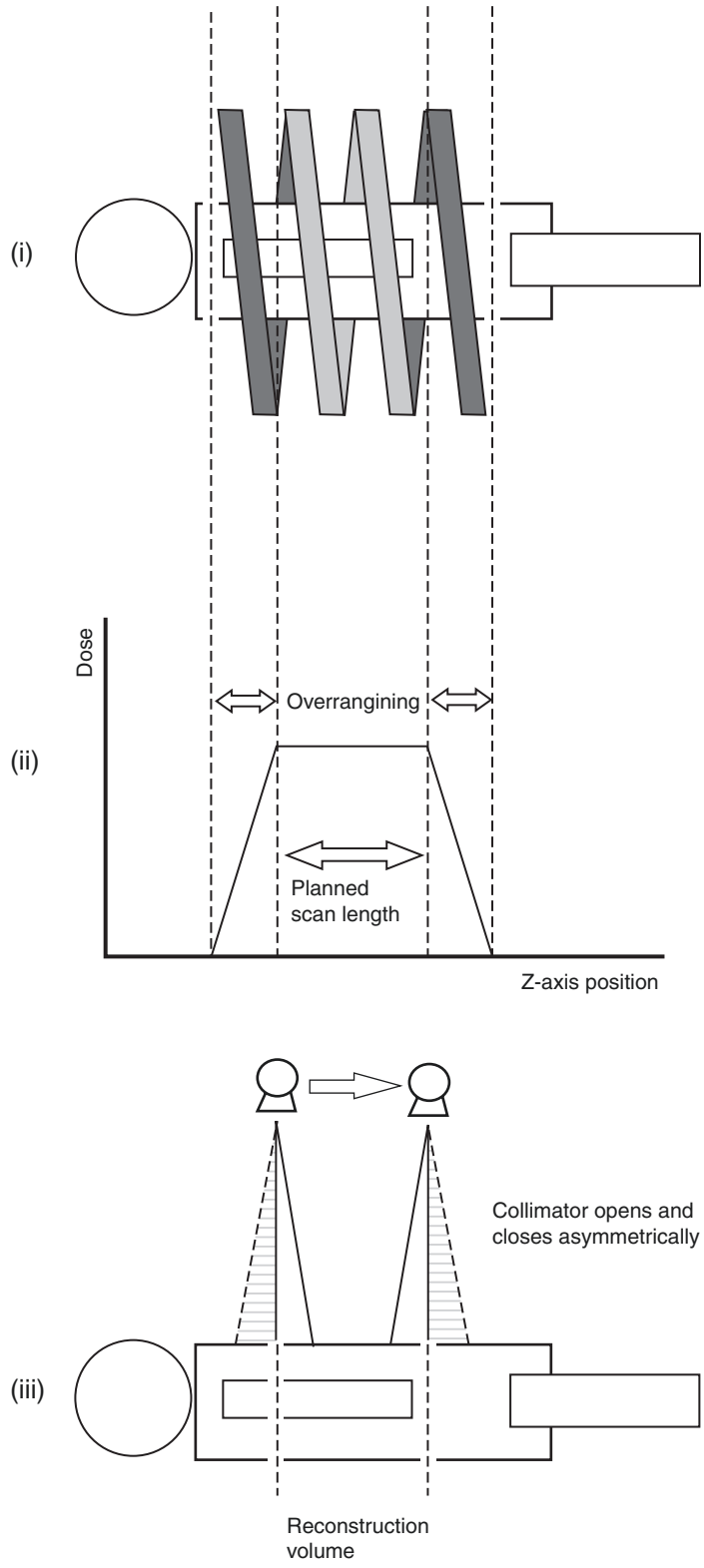

Fig. 6.2 (**i**), (**ii**) Over-ranging— the deposition of dose outside of the planned scan length. (**iii**) Active collimation to block parts of the beam that are not used for image reconstruction at the beginning and end of each spiral scan

6.4.9 Pitch

In single slice CT scanning, pitch is defined as the patient couch movement per rotation divided by the slice thickness. In multislice CT, this definition is altered slightly to patient couch movement per rotation divided by the beam width [59]. A pitch of less than 1, i.e. small couch increments, yields an improved spatial resolution along the *Z*-axis (along the length of the patient), but also results in higher patient doses because of overscanning (like in Fig. 6.3(i)). For pitches >1 patient dose is less, but data must be interpolated to preserve spatial resolution along the *Z*-axis (like in Fig. 6.3(ii)) [60]. By increasing the pitch, with a fixed scan length and mA, the radiation dose is reduced. The detectability of small lesions may be reduced due to a lower dose and an increase in image noise.

6.4.10 Slice Thickness

Thinner slices mean an increase in noise if all the other scanning parameters remain the same. The noise is increased because the number of X-rays used to form an image is reduced in proportion to the slice thickness [60]. A decrease in slice thickness by 50% will necessitate a dose increase by a factor of 2 to fully compensate.

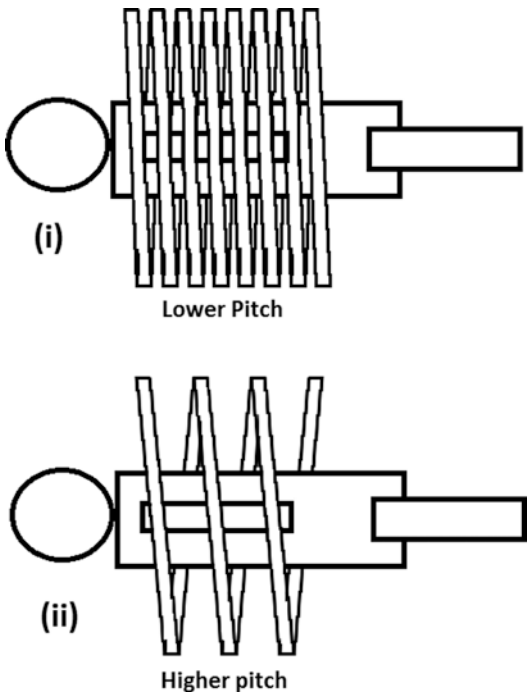

Fig. 6.3 (**i**), (**ii**) Explanation of pitch

6.4.11 Matrix Size

Choosing a larger matrix (more pixels) will increase the noise per pixel and will decrease the contrast if all other scanning parameters remain the same. Care must be taken to choose an appropriate matrix size.

6.5 Other Practical Dose Saving Approaches

The most obvious dose saving approach is to limit multiple scans and to perform only indicated CTC examinations. Another approach to reduce overall dose is to minimize the number of scan phases and limit the scan volume to the colon only [16]. Correct patient positioning is very important for the proper functioning of the automatic dose modulation and to optimise the image quality; bowtie filters work most efficiently when a patient is positioned in the gantry isocentre. If this is not the case, then the X-ray beam is not attenuated appropriately, which can lead to an increased patient dose. Additionally, because of the lower tube currents with automatic exposure control, unintentional X-ray beam attenuation can cause an unwanted increase in image noise or beam-hardening artefacts [61].

6.6 Diagnostic Reference Levels as an Optimisation Tool

Diagnostic reference levels (DRLs) are dose levels for typical examinations of groups of standard-sized patients [62]. The ICRP states in publication 105 [2] that it is inappropriate to set dose limits or dose constraints for patient exposures because the medical condition is more significant than the potential for radiation harm arising from any justified exposure. Dose management is implicit in

dose optimisation, and the patient doses can only be managed if the magnitude and range of doses encountered for a study are known. Diagnostic reference levels (DRLs) can then be set using this data and local practice can be improved by comparing the institution's data with appropriate DRLs. Radiology department should set local DRLs by taking into account appropriate national or international DRLs [62].

There are ongoing efforts to tally the CT dose metrics, in particular the $CTDI_{vol}$ and dose-length product (DLP), for various studies for the purpose of comparing dose levels. In the European Union, DRLs are required by law [62]. DRLs do not represent a dose constraint for individual patients but give an indication of the boundary between good or normal and bad practice. The DRL is usually set at the 75th percentile of the distribution of doses for a particular examination. If the typical average dose for a given procedure is consistently high compared to the set DRL, this could point to the necessity for dose optimisation and adaptation of local practice [62].

A search for published data on DRLs in CTC yielded very few results. One paper [63] referenced the 2016 UK data [64], which proposed a DRL of the CTDI of 11 mGy and of the DLP of 950 mGy cm. This data was updated in 2019 [65]. The 2019 dataset contained 16,842 patients from 92 hospitals and reported a third quartile DLP of the medians of the submitted datasets of 685 mGy cm, while the CTDI was reported at 6 mGy. This is an indication that an awareness of the patient doses can result in significant dose savings.

Key Messages

- Justification means ordering the right procedure for a specific clinical indication; optimisation means obtaining the required diagnostic information with a minimum detriment to the patient, taking into account economic and societal factors.
- An increase in the use of ionising radiation in medicine has led to a higher dose awareness and thus to increased pressure to optimise the procedures to keep the doses as low as reasonably achievable, while still maintaining diagnostic quality of images.
- CT vendors have introduced many dose-saving features, like automatic tube current modulation, new detectors, filters, or iterative reconstruction algorithms. Many of the newer innovations come at a premium and will have to be specified before the purchase of a CT scanner.
- However, the CT operator still has a number of variables to adjust to try and reduce the dose while maintaining image quality. These include the tube voltage and current, the slice thickness, and the pitch.
- Multiple and repeat scans should be limited as far as possible. Proper patient positioning on the CT couch is vital and often overlooked as a dose-saving feature.
- Diagnostic reference levels (DRLs) are not a dose-limiting tool in any given patient examination. They do however provide a good indication whether the radiological practice is operating at reasonable dose levels.

6.7 Ethics in Radiology Imaging

A 2022 publication of the WHO underscores the importance of ethics in imaging in terms of justification, optimisation and dose limitation in medical imaging [66]. The WHO also issued six guiding principles with respect to the design and use of AI in health [67] (the principles of AI are discussed in Chap. 25). These aspects with respect to dose optimisation should be considered in CTC clinical audits. The principles of the latter are presented in Chap. 27.

6.8 Conclusion

In response to the awareness of an increased population radiation burden, campaigns such as Image Gently (the alliance for radiation safety in paediatric imaging) and Image Wisely (radiation safety in adult medical imaging) were started. Their goal is to raise awareness of the opportunities to lower radiation dose in the imaging of children and adults, respectively, by providing information and free educational materials. Any imaging procedure that uses ionising radiation

should be justified, and once it has been justified it should be optimised.

Optimised protocols are essential in any dose reduction programme. It does not matter how sophisticated the dose reduction hardware and software is if it is not fully utilised. Dose reduction techniques often remain underused, but CTC is an imaging examination that can tolerate a relatively high level of noise compared to most other abdominal CT protocols. This allows for aggressive attempts at dose optimisation while preserving the diagnostic image quality. In addition, it is essential to promote and facilitate the implementation of a quality assurance programme, which includes appropriate training, use of well-designed and maintained equipment that is in proper operating condition, suitable and optimised examination protocols, and adequate viewing conditions for image interpretation.

References

1. ICRP. The 2007 Recommendations of the international commission on radiological protection, vol. 103. Vienna: ICRP Publication; 2007.
2. ICRP. Radiological protection in medicine, vol. 105. Vienna: ICRP Publication; 2007.
3. World Health Organization. Bonn call-for-action: joint position statement by IAEA and WHO. Geneva: World Health Organization; 2013.
4. Chodick G, Ronckers CM, Shalev V, Ron E. Excess lifetime cancer mortality risk attributable to radiation exposure from computed tomography examinations in children. Isr Med Assoc J. 2007;9(8):584.
5. Shah NB, Platt SL. ALARA: is there a cause for alarm? Reducing radiation risks from computed tomography scanning in children. Curr Opin Pediatr. 2008;20(3):243–7.
6. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. N Engl J Med. 2007;357(22):2277–84.
7. Brenner DJ, Elliston CD, Hall EJ, Berdon WE. Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR. 2001;176(2):289–96.
8. Brenner DJ, Georgsson MA. Mass screening with CT colonography: should the radiation exposure be of concern? Gastroenterology. 2005;129(1):328–37.
9. National Research Council. BEIR VII phase 2 Report. Health risks from exposure to low levels of ionizing radiation. Washington, DC: The National Academies Press; 2006. p. 2.
10. Semelka RC, Armao DM, Elias J Jr, Picano E. The information imperative: is it time for an informed consent process explaining the risks of medical radiation? Radiology. 2012;262(1):15–8.
11. de González AB, Kim KP, Knudsen AB, Lansdorp-Vogelaar I, Rutter CM, Smith-Bindman R, et al. Radiation-related cancer risks from CT colonography screening: a risk-benefit analysis. AJR. 2011;196(4):816.
12. Raman SP, Johnson PT, Deshmukh S, Mahesh M, Grant KL, Fishman EK. CT dose reduction applications: available tools on the latest generation of CT scanners. J Am Coll Radiol. 2013;10(1):37–41.
13. Cohnen M, Vogt C, Beck A, Andersen K, Heinen W, vom Dahl S, et al. Feasibility of MDCT colonography in ultra-low-dose technique in the detection of colorectal lesions: comparison with high-resolution video colonoscopy. AJR. 2004;183(5):1355–9.
14. Neri E, Faggioni L, Cerri F, Turini F, Angeli S, Cini L, et al. CT colonography versus double-contrast barium enema for screening of colorectal cancer: comparison of radiation burden. Abdom Imaging. 2010;35(5):596–601.
15. Hirofuji Y, Aoyama T, Koyama S, Kawaura C, Fujii K. Evaluation of patient dose for barium enemas and CT colonography in Japan. BJR. 2009;82:219–27.
16. Chang KJ, Yee J. Dose reduction methods for CT colonography. Abdom Imaging. 2013;38(2):224–32.
17. Iannaccone R, Laghi A, Catalano C, Brink JA, Mangiapane F, Trenna S, et al. Detection of colorectal lesions: lower-dose multi-detector row helical CT colonography compared with conventional colonoscopy. Radiology. 2003;229:775–81.
18. Iannaccone R, Catalano C, Mangiapane F, Murakami T, Lamazza A, Fiori E, et al. Colorectal polyps: detection with low-dose multi-detector row helical CT colonography versus two sequential colonoscopies. Radiology. 2005;237(3):927–37.
19. van Gelder RE, Venema HW, Serlie IW, Nio CY, Determann RM, Tipker CA, et al. CT colonography at different radiation dose levels: feasibility of dose reduction. Radiology. 2002;224(1):25–33.
20. van Gelder RE, Venema HW, Florie J, Nio CY, Serlie IW, Schutter MP, et al. CT colonography: feasibility of substantial dose reduction—comparison of medium to very low doses in identical patients. Radiology. 2004;232(2):611–20.
21. Kalender WA, Wolf H, Suess C. Dose reduction in CT by anatomically adapted tube current modulation. II. Phantom measurements. Med Phys. 1999;26(11):2248–53.
22. McCollough CH, Bruesewitz MR, Kofler JM Jr. CT dose reduction and dose management tools: overview of available options. Radiographics. 2006;26(2):503–12.
23. Flohr TG, Schaller S, Stierstorfer K, Bruder H, Ohnesorge BM, Schoepf UJ. Multi-detector row CT systems and image-reconstruction techniques. Radiology. 2005;235(3):756–73.
24. Graser A, Wintersperger B, Suess C, Reiser M, Becker C. Dose reduction and image quality in MDCT colonography using tube current modulation. AJR. 2006;187(3):695–701.

25. Duan X, Wang J, Christner JA, Leng S, Grant KL, McCollough CH. Dose reduction to anterior surfaces with organ-based tube-current modulation: evaluation of performance in a phantom study. AJR. 2011;197(3):689–95.
26. Lim HK, Lee KH, Kim SY, Kim KJ, Kim B, Lee H, et al. Does the amount of tagged stool and fluid significantly affect the radiation exposure in low-dose CT colonography performed with an automatic exposure control? Eur Radiol. 2011;21(2):345–52.
27. Elojeimy S, Tipnis S, Huda W. Relationship between radiographic techniques (kilovolt and milliampere-second) and $CTDI_{vol}$. Radiat Prot Dosim. 2010;141(1):43–9.
28. Chang KJ, Caovan DB, Grand DJ, Huda W, Mayo-Smith WW. Reducing radiation dose at CT colonography: decreasing tube voltage to 100 kVp. Radiology. 2013;266(3):791–800.
29. Huda W, Scalzetti EM, Levin G. Technique factors and image quality as functions of patient weight at abdominal CT. Radiology. 2000;217(2):430–5.
30. Yu L, Li H, Fletcher JG, McCollough CH. Automatic selection of tube potential for radiation dose reduction in CT: a general strategy. Med Phys. 2010;37(1):234–43.
31. Ramirez-Giraldo J, Primak A, Grant K, Schmidt B, Fuld M. Radiation dose optimization technologies in multidetector computed tomography: a review. Med Phys. 2014;2(2):420–30.
32. Winklehner A, Goetti R, Baumueller S, Karlo C, Schmidt B, Raupach R, et al. Automated attenuation-based tube potential selection for thoraco-abdominal computed tomography angiography: improved dose effectiveness. Investig Radiol. 2011;46(12):767–73.
33. Beister M, Kolditz D, Kalender WA. Iterative reconstruction methods in X-ray CT. Phys Med. 2012;28(2):94–108.
34. Elbakri I, Fessler J. Statistical image reconstruction for polyenergetic X-ray computed tomography. IEEE Trans Med Imaging. 2002;21(2):89–99.
35. Lasio GM, Whiting BR, Williamson JF. Statistical reconstruction for X-ray computed tomography using energy-integrating detectors. PMB. 2007;52(8):2247.
36. Candès EJ, Romberg J, Tao T. Robust uncertainty principles: exact signal reconstruction from highly incomplete frequency information. IEEE Trans Inf Theory. 2006;52(2):489–509.
37. Sidky EY, Kao C-M, Pan X. Accurate image reconstruction from few-views and limited-angle data in divergent-beam CT. 2009. https://arxiv.org/abs/0904.4495.
38. Irwan R, Nakanishi S, Blum A. AIDR 3D-reduces dose and simultaneously improves image quality. Tokyo: Toshiba Medical Systems; 2014. https://www.toshiba-medical.eu/eu/wp-content/uploads/sites/2/2014/10/AIDR-3D-white-paper1.pdf
39. Pontana F, Duhamel A, Pagniez J, Flohr T, Faivre J-B, Hachulla A-L, et al. Chest computed tomography using iterative reconstruction vs filtered back projection (part 2): image quality of low-dose CT examinations in 80 patients. Eur Radiol. 2011;21(3):636–43.
40. Hara AK, Paden RG, Silva AC, Kujak JL, Lawder HJ, Pavlicek W. Iterative reconstruction technique for reducing body radiation dose at CT: feasibility study. AJR. 2009;193(3):764–71.
41. Prakash P, Kalra MK, Kambadakone AK, Pien H, Hsieh J, Blake MA, et al. Reducing abdominal CT radiation dose with adaptive statistical iterative reconstruction technique. Investig Radiol. 2010;45(4):202–10.
42. Desai G, Thabet A, Elias A, Sahani D. Comparative assessment of three image reconstruction techniques for image quality and radiation dose in patients undergoing abdominopelvic multidetector CT examinations. BJR. 2013;86(1021):20120161.
43. Flicek KT, Hara AK, Silva AC, Wu Q, Peter MB, Johnson CD. Reducing the radiation dose for CT colonography using adaptive statistical iterative reconstruction: a pilot study. AJR. 2010;195(1):126–31.
44. Zhang Z, Seeram E. The use of artificial intelligence in computed tomography image reconstruction—a literature review. J Med Imaging Radiat Sci. 2020;51:671–7. https://doi.org/10.1016/j.jmir.2020.09.001.
45. Lee T, Seeram E. The use of artificial intelligence in computed tomography image reconstruction: a systematic review. Radiology. 2020;4(2):30–8. https://doi.org/10.17140/ROJ-4-129.
46. Singh R, Wu W, Wang G, Kalra M. Artificial intelligence in image reconstruction: the change is here. Phys Med. 2020;79:113–25.
47. McCollough C, Leng S. Use of artificial intelligence in computed tomography dose optimisation. Ann ICRP. 2020;49(1):113–25. https://doi.org/10.1177/0146645320940827.
48. Missert A, Yu L, Leng S, Fletcher J, McCollough C. Synthesizing images from multiple kernels using a deep convolutional network. Med Phys. 2020;2:422–30. https://doi.org/10.1002/mp.13918.
49. Toth TL, Cesmeli E, Ikhlef A, Horiuchi T. Image quality and dose optimization using novel X-ray source filters tailored to patient size. Int Soc Opt Eng. 2005;5745:283–91.
50. Yu L, Liu X, Leng S, Kofler JM, Ramirez-Giraldo JC, Qu M, et al. Radiation dose reduction in computed tomography: techniques and future perspective. Imaging Med. 2009;1(1):65–84.
51. Nicholson R, Fetherston S. Primary radiation outside the imaged volume of a multislice helical CT scan. BJR. 2002;75(894):518–22.
52. Tzedakis A, Damilakis J, Perisinakis K, Stratakis J, Gourtsoyiannis N. The effect of z overscanning on patient effective dose from multidetector helical computed tomography examinations. Med Phys. 2005;32(6):1621–9.
53. Walker MJ, Olszewski ME, Desai MY, Halliburton SS, Flamm SD. New radiation dose saving technologies for 256-slice cardiac computed tomography angiography. Int J Cardiovasc Imaging. 2009;25(2):189–99.

54. Christner JA, Zavaletta VA, Eusemann CD, Walz-Flannigan AI, McCollough CH. Dose reduction in helical CT: dynamically adjustable *z*-axis X-ray beam collimation. AJR. 2010;194(1):W49–55.
55. Von der Haar T, Klingenbeck-Regn K, Hupke R. Improvement of CT performance by UFC detector technology. Advances in CT IV. Berlin: Springer; 1998. p. 9–15.
56. Liu Y, Leng S, Michalak GJ, Vrieze TJ, Duan X, Qu M, et al. Reducing image noise in computed tomography (CT) colonography: effect of an integrated circuit CT detector. J Comput Assist Tomogr. 2014;38(3):398–403.
57. Kalra MK, Maher MM, Toth TL, Hamberg LM, Blake MA, Shepard J-A, et al. Strategies for CT radiation dose optimization. Radiology. 2004;230(3):619–28.
58. McCollough CH, Primak AN, Braun N, Kofler J, Yu L, Christner J. Strategies for reducing radiation dose in CT. Radiol Clin N Am. 2009;47(1):27–40.
59. Hendee WR, Ritenour ER. Medical imaging physics. New York: Wiley; 2002.
60. Bushberg JT, Boone JM. The essential physics of medical imaging. Philadelphia: Lippincott Williams & Wilkins; 2011.
61. Li J, Udayasankar UK, Toth TL, Seamans J, Small WC, Kalra MK. Automatic patient centering for MDCT: effect on radiation dose. AJR. 2007;188(2):547–52.
62. Dance DR, Christofides S, Maidment ADA, McLean ID, Ng KH. Diagnostic radiology physics—a handbook for teachers and students. Vienna: IAEA; 2014.
63. Paulo G, Damilakis J, Tsapaki V, Schegerer A, Repussard J, Jaschke W, Frija G. Diagnostic reference levels based on clinical indications in computed tomography: a literature review. Insights Imaging. 2020;11:96. https://doi.org/10.1186/s13244-020-00899-y.
64. Public Health England. National Diagnostic Reference Levels (NDRLs). London: Public Health England; 2016.
65. UKHSA-RCE-1: doses from computed tomography (CT) exams in the UK: 2019 review. 2022.
66. World Health Organization. Ethics and medical radiological imaging. A policy brief for health-care providers. Geneva: World Health Organization; 2022. https://www.who.int/publications/i/item/9789240047785
67. World Health Organization. Ethics and governance of artificial intelligence for health. Geneva: World Health Organization; 2021. https://www.who.int/publications/i/item/9789240029200

7 Overview of CTC in Imaging the Colon

Rachel Baldwin-Cleland and Stephen Wilson

7.1 Introduction

Colorectal cancer (CRC) is the third most common cancer worldwide, equating to 1.9 million people diagnosed in 2020 [1], and the third leading cause of cancer-related death in the United States of America (USA) [2]. Associated risk factors for CRC are diets with high consumption of red and processed meats, alcohol consumption, lack of physical activity, large body weight [3], smoking, and diabetes [4]. Outcome and survival of CRC are related strongly to the stage at which it is diagnosed [5]. A 5-year CRC survival rate of 90 [6, 7] to 92% [8] is possible if the cancer is diagnosed early at T1 stage; however, it can drop to 10% at T4 [8].

7.2 Reasons for Referral to CTC

Patients may present to the CTC service in numerous ways. Originally, most services started as completion examinations for patients who had incomplete optical colonoscopy (OC), either for pathological reasons, such as stenosing lesions, or technical reasons such as a fixed sigmoid. These patients would have traditionally been sent for a barium enema (BE) but peer review research in 2013 concluded that CTC had a high sensitivity in pathology identification, had better patient acceptability, was more cost effective than BE and consequently CTC should replace it immediately [9]. It was therefore important to continue the development of CTC to increase its accuracy and sensitivity for detecting adenomas and lesions when compared to barium enema. BE had a reported sensitivity of 86% [9], comparable to OC at 94.7% [10], and published CRC ranges were 93% [9], 96.1 [10], to 100% [11, 12]. Meta-analysis data in 2014 showed sensitivity of 89% and specificity of 75% of CTC detecting >6 mm adenomas and cancers [13]. Later meta-analysis data show a further increase in sensitivity and specificity of CTC in detecting clinically significant pathology [14, 15]; most likely as more studies were included in the data analysis which use faecal tagging, automated insufflators, and had more experienced staff and services.

Due to CTC's higher sensitivity, better patient tolerance, and published guidance recommending CTC instead of BE, most countries have now phased out the use of the latter for the detection of CRC [16]. Therefore, patients may now present directly to a CTC service, as they would have done with direct BE referrals, with symptoms

R. Baldwin-Cleland (✉)
Intestinal Imaging Unit, London North West University Healthcare NHS Trust-St Marks Hospital, Harrow, Middlesex, UK
e-mail: r.baldwin@nhs.net

S. Wilson
Diagnostic Imaging, Peterborough City Hospital, Peterborough, UK
e-mail: stephen.wilson3@nhs.net

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such as altered bowel habit, rectal bleeding, abdominal pain, weight loss, and anaemia [17]. However, some patients may present with no visible symptoms, but have been identified as having a risk of CRC by screening methods, such as a guaiac faecal occult blood test (gFOBt) [18], once-only flexible sigmoidoscopy (bowel scope) [5], and multi-target stool DNA tests such as Cologuard [19] or faecal immunochemical tests (FIT) [20]. These bowel screening methods were developed to aid the detection of CRC and adenomatous polyps, which are the precursors of CRC, and occur without symptoms in 20–30% of the population [5].

In 2008, 17 countries had established or piloted CRC bowel screening programmes [21] none of which had CTC as a first-line screening test. Evidence from bowel screening programmes has demonstrated a decrease in the incidence of CRC-related morbidity and mortality [3, 5, 22–24]. It is therefore important for CTC to demonstrate that it has high accuracy and sensitivity not just for cancer but also for small polyps, if it is to be part of a screening pathway in asymptomatic patients, and to ensure diagnostic accuracy in symptomatic patients.

The sensitivity and specificity of CTC for >6 mm polyps have also been reported as 82.9% and 91.4%, respectively [25], and adenomas >10 mm 87.9 and 97.6%. However, there are huge variations seen across the meta-analysis data [25]: some published findings ranging from 59 to 86% for sensitivity of polyps 6–9 mm in size [26–29]. The SIGGAR study [9, 30] was a large United Kingdom (UK) multicentre randomised study that compared CTC with BE and colonoscopy, respectively. It showed that the detection rate of cancer and polyps >10 mm was significantly higher in CTC than BE [9] but lower than the gold standard for comparison of colonoscopy's 100% detection rate [30]. However, most studies have shown a link in accuracy with the experience of the reporting radiologists and the CTC technique used.

Since 2017, the development of the 'straight-to-test' (STT) 2 week wait CTC referral has also increased the burden on CTC services within the UK. Patients who are referred by general practitioners to colorectal services have a CTC prior to attending a traditional outpatient appointment with a colorectal specialist. Referrer and patient satisfaction have been positive with reduced waiting times, cost savings to the UK NHS and earlier patient testing with CRC detection rates at 4.9% and polyp detection rate at 13.5% [31].

7.3 Development of CTC

Traditionally, BE was the radiology choice for imaging the large bowel, but as demonstrated, a poor comparator to colonoscopy in its sensitivity and specificity of pathology [32]. It was thought of as physically taxing for both operator (radiologist or BE trained radiographer) as well as the patient [33]. Evidence has shown BE to be highly operator dependent [33], with a 4.4–5% technical failure rate [9, 34]. Although the rate of perforation was less than 1 in 24,000 [35], the rate of mortality for barium-related perforated peritonitis patients was 10% [35]. Therefore, the search for a less-invasive, better tolerated, quicker, and more accurate test began.

CTC was first described in the 1980s [36], though most attribute Vining et al. [37] who described it as 'interactive 3D medical imaging'. It has been known as virtual endoscopy [38], virtual colonoscopy (VC) [39], and CT pneumocolon. It is now predominantly referred to as CT colonography or CTC for short. With the help of commercial companies and academic interest, the technology for CTC continued to improve [38]. Optimisation of data acquisition and display was the focus of some original research studies, with techniques, preparation, and interpretation following suit.

Annual patient numbers of over 3000 per district hospital are now commonplace within the UK NHS as CTC tests can not only detect intracolonic pathology but in some cases can also identify incidental findings that are significant and require follow-up [39].

7.3.1 Scanner Technology

It was not until the development of faster computer processing that the technique and images that we recognise today were made possible. The development from the incremental single-slice acquisition to spiral CT, due to slip ring technology, enabled single-breath hold images to be acquired although they were still 15–20 s long [40]. However, with further CT technology development, multi-detector scanners can now scan isotropic sub-millimetres slices within seconds and then process and display them almost as fast [41]. The entire colon can now be scanned within one breath hold of under 10 s, enabling better patient cooperation and image quality compared to the single or four-slice scanners originally used [16].

The slow image processing in the early days of CTC meant that a patient was routinely scanned in a supine and prone position and then taken out of the room to wait whilst the images were reviewed by a radiologist, which could sometimes take 30 min or more to load and review. In view of this, an additional scan was still sometimes needed to optimise imaging of any poorly visualised segments. Today, faster image processing allows image review of the resultant axial scans whilst the patient is still on the CT scanning table, enabling the test to be immediately tailored to individual patients. This allows the possibility for mobile and compliant patients to have their scan completed in as little as 10 min; on average, it is however recommended a 30-min appointment slot is required for each CTC [42].

Crucially, modern scanners have the opportunity to reduce the radiation dose received by patients by up to 50% during the test [16, 43], with the use of techniques such as dose modulation and iterative reconstruction. These dose-reduction measures are described in detail in Chap. 6.

Sophisticated computer graphics software enables three-dimensional (3D) and endoluminal fly-through, computer-aided detection processing (see Sect. 7.3.2). The software includes functions such as the 'filet' or band view turning the colon into a flat plane in order to aid review of the acquired images. However, these flattening techniques may cause mucosal fold distortion, which could make more subtle polyps more difficult to visualise [44]. Software and processing features such as these were originally acquired separately to the CT scanner. They now may come as a standard feature when a CT scanner is purchased.

7.3.2 Interpretation Methods

Accurate interpretation of CTC requires additional focused training [45] and involves the use of specific dedicated CTC software [16, 17, 42, 45–47].

Data acquired can be displayed in a variety of formats, namely

- Two-dimensional (2D) axial images including multiplanar reconstructions (coronal and sagittal), where the colon is reviewed in continuity by scrolling through the images (Fig. 7.1a(i)).
- 3D endoluminal fly-through in which the software generates a centreline throughout the colon lumen, which is then followed by the reader, mimicking a colonoscopy view (Fig. 7.1a(ii)).
- Virtual dissection view; the whole colon is displayed as a bisected tube 'filet' view (Fig. 7.1a(iii)).

Images may be reviewed using either a primary 2D or primary 3D read. To date there is no consensus on which approach is preferable. However, 3D has been shown to be more sensitive for polyp detection in a cohort of screening patients [48]. It is accepted that accurate interpretation must include a combination of 2D and 3D review [16, 49, 50].

Computer-aided detection, computer-assisted detection, or computer-aided diagnosis (CAD) is a software algorithm available with most post-processing CTC software packages (Fig. 7.2). It is designed to locate possible polyps or cancers

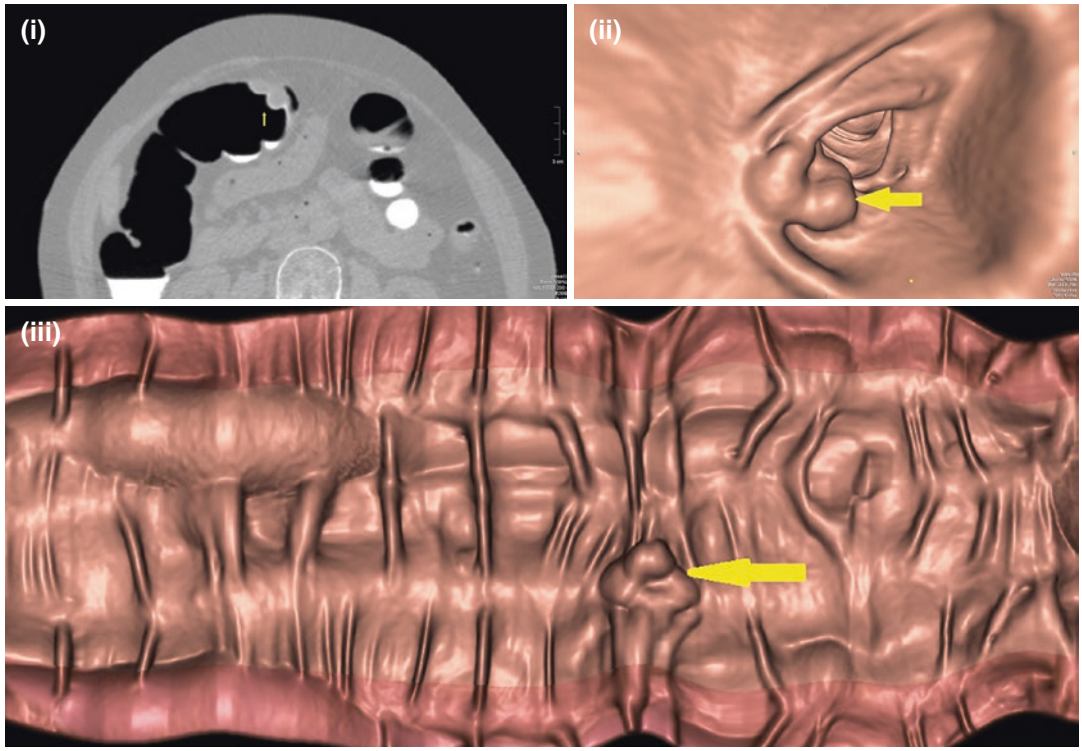

Fig. 7.1 (**i**) A supine 2D axial CTC scan visualised in a colon window, on which faecal tagging is seen as white pools of fluid. A centrally depressed 'jelly bean'-shaped cancer is demonstrated in the transverse colon (*yellow arrow*). (**ii**) The same supine CTC scan is now presented as a 3D endoluminal view. The cancer with its central depression can be seen in the middle of the picture (*yellow arrow*). The morphology or shape of the lesion can now be appreciated, compared to the axial image which shows a section through the cancer. (**iii**) The same supine CTC scan is now visualised in the filet view. The colon is 'unwrapped' and laid out. The centrally depressed cancer can be seen almost in the middle of the picture (*yellow arrow*). Its shape is more comparable to the 3D endoluminal view than the 2D image

by analysis of features such as curvature, and to mark these findings for the reader to review, in order to reduce interobserver variation and reduce interpretation time [51]. Technical developments have improved CAD over the years [51, 52]. Its performance however can be dependent on the quality of scan data obtained [53]. Regardless, it has been shown to significantly alter polyp identification in 3D review with the greatest positive effect seen in inexperienced CTC readers [54, 55]. However, poor bowel preparation can produce false-positive CAD findings, resulting in some experienced readers choosing not to use it [56].

Radiographers with comparable experience to radiologists have been shown to display similar ability to detect polyps [57, 58]. Currently in the UK, there is no established algorithm for radiographer interpretation, with most centres that have experienced reporting CTC radiographers offer-

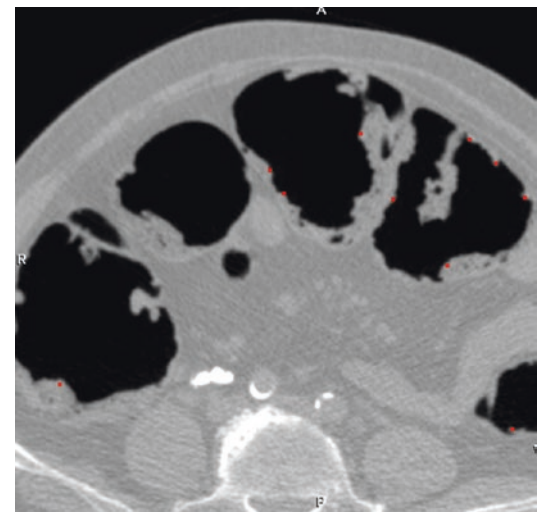

Fig. 7.2 2D axial image of a CTC performed in a poorly prepared bowel without faecal tagging. The CAD findings are shown as *red dots*. The inadequate bowel preparation resulted in a high number of CAD findings. In a well-prepared bowel, far fewer CAD findings would be expected

ing a preliminary read, with a radiologist reviewing the CTC as a second reader and providing the extracolonic report [47].

7.4 Evolution of the Technique

7.4.1 Bowel Preparation

The accuracy of CTC for the detection of small subtle lesions is diminished in an unprepared bowel. Therefore, in the early days of CTC, it was common practice to use the same cathartic bowel preparation that had previously been employed for colonoscopy or BE, for example, polyethylene glycol or sodium picosulphate (Picolax®) [59]. Whilst these generally resulted in adequate preparation, they were not always well tolerated by patients, having significant side effects and disruption to normal daily activities. They could also leave pools of low-density fluid in the colon, and this had the potential to hide pathology [41, 60]. As the cohort of patients referred to CTC are often frailer and more comorbid, a less vigorous bowel cleansing regime is preferable [61].

The aim of bowel cleansing is to balance patient acceptability with diagnostic accuracy, achieving adequate cleansing and faecal tagging [59]. There is a range of bowel preparation regimes utilised in UK institutions [56], involving varying quantities and combinations of water-soluble contrast media, barium, and laxative. One UK study demonstrated that there was a significant percentage of examinations that were deemed inadequate predominantly due to bowel preparation, crucially, the absence of faecal tagging in the cohort of patients having Picolax® alone as their preparation regime [59]. This study demonstrated that increased scan adequacy rate and positive predictive value (PPV) reporting a true and accurate finding coincided with increased use of faecal tagging. The increased PPV with the use of faecal tagging in CTC is why it is recommended across many countries [18, 42, 47, 49, 62, 63], and the UK now has strict guidance that it must be utilised when performing a CTC as part of the national bowel cancer screening programme (BCSP) [46]. The choice of tagging product is however dependent on local experience and no clear guideline on preference from ESGAR or BSGAR has been published [16, 42, 47]. CTC centres within the UK predominantly use sodium amidotrizoate 100 mg/meglumine amidotrizoate 660 mg (Gastrografin®) as both a laxative and faecal tagging agent in combination with an effective 24 h low residue diet to produce images with very low residual faecal load and dense, low viscosity residual fluid [64] see Chap. 8 for further details.

Figure 7.3a(i)–(v) shows examples of the effect tagging on reader confidence.

7.4.2 Insufflation

Good distension is essential to achieve an examination of diagnostic quality. During the development of CTC, the colon was often insufflated with room air, via a handheld air bulb and a rigid rectal tube as this was a common technique used to insufflate the colon during BE [64]. This technique meant that the operator was not aware of the total volume of air introduced or the pressure achieved within the colon. Additionally, insufflation had to be ceased during the CT scans as the operator could not remain in the scan room whilst the images were being acquired.

In 2003, E-Z-EM introduced the first insufflator (PROTOCO$_2$L®) specifically designed for CTC. A thinner latex-free, flexible rectal tube replaced the rigid tube previously utilised, and the colon was insufflated with carbon dioxide [65]. Other manufactures have also developed automated insufflators, and automated insufflation is now the recommended way to insufflate the colon [16, 47, 63]. The use of an automated pressure-controlled insufflator is described in detail in Chaps. 8, 9, and 10.

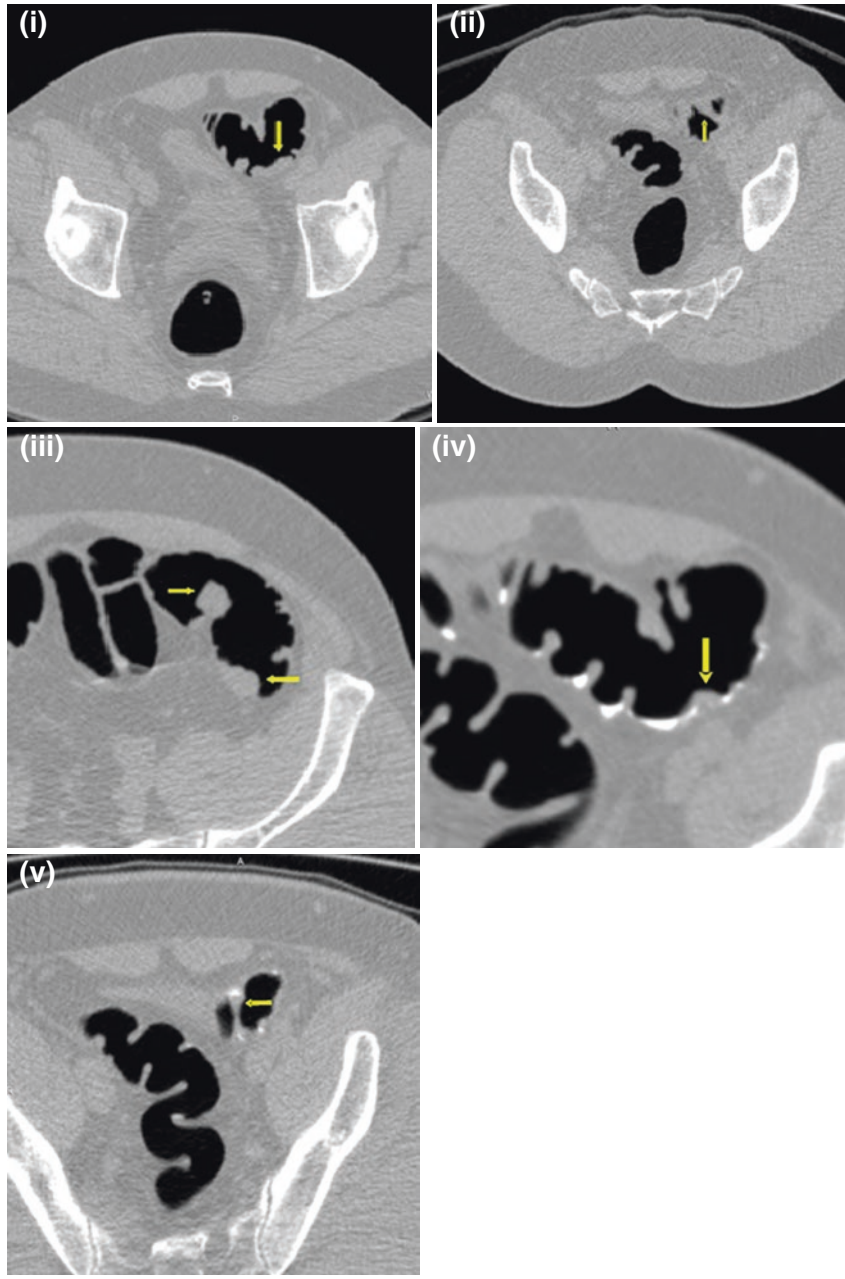

Fig. 7.3 (**i**) 2D axial supine image of a CTC performed with cathartic regime only (Picolax®). The *yellow arrow* indicates a soft tissue density within the sigmoid colon which could possibly represent a polyp or may simply be untagged residue. (**ii**) 2D axial prone image of the same colonic segment. The *yellow arrow* indicates a possible stalked polyp within the sigmoid colon, but the CTC is untagged and poorly distended in this segment. It therefore diminished the reader's confidence that this was a true polyp finding. (**iii**) A 2D axial supine image of another colonic segment in the same study. The *yellow arrows* indicate other faecal residue mimicking polyp candidates, further diminishing the confidence of the reader. (**iv**) and (**v**) supine and prone images of the repeated examination undertaken in (**i–iii**). This was performed with combination of catharsis (Picolax®) and faecal tagging (Gastrografin®). (**iv**) 2D axial supine image indicates the previously noted polyp candidate (*yellow arrow*) in the sigmoid, which is now more easily identifiable as a homogenous soft tissue polyp. Note the pools of tagged residue (white fluid around it). (**v**) 2D prone axial image of repeat examination. The 'polyp candidate' can now be confidently identified as a pedunculated polyp (*yellow arrow*). Note that in the prone position, the stalk is seen stretching across from the posterior to the anterior wall, with the head of the polyp sitting within a pool of tagging. Endoscopy confirmed the presence of a solitary pedunculated polyp

7.5 Limitations of CTC

In 2003, the American College of Radiology [66] commented that there was a lack of standards for CTC training, technical performance, interpretation methods, and the management of extracolonic findings (ECFs). This document also highlighted that CTC had further limitations.

- Polyps cannot be removed during the CTC.
- Polyps could be misinterpreted or missed.
- Image quality degradation by metal-streaking artefacts such as hip prostheses which may reduce reader accuracy of the sigmoid and rectum located in the pelvis.

The American College of Radiology [66] also commented that the cost of CTC may be higher than a conventional colonoscopy, comprising the cost of bowel preparation, the test itself (CT scanner time, staffing) and interpretation and the possible cost of any follow-up tests or imaging, for example, subsequent endoscopy or further evaluation of clinically relevant ECFs or due to the work-up of indeterminate incidental extracolonic findings. More recent literature [67] showed that CTC is 29% less expensive than OC in the American Medicare population. The complexity of the CTC test will affect the cost in comparison to a BE. In the UK, there is currently no national specific tariff, and the price of the CTC is often locally negotiated [42]. America now recognises CTC as part of the screening algorithm [18, 24] with reimbursement being subject to insurance company tariffs.

Metal artefacts can now be reduced by products such as MAR (Smart Metal Artefact Reduction—GE®) [68] and O-MAR (Metal Artefact Reduction for Orthopaedic Implants—Philips®) [69] by using projection-based and iterative methods to reduce streak artefacts, beam hardening, edge artefacts, and photon starvation [68, 69]. Figure 7.4a(i) and (ii) demonstrates the effect of using metal artefact reduction software.

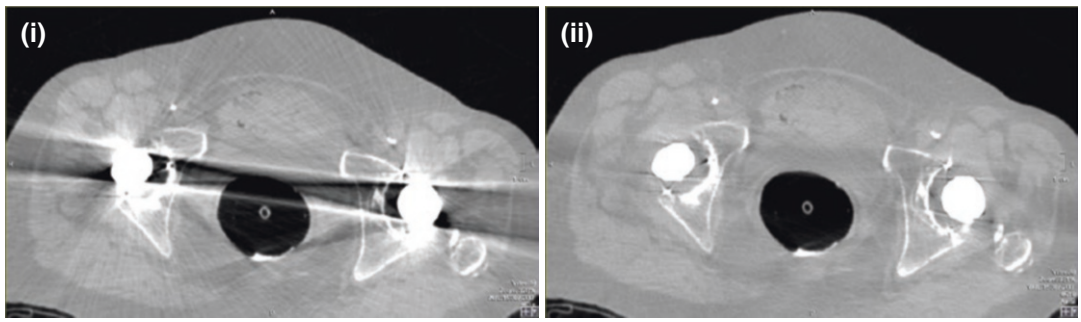

Fig. 7.4 (**i**) 2D axial supine image of a patient with bilateral metal hip prosthesis. (**ii**) 2D axial supine image with Philips O-MAR® applied to the original image data

7.6 Team Approach and Training

To deliver a CTC service, a team approach is vital [47]. The UK published CTC standards recommending local development of department protocols, which clearly define skills and competencies for all team members [42, 46, 47]. Appropriate training for each role is recommended for all members of the team, with effective leadership by a radiologist with substantial CTC expertise. It is best practice to maintain quality assurance of all aspects of the service such as patient experience, distension, and reporting accuracy in order to improve performance and patient outcomes [47]. This implementation has a training and workforce impact for both the team and the hospital and, therefore, a financial cost to any institution. Training alone does not ensure competency [42, 47].

Training, combined with structured competencies, can help reduce the performance gaps between different institutions [47, 70]. It has been shown that radiographers, having been provided with the appropriate training, can acquire a level of interpretation expertise that enables them to accurately evaluate the acquired images at the time of examination [57, 70–72]. The opportunity for a skilled reader to review the images at the time of scanning allows adaptation of technique to optimise distension and to adapt the patient pathway during the test (e.g., to perform a staging scan where CRC is identified) [47, 70]. This optimises efficiency and helps to ensure patients receive the best possible experience and outcome [47].

Radiographers should be provided with information and training with regard to all aspects of CTC including; patient-centred communication (see Chap. 2), patient consent (see Chap. 3), optimising distension, luminal navigation, and problem-solving, with a strong focus on the initial clinical evaluation of the images acquired. This enables radiographers to critically evaluate their images, whilst the patient is still on the scanner, and make decisions regarding additional imaging based upon that evaluation, for example, the decision to administer intravenous (IV) contrast or to perform a decubitus scan when the two initial scans are deemed inadequate. In those facilities where the responsibility for this decision-making is devolved to radiographers, it is essential that local policies and protocols are in place which support this and appropriate training and feedback is provided.

CTC courses specifically aimed at radiographer training are available in the UK [73]. These range from ‘hands-on’ courses covering the practical aspects of image acquisition to those which are more targeted at image interpretation and at a postgraduate degree level, which is a requirement of radiographer reporting in the UK. The development of the National CT Colonography Training and Accreditation Programme at the time of writing is in the early stages of national rollout after a successful pilot within London [74]. This new training is a multi-disciplinary scheme and educates and tests radiographers and radiologists in the same manner, and on the same platform [74].

7.7 Published Documentation Which Has Influenced CTC

The international collaboration by the UK, Europe, Australia, and New Zealand resulted in the CTC standards [49] published in 2010. This paved the way for the 2012 NHS national bowel cancer screening programme (BCSP) guidelines to be published in England and were updated in 2021 [46]. The European Society of Gastrointestinal and Abdominal Radiology (ESGAR) published a second consensus statement on CTC in 2013, a publication by the European Society of Gastrointestinal Endoscopy (ESGE) and ESGAR in 2014 [63], with a further publication in 2020 on CTC’s use as an imaging alternative to colonoscopy [75]. The UK Royal College of Radiologists, in conjunction with the British Society of Gastrointestinal and Abdominal Radiology (BSGAR), published their own in 2014 [42], with an update in 2021 [47]. The American Cancer Society did not recommend CTC in 2003 as a screening tool [66], but did state they would relook at CTC as additional data became available. In 2008 they included CTC, every 5 years, as an alternative CRC prevention test, and colonoscopy every 10 years [76]. Further guidance for America by the American College

of Radiology on performance parameters was published in 2014 and then updated in 2019 [17].

The outbreak of Covid-19 in 2020 altered cancer screening tests worldwide, with 86–96% reduction seen in America [77]. Due to the initial thoughts of the risk of Covid virus within stool samples, it also affected CTC services [78]. BSGAR and the Society of Radiographers (SoR) therefore researched and agreed to principles regarding CTC to help restart services and mitigate the risk to staff [79]. The following was agreed: no pre-test Covid screening was required for patients; CTC was not an aerosol generating procedure (unlike OC), but more research was required in this area; PPE should be worn when conducting a CTC examination including mandatory apron, face visor, surgical mask and gloves; no mandate on deep cleaning CT scanners between patients; and service necessity should be reviewed as not to over stretch strained services [79].

Research published in America supported the lower risk to staff and patients in cancer screening by CTC during the pandemic; they did state the risk of faecal aerosolisation was unknown, but use of appropriate PPE reduces the risk of infection [77]. A single case control study has shown that the room disinfection policy was sufficient to maintain a safe working environment in the CTC scanner, but there was evidence detected of airborne dissemination of bacteria in >30% of CTC examinations compared to <10% of the CT control examinations measured [80]. Adapted and reduced CTC services continued throughout 2020 and early 2021 within the UK [81] using Red (Covid hospitals) and Green sites (Non-Covid hospitals) until vaccination services for Covid-19 increased and positive Covid-19 case numbers fell. CTC services then increased back to pre-pandemic numbers, supported by research confirming no staff had contracted Covid-19 from conducting CTC imaging [78].

7.8 CTC in the Future

The sensitivity and specificity of CTC imaging continues to improve [82]; however, some papers have shown that CTC is still thought to be inferior to OC even in advanced colorectal neoplasia [83]. Others have shown CTC pathology identification is comparable to that of colonoscopy for polyps >10 mm, close to that of colonoscopy for lesions between 5 and 9 mm [14, 84], but poor when compared to OC for lesions <5 mm [84]. Pickhardt et al. [15] meta-analysis on 34 papers, covering over 17,000 episodes, shows CTC in >65 year olds as an efficient, effective, and convenient colorectal test, particularly in >10 mm colorectal pathology. When CTC was compared to other 'non-invasive' CRC screening tests in a meta-analysis with multitarget stool DNA (mt-sDNA) testing, and faecal immunochemical testing (FIT), it was shown to have a higher detection rate (4.8%) even at 6 mm for advanced neoplasia [85].

Patient dose within CT imaging remains a concern although all CTC referrals must be medically justified and completed within the ALARA principle (as low as reasonably achievable) [86], and methods to reduce radiation dose during CTC have been published [87–89]. The ionising radiation risk and inconsistency in sensitivity and specificity results mean CTC at present has only been integrated into colorectal screening programmes as an alternative test to current algorithms and not as a primary option in Europe [46, 90].

Further developments at the time of writing is the use of artificial intelligence (AI) to reduce CT dose without the loss of image resolution [91] to find polyps [92] which could potentially increase the argument of CTC being used as a primary option for colorectal screening. Software can be taught to distinguish specific image or pathology features [91]. Research is ongoing into the use of AI features such as machine learning (trained computer algorithms performing tasks after learning from extensive data sets [91]) and deep learning (division of machine learning whereby complex problems are solved by involving artificial neural networks in concurrence with vast data sets [91]) to de-noise CTC images and increase the sensitivity of detecting polyps in ultra-low dose scans [93–95] and serrated polyps on CTC [96]. CAD has been a tool used within CTC image reporting for over 20 years [97], with new deep learning techniques showing a range of measured accuracies of 98% [98], and differentiating between premalignant and benign polyps of

69% specificity and 80% sensitivity [99]. Image interpretation could potentially shift from human interpretation to computer-based AI in the future if the ongoing research shows more stability and reproducibility. The development of AI is so profound within medical imaging and medical technology that the World Health Organisation released six guiding principles in 2021 to protect human rights and the ethics of its use [100]. The principles of AI are presented in Chap. 25.

The USA has seen a falling incidence and mortality from colorectal pathology, which is attributed to the screening work on prevention by polypectomy and early detection of CRC, alongside improved cancer treatment and reduced exposure to risk factors. They advocate regular bowel screening [6] which is supported by Canada, the UK, and Europe. The joint guidelines issued in the USA in 2021, updated from those of 2016, recommend full assessment of the colon by either OC (every 10 years) or by radiology (CTC every 5 years), as the preferred choice over the faecal tests such as gFOBt or FIT [24].

The use of CTC as a primary algorithm in CRC screening, and its use as a surveillance tool in resected CRC patients and in those who have had a polyp identified, which could not be removed via endoscopy, are already emerging practices in the USA [15, 101]. European colorectal screening services are yet to adopt these practices. Three recent European trials however concluded that CTC screening had higher participation than that for primary screening colonoscopy with only slightly lower detection rates [101–103]. CTC preparation and technique results in less burden to patients and can be performed on those that are at a higher risk [104]. Other studies have proposed CTC as a primary screening test to look for adenomas and CRC directly; they believe that in competent hands CTC has shown similar detection rates comparable to colonoscopy [18, 39, 105, 106].

Developments in CT scanning technology (dual source and spectral-based electronic fluid removal) to increase detection rates and lower patient dose, further increase the possibility of CTC becoming a primary screening tool [84, 107]. Recent studies have evaluated the diagnostic accuracy of combined CTC and dual-energy iodine map imaging for detecting colorectal masses using high-pitch dual-source CT compared to conventional OC. The findings show that when CTC is combined with dual-energy iodine mapping, residual stool can be distinguished from colonic neoplasia and results in an improved diagnostic accuracy of the CTC examination. This can be further enhanced by the use of spectral-based electronic cleansing of tagged stool as high-quality images can be produced that result in less perceived artefacts than conventional electronic cleansing. Previous studies with minimal preparation resulted in negative results, where for higher detection rates full cathartic preparation was recommended [108]. Using spectral-based electronic cleansing allows a minimally cathartic prepared CTC and could mean less burden to a patient.

The English BCSP radiologists are in favour of accreditation for CTC interpretation [56]. The BCSP quality assurance committee is looking into accreditation schemes for English BCSP practices. The PERFECTS research study in the UK [109] showed that just 1 day of dedicated CTC training, with periodic testing and feedback, could show prolonged improvement in cancer detection rates over a period of time in reporting radiologists, regardless of previous experience. Despite this data and international guidelines recommending training (in reporting and performing), there is still a diverse variation of how this training should occur in publication [110]. Recommendations for best practice interpretation training within CTC were published by Obaro et al. [111]. They recommended a considered reproducible methodology for CTC interpretation training in order to prevent missing polyps and cancers, calling for regulating bodies to support and help deliver this. The National CT Colonography Training and Accreditation Programme [74] was set up in 2020 in the UK to facilitate new learning and raise standards within CTC imaging. At the time of writing, the programme is beginning its national roll out in England after a successful

London pilot. The accreditation process would be for centres performing CTC and for individual radiographers, specialist radiology registrars, and new consultant radiologists in order to perform and report CTC. A further research study (PERFECTS-2) is planned to look at the accuracy of radiographers reporting CTCs when trained in the exact same manner and electronic platform to radiologists [74], which may have a clinical and cost benefit to sites, especially in a time when there is a shortage of CTC-trained radiologists [112].

To raise standards further, the English RCR is calling for clinical audits within CTC to be promoted; however, they are not mandatory [113]. Nonetheless BSGAR have audited English CTC services in 2022 and are due to publish their findings in 2023. Completing clinical audits and publishing the data makes individuals and services more transparent and can lead to better optimal outcomes for both patients and hospital trusts. The principles of clinical audit are discussed in Chap. 27.

Key Messages

- CTC is a more accurate test than barium enema. It has replaced barium enema as the choice for radiological imaging of the large bowel in the diagnosis of CRC.
- Sensitivity and specificity of CTC are still variable in terms of published data.
- Modern CT scanning technology has decreased the time taken for the test and has improved imaging quality by features such as metal artefact reduction packages.
- Combined 2D and 3D review on dedicated CTC software is recommended.
- Published standards and guidelines are steering CTC services towards recommended best practice.
- Training, accreditation, radiographer reporting, and the use of CTC in screening algorithms are hot topics for the future development of CTC.
- Clinical audits should be ongoing for best practice and optimal patient outcomes.
- Artificial intelligence is still a growing topic within radiology and CTC.

7.9 Summary

CTC has evolved considerably since its inception in the 1980s. Its sensitivity and specificity are higher than barium enema. Literature shows that it is still inconsistent, perhaps due to variable performance throughout the world, in its detection of colorectal cancer and polyps in comparison to colonoscopy. The variation in CTC outcomes mean, for example, that there are some challenges in the UK that need to be addressed before CTC can become a direct pathway to bowel screening algorithms. It is envisaged that the development of training and accreditation schemes, such as those planned in England, will drive and support improvements in CTC service delivery and reporting accuracy by trained and validated individuals. It is hoped that radiographers will continue to have a significant and potentially greater impact on the CTC process.

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References

1. WHO: International Agency for Research on Cancer. Cancer Today: Estimated number of new cases in 2020. 2020. https://gco.iarc.fr/today/online-analysis-table?v=2020&mode=cancer&mode_population=continents&population=900&populations=900&key=asr&sex=0&cancer=39&type=0&statistic=5&prevalence=0&population_group=0&ages_group%5B%5D=0&ages_group%5B%5D=17&group_cancer=1&include_nmsc=0&include_nmsc_other=1. Accessed 29 Nov 2022.
2. American Cancer Society. Cancer facts and figures: what are the key statistics about colorectal cancer? http://www.cancer.org/cancer/colonandrectumcancer/detailedguide/colorectal-cancer-key-statistics. Accessed 29 Nov 2022.
3. Cancer Research UK. Risks and causes of Bowel Cancer. 2021. https://www.cancerresearchuk.org/about-cancer/bowel-cancer/risks-causes. Accessed 29 Nov 2022.

4. Felsen CB, Piasecki A, Ferrante JM, Ohman-Strickland PA, Crabtree BF. Colorectal cancer screening among primary care patients: does risk affect screening behavior? J Community Health. 2011;36:605–11. https://doi.org/10.1007/s10900-010-9348-0.
5. Atkin WS, Edwards R, Kralj-Hans I, Wooldrage K, Hart AR, Northover JM, Parkin DM, Wardle J, Duffy SW, Cuzick J, UK Flexible Sigmoidoscopy Trial Investigators. Once-only flexible sigmoidoscopy screening in prevention of colorectal cancer: a multicentre randomised controlled trial. Lancet. 2010;375:1624–33. https://doi.org/10.1016/S0140-6736(10)60551-X.
6. Levin B, Lieberman DA, McFarland B, Andrews KS, Brooks D, Bond J, Dash C, Giardiello FM, Glick S, Johnson D, Johnson CD. Screening and surveillance for the early detection of colorectal cancer and adenomatous polyps, 2008: a joint guideline from the American Cancer Society, the US Multi-Society Task Force on Colorectal Cancer, and the American College of Radiology. CA Cancer J Clin. 2008;58:130–60. https://doi.org/10.1053/j.gastro.2008.02.002.
7. American Cancer Society. Colorectal cancer: early detection, diagnosis and staging topics. 2022. http://www.cancer.org/cancer/colonandrectumcancer/detailedguide/colorectal-cancer-survival-rates. Accessed 29 Nov 2022.
8. Cancer Research UK. Bowel cancer survival statistics: bowel cancer survival Statistics: Bowel Cancer survival by stage at diagnosis. 2019. http://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/bowel-cancer/survival#heading-Three. Accessed 29 Nov 2022.
9. Halligan S, Dadswell E, Wooldrage K, Wardle J, von Wagner C, Lilford R, Yao GL, Zhu S, Atkin W. Computed tomographic colonography compared with colonoscopy or barium enema for diagnosis of colorectal cancer in older symptomatic patients: two multicentre randomised trials with economic evaluation (the SIGGAR trials). Health Technol Assess (Winchester, England). 2015;19(54):1–34. https://doi.org/10.3310/hta19540.
10. Pickhardt PJ, Hassan C, Halligan S, Marmo R. Colorectal cancer: CT colonography and colonoscopy for detection—systematic review and meta-analysis. Radiology. 2011;259:393–405. https://doi.org/10.1148/radiol.11101887.
11. Hara AK, Johnson CD, Reed JE, Ahlquist DA, Nelson H, MacCarty RL, Harmsen WS, Ilstrup DM. Detection of colorectal polyps with CT colonography: initial assessment of sensitivity and specificity. Radiology. 1997;205:59–65. https://doi.org/10.1148/radiology.205.1.9314963.
12. Royster AP, Fenlon HM, Clarke PD, Nunes DP, Ferrucci JT. CT colonoscopy of colorectal neoplasms: two-dimensional and three-dimensional virtual-reality techniques with colonoscopic correlation. AJR Am J Roentgenol. 1997;169:1237–42. https://doi.org/10.2214/ajr.169.5.9353434.
13. Plumb AA, Halligan S, Pendsé DA, Taylor SA, Mallett S. Sensitivity and specificity of CT colonography for the detection of colonic neoplasia after positive faecal occult blood testing: systematic review and meta-analysis. Eur Radiol. 2014;24:1049–58. https://doi.org/10.1007/s00330-014-3106-0.
14. Bai W, Yu D, Zhu B, Yu X, Duan R, Li Y, Yu W, Hua W, Kou C. Diagnostic accuracy of computed tomography colonography in patients at high risk for colorectal cancer: a meta-analysis. Color Dis. 2020;22(11):1528–37. https://doi.org/10.1111/codi.15060.
15. Pickhardt PJ, Correale L, Delsanto S, Regge D, Hassan C. CT colonography performance for the detection of polyps and cancer in adults ≥65 years old: systematic review and meta-analysis. Am J Roentgenol. 2018;211(1):40–51. https://doi.org/10.2214/AJR.18.19515.
16. Laghi A. Computed tomography colonography in 2014: an update on technique and indications. World J Gastroenterol. 2014;20:16858–67. https://doi.org/10.3748/wjg.v20.i45.16858.
17. ACR-SAR-SCBT-MR practice parameter for the performance of computed tomography (CT) colonography in adults. 2019. https://www.acr.org/-/media/ACR/Files/Practice-Parameters/ct-colonog.pdf. Accessed 3 Nov 2022.
18. Guittet L, Bouvier V, Mariotte N, Vallee JP, Arsene D, Boutreux S, Tichet J, Launoy G. Comparison of a guaiac based and an immunochemical faecal occult blood test in screening for colorectal cancer in a general average risk population. Gut. 2007;56:210–4. https://doi.org/10.1136/gut.2006.101428.
19. Imperiale TF, Ransohoff DF, Itzkowitz SH, Levin TR, Lavin P, Lidgard GP, Ahlquist DA, Berger BM. Multitarget stool DNA testing for colorectal-cancer screening. N Engl J Med. 2014;370:1287–97. https://doi.org/10.1056/NEJMoa1311194.
20. Allison JE, Fraser CG, Halloran SP, Young GP. Population screening for colorectal cancer means getting FIT: the past, present, and future of colorectal cancer screening using the fecal immunochemical test for hemoglobin (FIT). Gut Liver. 2014;8:117–30. https://doi.org/10.5009/gnl.2014.8.2.117.
21. Benson VS, Patnick J, Davies AK, Nadel MR, Smith RA, Atkin WS. Colorectal cancer screening: a comparison of 35 initiatives in 17 countries. Int J Cancer. 2008;122:1357–67. https://doi.org/10.1002/ijc.23273.
22. Sewitch MJ, Fournier C, Ciampi A, Dyachenko A. Adherence to colorectal cancer screening guidelines in Canada. BMC Gastroenterol. 2007;7:39–48. https://doi.org/10.1186/1471-230X-7-39.
23. Center MM, Jemal A, Smith RA, Ward E. Worldwide variations in colorectal cancer. CA Cancer J Clin. 2009;59:366–78. https://doi.org/10.3322/caac.20038.

24. Davidson KW, Barry MJ, Mangione CM, Cabana M, Caughey AB, Davis EM, Donahue KE, Doubeni CA, Krist AH, Kubik M, Li L. Screening for colorectal cancer: US Preventive Services Task Force recommendation statement. JAMA. 2021;325(19):1965–77. https://doi.org/10.1001/jama.2021.6238.
25. de Haan MC, van Gelder RE, Graser A, Bipat S, Stoker J. Diagnostic value of CT-colonography as compared to colonoscopy in an asymptomatic screening population: a meta-analysis. Eur Radiol. 2011;21:1747–63. https://doi.org/10.1007/s00330-011-2104-8.
26. Sosna J, Morrin MM, Kruskal JB, Lavin PT, Rosen MP, Raptopoulos V. CT colonography of colorectal polyps: a meta-analysis. AJR Am J Roentgenol. 2003;181:1593–8. https://doi.org/10.2214/ajr.181.6.1811593.
27. Mulhall BP, Veerappan GR, Jackson JL. Meta-analysis: computed tomographic colonography. Ann Intern Med. 2005;142:635–50. https://doi.org/10.7326/0003-4819-142-8-200504190-00013.
28. Halligan S, Altman DG, Taylor SA, Mallett S, Deeks JJ, Bartram CI, Atkin W. CT colonography in the detection of colorectal polyps and cancer: systematic review, meta-analysis, and proposed minimum data set for study level reporting. Radiology. 2005;237:893–904. https://doi.org/10.1148/radiol.2373050176.
29. Chaparro M, Gisbert JP, Del Campo L, Cantero J, Maté J. Accuracy of computed tomographic colonography for the detection of polyps and colorectal tumors: a systematic review and meta-analysis. Digestion. 2009;80:1–17. https://doi.org/10.1159/000215387.
30. Atkin W, Dadswell E, Wooldrage K, Kralj-Hans I, von Wagner C, Edwards R, Halligan S. Computed tomographic colonography versus colonoscopy for investigation of patients with symptoms suggestive of colorectal cancer (SIGGAR): a multicentre randomised trial. Lancet. 2013;381:1194–202. https://doi.org/10.1016/S0140-6736(12)62186-2.
31. Stephenson JA, Pancholi J, Ivan CV. Straight-to-test faecal tagging CT colonography for exclusion of colon cancer in symptomatic patients under the English 2-week-wait cancer investigation pathway: a service review. Clin Radiol. 2018;73:836.e1–7. https://doi.org/10.1016/j.crad.2018.05.013.
32. Rex DK, Rahmani EY, Haseman JH, Lemmel GT, Kaster S, Buckley JS. Relative sensitivity of colonoscopy and barium enema for detection of colorectal cancer in clinical practice. Gastroenterology. 1997;112:17–23. https://doi.org/10.1016/S0016-5085(97)70213-0.
33. Levine MS, Rubesin SE, Laufer I. Barium studies in modern radiology: do they have a role? Radiology. 2009;250:18–22. https://doi.org/10.1148/radiol.2501080806.
34. Tawn DJ, Squire CJ, Mohammed MA, Adam EJ. National audit of the sensitivity of double-contrast barium enema for colorectal carcinoma, using control charts: for the royal college of radiologists clinical radiology audit sub-committee. Clin Radiol. 2005;60:558–64. https://doi.org/10.1016/j.crad.2004.09.014.
35. Blakeborough A, Sheridan MB, Chapman AH. Complications of barium enema examinations: a survey of consultant radiologists 1992–1994. Clin Radiol. 1997;52:142–8. https://doi.org/10.1016/S0009-9260(97)80108-0.
36. Coin CG, Wollett FC, Coin JT, Rowland M, Deramos RK, Dandrea R. Computerized radiology of the colon: a potential screening technique. Comput Radiol. 1987;7:215–21. https://doi.org/10.1016/0730-4862(83)90145-2.
37. Vining DJ, Gelfand DW, Bechtold RE, et al. Technical feasibility of colon imaging with helical CT and virtual reality (abstr). AJR Am J Roentgenol. 1994;162:104.
38. Vining DJ. Virtual endoscopy: is it reality? Radiology. 1996;200:30–1.
39. Pickhardt PJ, Choi JR, Hwang I, Butler JA, Puckett ML, Hildebrandt HA, Wong RK, Nugent PA, Mysliwiec PA, Schindler WR. Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. N Engl J Med. 2003;349:2191–200. https://doi.org/10.1056/NEJMoa031618.
40. Halligan S, Fenlon HM. Virtual colonoscopy. BMJ. 1999;319:1249–52. https://doi.org/10.1136/bmj.319.7219.1249.
41. Yee J, Weinstein S, Morgan T, Alore P, Aslam R. Advances in CT colonography for colorectal cancer screening and diagnosis. J Cancer. 2013;4:200–9. https://doi.org/10.7150/jca.5858.
42. British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiologists (RCR). Guidance on the use of CT colonography for suspected colorectal cancer. 2014. https://www.rcr.ac.uk/system/files/publication/field_publication_files/BFCR(14)9_COLON.pdf. Accessed 25 Nov 2022.
43. Yoon MA, Kim SH, Lee JM, Woo HS, Lee ES, Ahn SJ, Han JK. Adaptive statistical iterative reconstruction and Veo: assessment of image quality and diagnostic performance in CT colonography at various radiation doses. J Comput Assist Tomogr. 2012;36:596–601. https://doi.org/10.1097/RCT.0b013e31826092be.
44. Bortz JH. An approach for performing a successful computed tomography colonography. S Afr J Radiol. 2014;18(1):607. https://sajr.org.za/index.php/sajr/article/view/607/836
45. Heresbach D, Djabbari M, Riou F, et al. Accuracy of computed tomographic colonography in a nationwide multicentre trial, and its relation to radiologist expertise. Gut. 2011;60:658–65. https://doi.org/10.1136/gut.2010.225623.
46. The Radiology Clinical and Professional Group for the NHS Bowel Cancer Screening Programme

(BCSP). Public Health England. Bowel Cancer Screening: guidelines for CTC imaging. 2021. https://www.gov.uk/government/publications/bowel-cancer-screening-imaging-use/bowel-cancer-screening-guidelines-for-ctc-imaging. Accessed 25 Nov 2022.
47. British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiologists (RCR). Standards of practice for computed tomography colonography (CTC) Joint guidance from the British Society of Gastrointestinal and Abdominal Radiology and The Royal College of Radiologists. 2021. https://www.rcr.ac.uk/publication/standards-practice-computed-tomography-colonography-ctc-joint-guidance-british-society. Accessed 25 Nov 2022.
48. Pickhardt PJ, Lee AD, Taylor AJ, et al. Primary 2D versus primary 3D polyp detection at screening CT colonography. AJR Am J Roentgenol. 2007;189:1451–6. https://doi.org/10.2214/AJR.07.2291.
49. Burling D. International collaboration for CT colonography standards. Clin Radiol. 2010;65:474–80. https://doi.org/10.1016/j.crad.2009.12.003.
50. Neri E, Mang T, Hellstrom M, Mantarro A, Faggioni L, Bartolozzi C. How to read and report CTC. Eur J Radiol. 2013;82:1166–70. https://doi.org/10.1016/j.ejrad.2012.03.035.
51. Bielen D, Kiss G. Computer-aided detection for CT colonography: update 2007. Abdom Imaging. 2007;32:571–81. https://doi.org/10.1007/s00261-007-9293-2.
52. Yoshida H, Dachman AH. CAD techniques, challenges, and controversies in computed tomographic colonography. Abdom Imaging. 2004;30:26–41. https://doi.org/10.1007/s00261-004-0244-x.
53. Nasirudin RA, Tachibana R, Näppi JJ, Mei K, Kopp FK, Rummeny EJ, Yoshida H, Noël PB. A comparison of material decomposition techniques for dual-energy CT colonography. Proc SPIE Int Soc Opt Eng. 2015;2015:9412. https://doi.org/10.1117/12.2081982.
54. Burling D, Moore A, Marshall M, Weldon J, Gillen C, Baldwin R, Smith K, Pickhardt P, Honeyfield L, Taylor S. Virtual colonoscopy: effect of computer-assisted detection (CAD) on radiographer performance. Clin Radiol. 2008;63:549–56. https://doi.org/10.1016/j.crad.2007.11.006.
55. Helbren E, Fanshawe TR, Phillips P, Mallett S, Boone D, Gale A, Altman DG, Taylor SA, Manning D, Halligan S. The effect of computer-aided detection markers on visual search and reader performance during concurrent reading of CT colonography. Eur Radiol. 2015;25:1570–8. https://doi.org/10.1007/s00330-014-3569-z.
56. Plumb AA, Halligan S, Taylor SA, Burling D, Nickerson C, Patnick J. CT colonography in the English bowel cancer screening programme: national survey of current practice. Clin Radiol. 2013;68:479–87. https://doi.org/10.1016/j.crad.2012.10.018.
57. Jensch S, van Gelder RE, Florie J, Thomassen-de Graaf MA, Lobé JV, Bossuyt PMM, Bipat S, Nio CY, Stoker J. Performance of radiographers in the evaluation of CT colonographic image. Gastrointest Imaging. 2007;188:249–55. https://doi.org/10.2214/AJR.06.0451.
58. Lauridsen C, Lefere P, Gerke O, Hageman S, Karstoft J, Gryspeerdt S. Comparison of the diagnostic performance of CT colonography interpreted by radiologists and radiographers. Insights Imaging. 2013;4:491–7. https://doi.org/10.1007/s13244-013-0260-x.
59. Yee J, Akerkar GA, Hung RK, Steinauer-Gebauer AM, Wall SD, McQuaid KR. Colorectal neoplasia: performance characteristics of CT colonography for detection in 300 patients. Radiology. 2001;219:685–92. https://doi.org/10.1148/radiology.219.3.r01jn40685.
60. Lung P, Burling D, Kallarackel L, Muckian J, Ilangovan R, Gupta A, Marshall M, Shorvon P, Halligan S, Bhatnagar G, Bassett P, Taylor SA. Implementation of a new CT colonography service: 5 years experience. Clin Radiol. 2014;69:597–605. https://doi.org/10.1016/j.crad.2014.01.007.
61. Ristvedt SL, McFarland EG, Weinstock LB, Thyssen EP. Patient preferences for CT colonography, conventional colonoscopy, and bowel preparation. Am J Gastroenterol. 2003;98:578–85. https://doi.org/10.1016/S0002-9270(02)06024-0.
62. Park SH, Yee J, Kim SH, Kim YH. Fundamental elements for successful performance of CT colonography [virtual colonoscopy]. Korean J Radiol. 2007;8:264–75. https://doi.org/10.3348/kjr.2007.8.4.264.
63. Spada C, Stoker J, Alarcon O, Barbaro F, Bellini D, Bretthauer M, et al. Clinical indications for computed tomographic colonography: European Society of Gastrointestinal Endoscopy (ESGE) and European Society of Gastrointestinal and Abdominal Radiology (ESGAR) guideline. Eur Radiol. 2015;25:331–45. https://doi.org/10.1007/s00330-014-3435-z.
64. Wilson S, Thompson JD. Comparison of two meglumine–diatrizoate based bowel preparations for computed tomography colonography: comparison of patient symptoms and bowel preparation quality. Radiography. 2020;26(4):e290–6. https://doi.org/10.1016/j.radi.2020.04.007.
65. Yee J. CT colonography: techniques and applications. Radiol Clin N Am. 2009;47:133–45. https://doi.org/10.1016/j.rcl.2008.11.002.
66. Levin B, Brooks D, Smith RA, Stone A. Emerging technologies in screening for colorectal cancer: CT colonography, immunochemical fecal occult blood tests, and stool screening using molecular mark-

ers. CA Cancer J Clin. 2003;53:44–55. https://doi.org/10.3322/canjclin.53.1.44.
67. Pyenson B, Pickhardt PJ, Sawhney TG, Berrios M. Medicare cost of colorectal cancer screening: CT colonography vs. optical colonoscopy. Abdom Imaging. 2015;40:1–11. https://doi.org/10.1007/s00261-015-0538-1.
68. GE Healthcare—Smart Metal Artifact Reduction (AMR), Document ID: DOC1381483; JB23002XX. https://www.gehealthcare.co.uk/products/computed-tomography/radiation-therapy-planning/metal-artifact-reduction. Accessed 27 Nov 2022.
69. Philips healthcare community—Metal Artifact Reduction for Orthopedic Implants (O-MA). https://www.usa.philips.com/healthcare/product/HCNOCTN192/omar-metal-artifact-reduction-for-orthopedic-implants. Accessed 27 Nov 2022.
70. Haycock A, Burling D, Wylie P, Muckian J, Ilangovan R, Thomas-Gibson S. CT colonography training for radiographers—a formal evaluation. Clin Radiol. 2010;65:997–1004. https://doi.org/10.1016/j.crad.2010.05.009.
71. Thomsen H, Egelund M, Strozik JE, Vuust M. Radiographers are valuable contributors in interpreting computed tomography colonography. Dan Med J. 2016;63(2):A5193.
72. Rimes SJ, Knapp KM, Meertens RM, Fox DL. Computed tomography colonography: radiographer independent preliminary clinical evaluation for intraluminal pathology. Radiography. 2019;25(4):359–64. https://doi.org/10.1016/j.radi.2019.04.014.
73. GIRSIG: Available courses in the UK. https://www.girsig.org.uk/trinity/courses/. Accessed 29 Nov 2022.
74. National CTC Training and Accreditation Programme. https://www.nationalctctrainingprogramme.org/. Accessed 27 Nov 2022.
75. Spada C, Hassan C, Bellini D, Burling D, Cappello G, Carretero C, Dekker E, Eliakim R, de Haan M, Kaminski MF, Koulaouzidis A. Imaging alternatives to colonoscopy: CT colonography and colon capsule. European Society of Gastrointestinal Endoscopy (ESGE) and European Society of Gastrointestinal and Abdominal Radiology (ESGAR) guideline—update 2020. Endoscopy. 2020;52(12):1127–41. https://doi.org/10.1055/a-1258-4819.
76. Rex DK, Johnson DA, Anderson JC, Schoenfeld PS, Burke CA, Inadomi JM. American College of Gastroenterology guidelines for colorectal cancer screening 2008. Am J Gastroenterol. 2009;104:739–50. https://doi.org/10.1038/ajg.2009.104.
77. Moreno CC, Yee Y, Ahmed FS, Barish MA, Brewington C, Dachman AH, Gollup MJ, Kim DH, McFarland E, Pickhardt PJ, Reddy S, Zalis M, Chang KJ. CT colonography's role in the Covid-19 pandemic: a safe (r), socially distanced total colon examination. Abdom Radiol. 2021;46(2):486–90. https://doi.org/10.1007/s00261-020-02674-5.
78. Peprah D, Plumb A, Corr A, Muckian J, Smith K, Sergot A, Kuah JY, Stephenson J. Re-initiation of CT colonography services during the COVID-19 pandemic: preliminary evaluation of safety. Br J Radiol. 2021;94(1121):20201316. https://doi.org/10.1259/bjr.20201316.
79. Joint guidance on performing CT colonography in the early recovery phase of the Covid-19 pandemic. British Society of Gastrointestinal and Abdominal Radiology and Society of Radiographers. BSGAR and SoR. 2020. https://www.sor.org/getmedia/04cbf7b5-aa23-4a25-a259-a04a692a9375/joint_guidance_on_performing_ctcolonography_in_the_earlyrecovery-phases_of_covid.pdf_2. Accessed 27 Nov 2022.
80. Taylor A, Williams C, Brown A. A case-control study of airborne dissemination of bacteria during CT colonography. Br J Radiol. 2021;94(1127):20210607. https://doi.org/10.1259/bjr.20210607.
81. Harris MA, Adamson HK, Foster B. Computed tomography during the COVID-19 pandemic: a survey of changes to service delivery, working practices and decision-making role of radiographers. J Med Imaging Radiat Sci. 2021;52(3):363–73. https://doi.org/10.1016/j.jmir.2021.04.006.
82. McComiskey DA, Barrett B, Flemming J, McKay K, Sala E. Colorectal cancer outcomes in a large negative computed tomography colonography screening cohort. Can Assoc Radiol J. 2019;70(4):452–6. https://doi.org/10.1016/j.carj.2018.09.009.
83. Duarte RB, Bernardo WM, Sakai CM, Silva GL, Guedes HG, Kuga R, Ide E, Ishida RK, Sakai P, De Moura EG. Computed tomography colonography versus colonoscopy for the diagnosis of colorectal cancer: a systematic review and meta-analysis. Ther Clin Risk Manag. 2018;14:349–60. https://doi.org/10.2147/TCRM.S152147.
84. Chini A, Manigrasso M, Cantore G, Maione R, Milone M, Maione F, De Palma GD. Can computed tomography colonography replace optical colonoscopy in detecting colorectal lesions? State of the art. Clin Endosc. 2022;55(2):183–90. https://doi.org/10.5946/ce.2021.254.
85. Pickhardt PJ, Correale L, Hassan C. PPV and detection rate of mt-sDNA testing, FIT, and CT colonography for advanced neoplasia: a hierarchic Bayesian meta-analysis of the noninvasive colorectal screening tests. Am J Roentgenol. 2021;217(4):817–30. https://doi.org/10.2214/AJR.20.25416.
86. Yu L, Liu X, Leng S, Kofler JM, Ramirez-Giraldo JC, Qu M, Christner J, Fletcher JG, McCollough CH. Radiation dose reduction in computed tomography: techniques and future perspective. Imaging Med. 2009;1:65–84. https://doi.org/10.2217/iim.09.5.
87. Yee J, McFarland E. Extracolonic findings and radiation at CT colonography: what the referring provider needs to know. Abdom Radiol. 2018;43(3):554–65. https://doi.org/10.1007/s00261-018-1461-z.

88. Popic J, Tipuric S, Balen I, Mrzljak A. Computed tomography colonography and radiation risk: how low can we go? World J Gastrointest Endosc. 2021;13(3):72. https://doi.org/10.4253/wjge.v13.i3.72.
89. Yasuda T, Honda T, Utano K, Kato T, Togashi K, Yamaguchi S, Yasaka T. Diagnostic accuracy of ultra-low-dose CT colonography for the detection of colorectal polyps: a feasibility study. Jpn J Radiol. 2022;40(8):831–9. https://doi.org/10.1007/s11604-022-01266-.
90. Graser A, Stieber P, Nagel D, Schäfer C, Horst D, Becker CR, et al. Comparison of CT colonography, colonoscopy, sigmoidoscopy and faecal occult blood tests for the detection of advanced adenoma in an average risk population. Gut. 2009;58:241–8. https://doi.org/10.1136/gut.2008.156448.
91. McCollough CH, Leng S. Use of artificial intelligence in computed tomography dose optimisation. Ann ICRP. 2020;49(1_suppl):113–25. https://doi.org/10.1177/0146645320940820 82.
92. Hegde N, Shishir M, Shashank S, Dayananda P, Latte MV. A survey on machine learning and deep learning-based computer-aided methods for detection of polyps in CT colonography. Curr Med Imaging. 2021;17(1):3–15. https://doi.org/10.2174/2213335607999200415141427.
93. Wang H, Liang Z, Li LC, Han H, Song B, Pickhardt PJ, Barish MA, Lascarides CE. An adaptive paradigm for computer-aided detection of colonic polyps. Phys Med Biol. 2015;60(18):7207. https://doi.org/10.1088/0031-9155/60/18/7207.
94. Immonen E, Wong J, Nieminen M, Kekkonen L, Roine S, Törnroos S, Lanca L, Guan F, Metsälä E. The use of deep learning towards dose optimization in low-dose computed tomography: a scoping review. Radiography. 2022;28(1):208–14. https://doi.org/10.1016/j.radi.2021.07.010.
95. Uemura T, Näppi JJ, Ryu Y, Watari C, Kamiya T, Yoshida H. A generative flow-based model for volumetric data augmentation in 3D deep learning for computed tomographic colonography. Int J Comput Assist Radiol Surg. 2021;16(1):81–9. https://doi.org/10.1007/s11548-020-02275-z.
96. Näppi JJ, Pickhardt P, Kim DH, Yoshida H. Uncertainty quantification in 3D deep learning for detecting serrated polyps in CT colonography. SPIE. 2022;12037:186–90. https://doi.org/10.1117/12.2612637.
97. Bogoni L, Cathier P, Dundar M, Jerebko A, Lakare S, Liang J, Periaswamy S, Baker ME, Macari M. Computer-aided detection (CAD) for CT colonography: a tool to address a growing need. Br J Radiol. 2005;78(suppl_1):S57–62. https://doi.org/10.1259/bjr/25777270.
98. Wang W, Tian J, Zhang C, Luo Y, Wang X, Li J. An improved deep learning approach and its applications on colonic polyp images detection. BMC Med Imaging. 2020;20(1):1–4. https://doi.org/10.1186/s12880-020-00482-3.
99. Wesp P, Grosu S, Graser A, Maurus S, Schulz C, Knösel T, Fabritius MP, Schachtner B, Yeh BM, Cyran CC, Ricke J. Deep learning in CT colonography: differentiating premalignant from benign colorectal polyps. Eur Radiol. 2022;32(7):4749–59. https://doi.org/10.1007/s00330-021-08532-2.
100. World Health Organisation. WHO issues first global report on artificial intelligence (AI) in health and six guiding principles for its design and use. https://www.who.int/news/item/28-06-2021-who-issues-first-global-report-on-ai-in-health-and-six-guiding-principles-for-its-design-and-use. Accessed 15 Dec 2022.
101. Levine MS, Yee J. History, evolution, and current status of radiologic imaging tests for colorectal cancer screening. Radiology. 2014;273:S160–80. https://doi.org/10.1148/radiol.14140531.
102. Zhu H, Li F, Tao K, Wang J, Scurlock C, Zhang X, Xu H. Comparison of the participation rate between CT colonography and colonoscopy in screening population: a systematic review and meta-analysis of randomized controlled trials. Br J Radiol. 2020;93:20190240. https://doi.org/10.1259/bjr.20190240.
103. Sali L, Regge D. CT colonography for population screening of colorectal cancer: hints from European trials. Br J Radiol. 2016;89:20160517. https://doi.org/10.1259/bjr.20160517.
104. Kadari M, Subhan M, Saji Parel N, Krishna PV, Gupta A, Uthayaseelan K, Uthayaseelan K, Sunkara NABS. CT colonography and colorectal carcinoma: current trends and emerging developments. Cureus. 2022;14(5):e24916. https://doi.org/10.7759/cureus.24916.
105. Brenner DJ, Georgsson MA. Mass screening with CT colonography: should the radiation exposure be of concern? Gastroenterology. 2005;129:328–37. https://doi.org/10.1053/j.gastro.2005.05.021.
106. Kim DH, Pickhardt PJ, Taylor AJ, Leung WK, Winter TC, Hinshaw JL, Gopal DV, Reichelderfer M, Hsu RH, Pfau PR. CT colonography versus colonoscopy for the detection of advanced neoplasia. N Engl J Med. 2007;357:1403–12. https://doi.org/10.1056/NEJMoa070543.
107. Grosu S, Wiemker R, An C, Obmann MM, Wong E, Yee J, Yeh BM. Comparison of the performance of conventional and spectral-based tagged stool cleansing algorithms at CT colonography. Eur Radiol. 2022;32(11):7936–45. https://doi.org/10.1007/s00330-022-08831-2.
108. Trilisky I, Ward E, Dachman AH. Errors in CT colonography. Abdom Imaging. 2015;40(7):2099–111. https://doi.org/10.1007/s00261-015-0501-1.
109. Obaro AE, Plumb AA, Halligan S, Mallett S, Bassett P, McCoubrie P, Baldwin-Cleland R, Ugarte-Cano

C, Lung P, Muckian J, Ilangovan R. Colorectal cancer: performance and evaluation for CT colonography screening—a multicenter cluster-randomized controlled trial. Radiology. 2022;303(2):361–70. https://doi.org/10.1148/radiol.211456.

110. Obaro AE, McCoubrie P, Burling D, Plumb AA. Effectiveness of training in CT colonography interpretation: review of current literature. Semin Ultrasound CT MRI. 2022;43(6):430–40. https://doi.org/10.1053/j.sult.2022.06.002.
111. Obaro AE, McCoubrie P, Burling D, Plumb AA. Training in CT colonography interpretation: recommendations for best practice. Semin Ultrasound CT MRI. 2022;43(6):422–9. https://doi.org/10.1053/j.sult.2022.06.001.
112. The Royal College of Radiologists. Clinical radiology UK workforce census 2020 report. London: The Royal College of Radiologists. 2021. https://www.rcr.ac.uk/system/files/publication/field_publication_files/clinical-radiology-uk-workforce-census-2020-report.pdf. Accessed 27 Nov 2022.
113. The Royal College of Radiologists. Audit to assess adequacy of CT colonography. 2019. https://www.rcr.ac.uk/audit/audit-assess-adequacy-ct-colonography. Accessed 15 Dec 2022.

8 The Role of Contrast Media in CTC: Types, Usage, Allergic Reactions, and Patient Safety

Rachel Baldwin-Cleland and Stephen Wilson

8.1 Introduction

Although CT colonography (CTC) has been described as safer than optical colonoscopy (OC) [1, 2], it still has the potential for adverse events [2]. Departments offering CTC examinations must have appropriate training and procedure guidelines to cover events such as colonic perforation, obstruction, and vasovagal reactions. Images should be reviewed during and after the procedure for colonic perforation and staff must be fully trained in recognising the appearance of a perforation within CTC images. Patients should be observed for a period of time and ideally be provided with a beverage before they can safely leave the hospital [3].

Bowel preparation and techniques for optimising distension are covered in Chaps. 9 and 10. However, the focus of this chapter is on medications which may be used, patient comfort and safety during the CTC pathway.

R. Baldwin-Cleland (✉)
Intestinal Imaging Unit, London North West University Healthcare NHS Trust-St Marks Hospital, Harrow, Middlesex, UK
e-mail: r.baldwin@nhs.net

S. Wilson
Diagnostic Imaging, Peterborough City Hospital, Peterborough, UK
e-mail: stephen.wilson3@nhs.net

8.2 Oral Contrast Within Bowel Preparation

The use of oral contrast as a faecal tagging agent has become integral to the CTC procedure and has resulted in the increased sensitivity of the test to rival OC [4]. There remains no standardisation in preparations or protocols for CTC, and these can further differ between hospitals due to individual contracts, pharmacy availability, and clinician preferences. Research has shown that the use of sodium amidotrizoate 100 mg/meglumine amidotrizoate 660 mg (Gastrografin®) as both a laxative and faecal tagging agent combined with an effective 24 h low residue diet [5] or clear liquid diet [6] can result in highly diagnostic images. The high osmolality of Gastrografin® draws fluid into the colonic lumen and increases the density of the residual fluid [7]. Further research into this has shown using Gastrografin® in a split bolus regime (75 mL/25 mL) split 24 h prior to the test consistently gives better colonic lavage and impacts the patient less, although this study was of 100 patients with a mean age of 76 years [8]. However, with the use of Gastrografin® any remaining intraluminal fluid is of low viscosity, identifiable as 'tagged fluid' and moves easily with the movement of the patient [8]. Therefore, the use of faecal tagging is recommended by gastrointestinal imaging groups in optimising CTC outcomes [3, 9].

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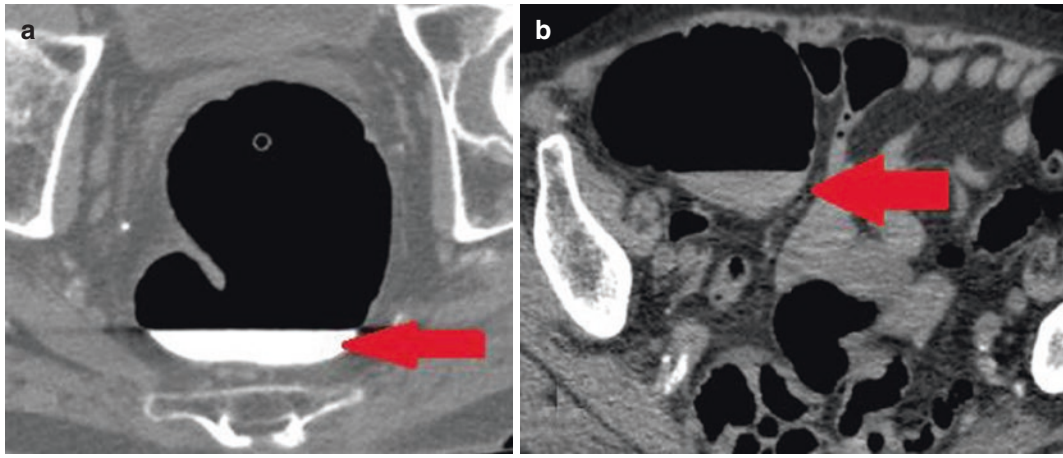

Fig. 8.1 (**a**) Residual high-density 'tagged' fluid (*red arrow*) is seen as bright white on the supine CTC image. (**b**) Untagged fluid (*red arrow*) will be seen as much darker, with an almost soft tissue density

Figure 8.1a, b shows CTC images of tagged and untagged bowel preparation.

The use of oral contrast, to provide faecal/fluid tagging, enables a reader to more easily distinguish between faecal residue and colonic pathology. This improves both positive predictive values (PPV) for small polyps and the adequacy rate of the test [5]. Most recent literature on CTC encourages faecal tagging to help improve reader confidence when reporting and reduce false-positive findings [3, 9–11]. As well as increasing the sensitivity of CTC, faecal tagging decreases the necessity of a residual dry bowel, as required in endoscopy procedures [12]. Pathology within tagged fluid can be clearly differentiated when combined with adequate distension and low faecal residue preparation as shown in Fig. 8.2a–d. An optimum residual fluid value of 900–1100 HU increases the readers confidence in discounting potential pathology (200 HU) from adhered faecal matter (900 HU) [8, 13, 14].

With regard to the choice of preparation regime, cost, image quality, reader accuracy, patient tolerance, and overall test experience must be considered. The historic use of sodium picosulfate (Dulcolax®; Boehringer Ingelheim—Germany or Picolax®; Ferring Pharmaceuticals Ltd.—UK), combined with an oral contrast agent (such as Gastrografin®) or an orally ingested intravenous (IV) contrast agent (such as Omnipaque®, Visipaque® or Niopam®), can be effective, but high sodium preparations can result in significant electrolyte imbalance and renal toxicity within the frail patient [10].

The United Kingdom (UK) NHS National Patient Safety Agency alert issued guidance in 2009 covering the use of Picolax®, Citramag®, Fleet Phospho-Soda®, Klean Prep® and Moviprep® along with their distribution prior to interventional procedures, due to one death and 218 safety incidents occurring after ingestion of these types of medications prior to a medical procedures [15]. The NHS National patient safety agency stipulates that a clinical assessment must be undertaken by the clinician referring and authorising the CTC (including general practitioners using the direct access route), which must be documented on the referral form to ensure that there is no contraindication [15]. The supply of the medicine must be authorised by a clinical professional, and each patient must receive written information (including named contact) and an explanation on the safe use of the product [15]. This is now a compulsory practice in the UK for distribution of these bowel preparation products. Gastrografin® was not listed in the alert, but it is still best practice to include it to ensure the same safety standards.

Patient bowel preparation instructions should advise patients to remain hydrated and continue consuming approximately 250 mL of non-diuretic fluids per hour whilst awake [16]. If this

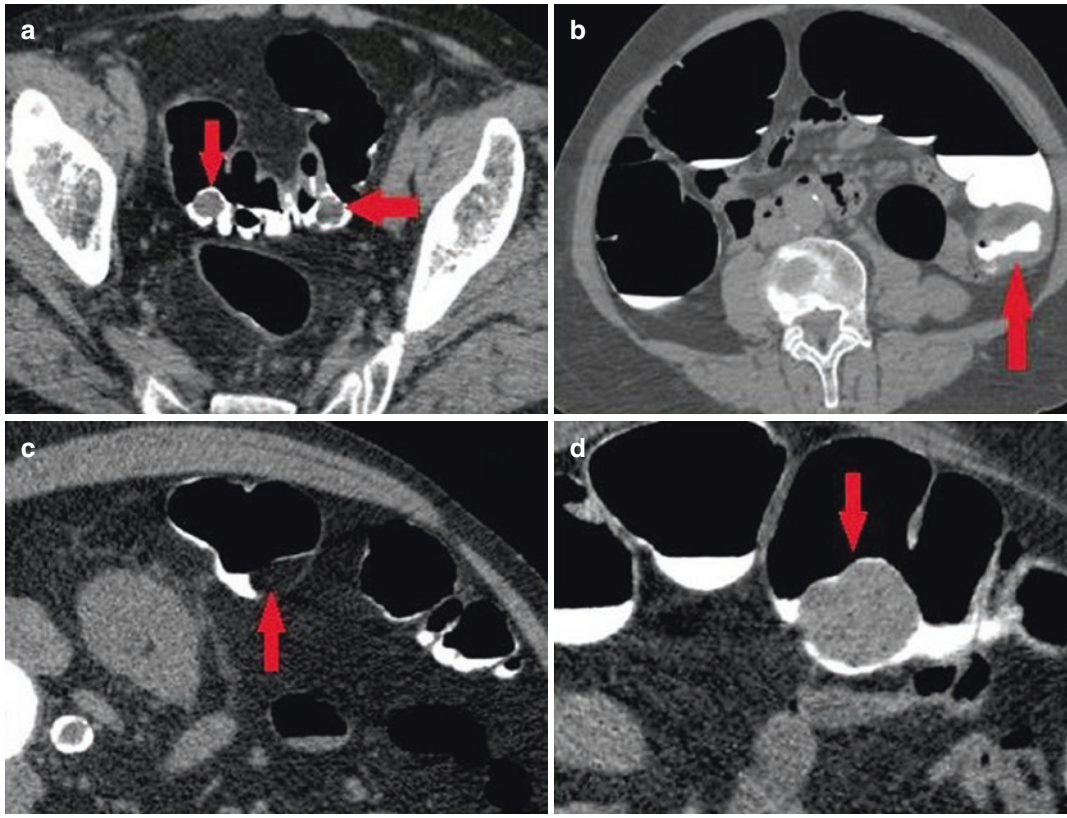

Fig. 8.2 (**a**) Supine image of a patient who was administered oral tagging as part of bowel preparation shows two polyps (*red arrows*) in the sigmoid colon surrounded by faecal tagging. (**b**) Supine image of a patient who was administered oral tagging as part of bowel preparation shows an annular carcinoma in the descending colon (*red arrow*). (**c**) Supine image of a patient who was administered oral tagging as part of bowel preparation shows a lipoma in the sigmoid colon (*red arrow*). (**d**) Supine image of a patient who was administered oral tagging as part of bowel preparation shows a very large pedunculated polyp in the transverse colon lying in a pool of tagged fluid (*red arrow*)

is not followed, there is a risk of hypokalaemia (low potassium) and requires prompt medical attention to restore the fluid/electrolyte imbalance. If left unresolved hypokalaemia can be serious in the frail and debilitated patient [16]. Previously, it was recommended that a recent eGFR (estimated glomerular filtration rate) level within the past 3 months should be obtained, and values less than 40 mL/min/1.73 m^2 should be discussed between consultant clinicians to decrease the possibility of a contrast-induced acute kidney injury (contrast nephrotoxicity/radio-contrast nephropathy) due to dehydration from the bowel preparation [17]. Newer guidelines do not recommend specific eGFR levels for patients in relation to oral intake of faecal tagging contrast media, but do recommend correction of dehydration or severe electrolyte disturbances prior to the administration of oral iodinated contrast media where possible, with electrolyte monitoring in severely ill patients or those with severe diarrhoea and/or vomiting [18]. They also recommend the same precautions should be taken as intravascular contrast use in relation to anaphylactic reactions [18].

The delivery of pharmaceuticals to patients by special delivery mail within the UK has been successful at specific institutions. However, not all institutions operate this service so the feasibility of offering a service of this nature must be discussed with individual departments. Careful packaging, tracking each individual parcel, clear medicines label with patient details, and the inclusion of the appropriate literature with the

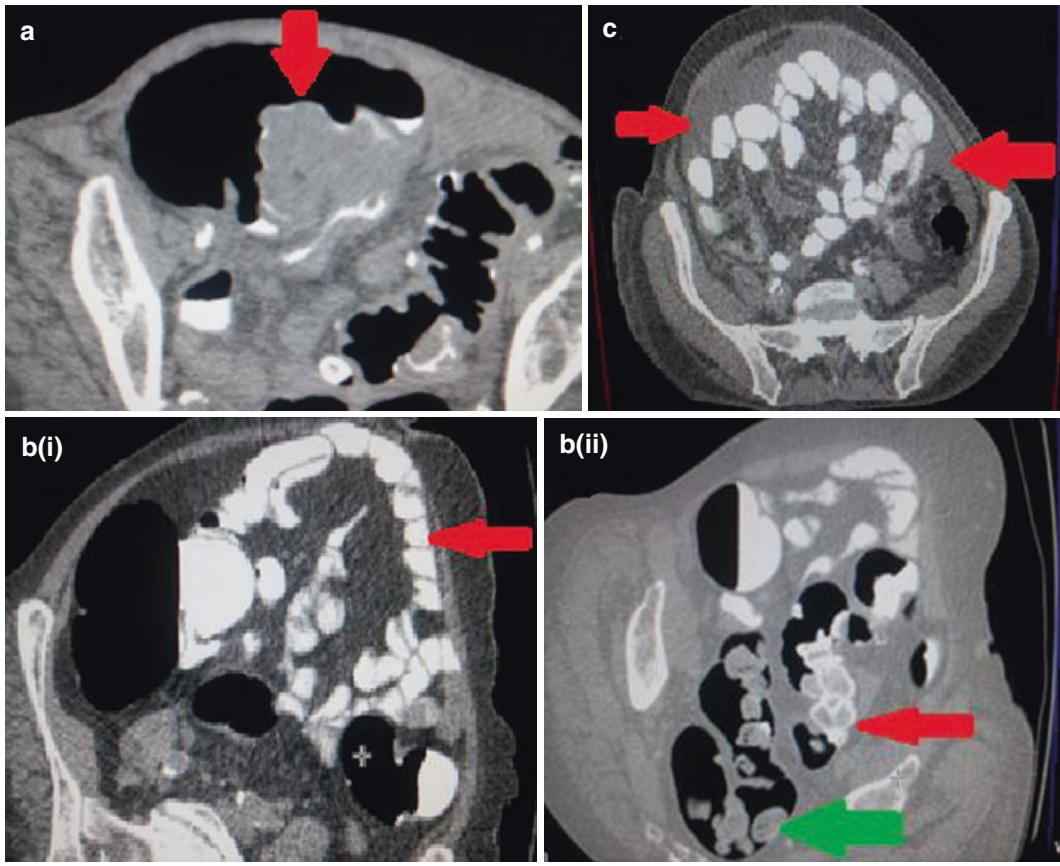

Fig. 8.3 (**a**) Patient 1: large polypoidal mass within the caecum (*red arrow*) including the ileocaecal valve. This mass is not obstructing as the small bowel and large bowel contain very little faecal matter and there is tagging seen throughout. The patient is still a priority but does not require emergency admission. Radiographers should however flag this for urgent reporting. (**b**) (**i**) and (**ii**). Patient 2: images from the same CTC. The patient is imaged in the left lateral decubitus position (*left side down*). In (**b**) (**i**), there is no obstructing mass, but the small bowel contains a large amount of contrast (*red arrow*). In (**b**) (**ii**), both tagged and untagged faecal matter can be identified in the distal sigmoid (*red arrow*) and untagged faeces (*green arrow*) can be seen in the rectum. The untagged faeces in the rectum suggest noncompliance with the preparation instructions. This, along with the small bowel tagging is consistent with either the bowel preparation being ingested later than instructed, or slow motility such as delayed gastric emptying. Such patients do not need emergency admission. (**c**) Patient 3: a large amount of tagging remains within the small bowel accompanied with ascites (*red arrows*) within the abdomen and pelvis. The patient has an obstructing mass and needs urgent surgical review and should not leave the hospital without this review

enclosed medication are essential to avoid ingestion by an individual other than the intended recipient. Figure 8.3a–c demonstrates the role of tagging in a CTC study. Staff reviewing images must be aware of the appearances of tagging contrast within the small bowel and its significance.

A patient with an iodine allergy or high sensitivity may be referred for a CTC. Historic shellfish or strawberry allergy must not be confused with a specific iodine allergy, and there remains no link between high sensitivity and iodine-based oral/IV contrast agents [17, 18]. If a patient has a documented IV contrast allergy, then an untagged CTC or a catharsis regime with barium tagging may be discussed with your clinicians depending on your department's protocols [19]. The drawback with untagged studies is residual faecal matter, which may mimic or obscure pathology, especially within areas of poor distension [12]. Some institutions routinely use barium-based tagging, but a change in diet and bowel cleansing must be used in conjunction [20]. Perforation of

barium into the abdominal cavity may have a higher mortality rate for patients than a water-soluble tagging agent (such as Omnipaque® or Gastrografin®), with a 10% mortality rate seen for patients who perforated during barium enema studies [21].

8.3 Colonic Insufflation with CO_2 and Perforation

It is recommended that low-pressure distension with CO_2 via an automated insufflator should be used for CTC colonic insufflation [3, 5, 22, 23]. The use of CO_2 automated insufflators, which have inbuilt safeguards to protect patients, also ensure better colonic distension, decreased operator dependency, result in lower patient discomfort, shorten procedure time and show quicker patient recovery post-procedure than room air and manual insufflation [2, 22, 24, 25]. Due to differences in colonic volume and the ability of some ileocecal valves to reflux CO_2, the volume of CO_2 will vary between patients.

A rare but possible side effect during CTC is that of vasovagal episodes. The patient may experience abdominal pain, blurred vision, cold sweat, and nausea leading to bradycardia and hypotension resulting in loss of consciousness [26] although one Italian study found this occurrence to be low at 0.079% [27]. This effect may be due to the distension of the colon causing pain and stretching of the mesentery and thereby stimulating the vagus nerve, which increases the outflow to the sinus node of the heart [28]. If this occurs insufflation should be stopped immediately and a detailed vasovagal procedure/policy should be followed. This may include deflating the colon by releasing the tube from the automated insufflator or using an appropriate vent function on the insufflator. Medical help should also be sought for observation of the patient (ECG and oxygen saturations). It may take the patient 30 min or more to recover from all symptoms [28]. However, it should be discussed with both the consultant radiologist and the patient to determine whether the test should be restarted/completed.

Another rare but possible complication of insufflation during CTC is colonic perforation, which is the presence of gas or luminal contents outside of the colon [29]. Figure 8.4(i–iv) shows a perforation in a patient who was referred for a CTC with abdominal pain and change in bowel habit, as she was not fit enough for a colonoscopy.

Figure 8.5 is an image of the rectum demonstrating the importance of good competent technique during a CTC and the possibility of perforating distal pathology. Figure 8.6 shows a small perforation. A large perforation is shown in Fig. 8.7. Figure 8.8(i and ii) is also an example of a large perforation. Studies in colonoscopy and barium enema patients [30–32] revealed that perforation can occur if the pressure was greater than 140 mmHg, with the left side of the colon requiring higher pressures to cause perforation than the right side of the colon. The safe upper limit for colonic pressure in humans is estimated at 80 mmHg [32] as the air contributes to the volume and expansion of the colon but has little effect on the pressure [33]. Above 80 mmHg, the pressure and radius of the colon increase as the volume of air does, resulting in increasing wall tension (Laplace's law) and the risk of colonic perforation becomes much higher [33]. The upper limit of most CO_2 automated insufflators is 30 mmHg, and it may automatically vent above 50 mmHg. You may notice when patients cough, sneeze, or move into a new position, the pressure will rise above 30 mmHg but will always settle down once they are settled. To prevent significant fluctuations in intra-colonic pressure due to colonic spasm the use of hyoscine butylbromide (Buscopan®, Boehringer Ingelheim, Germany) is recommended in patients without contraindication by the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) [3]. Colonic perforation must be looked for on the CTC by a competent trained individual, ideally prior to the patient leaving the CT scan room, but certainly before they leave the department [3, 34].

Sosna et al. [35, 36] are of the opinion that the lower recorded pressure at CTC compared to conventional non-therapeutic colonoscopy may explain why the incidence of perforation at CTC

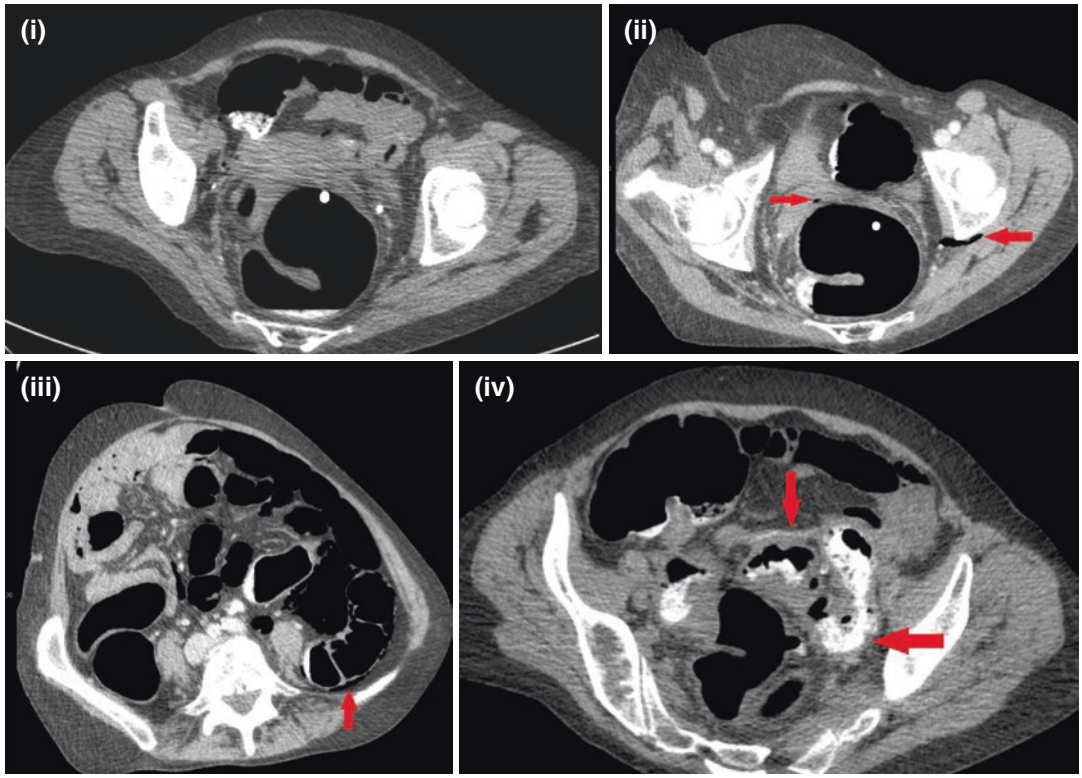

Fig. 8.4 (**i**) Supine position, during the CTC the patient experienced some abdominal pain similar to the pain with which she had been referred. (**ii**) The patient was then moved into the right lateral decubitus position. The patient felt a sudden 'release' feeling and then felt slightly better. A thin strip of air can be seen outside of the colon in the retroperitoneal area (*red arrows*). (**iii**) *Red arrow* air outside of the colon in the retroperitoneal area. (**iv**) Thickened sigmoid colon (*red arrows*), which was the likely site of perforation. The patient was monitored in hospital for 48 h and given IV antibiotics. A subsequent flexible sigmoidoscopy occurred 6 weeks later when the patient was feeling better in general. This showed a previously undiagnosed ulcerative colitis in the rectum and sigmoid colon

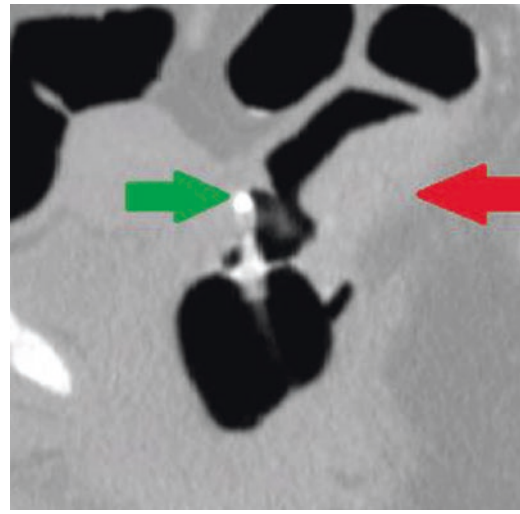

Fig. 8.5 A large rectal tumour (*red arrow*) is seen adjacent to the rectal catheter (*green arrow*). Trauma to distal pathology can be caused by the insertion of the rectal catheter. If there is resistance when placing the rectal catheter or it cannot be inserted, refer to a senior CTC radiographer or radiologist, as a change in procedure may be necessary

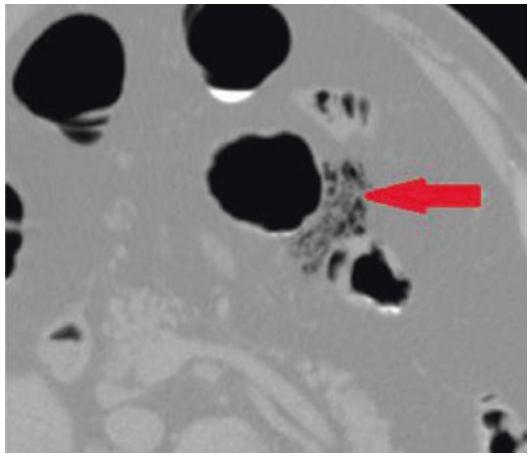

Fig. 8.6 This supine image (shown using a colon window levels) reveals a small localised perforation in the sigmoid colon (*red arrow*) which occurred during the CTC examination

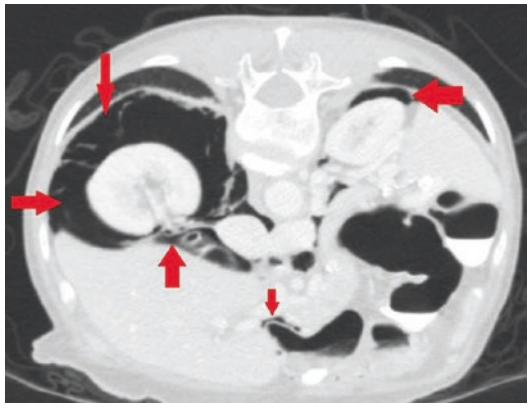

Fig. 8.7 This prone image (shown using lung window levels) reveals a perforation at CTC. A large amount of retroperitoneal gas shown behind the right kidney, but with a small amount also seen behind the left kidney (*red arrows*)

is lower. The incidence of perforation at CTC is in the range of 0.005–0.9% [29, 37] compared to diagnostic colonoscopies' rate of 0.1% [29] or 1 in 1700 in a screening population [38]. There have been no known patient deaths at CTC [22, 37]. Pickhardt's [22] review of published data on colonic perforation during CTC showed only one recorded perforation in a screening (asymptomatic) patient, with the rest involving symptomatic high-risk patients (such as active ulcerative colitis, severe diverticulosis, and active Crohn's disease), who were not suitable for or have had a previous incomplete colonoscopy. Nearly all of the CTC perforations had involved manual insufflation rather than distension with CO_2 via an automated insufflator [22]. The use of a soft, flexible rectal tube has also decreased the likelihood of colonic perforation due to rectal trauma [22] as discussed in Chaps. 9 and 10. Even so, Duxbury et al. [6] reported 9 perforations during a 6-year period in a well-trained large volume service (0.068% perforation rate—1 in 1500), but only one patient displayed symptoms at the time of perforation (0.008%—1 in 13,143 patients). The rest were picked up by the team, and all patients were managed conservatively and discharged from hospital clinically well. This data is higher than the normally quoted risk of 1 in 3000 in the UK [39].

The sensitivity of CTC to demonstrate small volumes of extracolonic gas, even in patients who are asymptomatic of perforation may mean that CTC records more perforations than recorded at colonoscopy in asymptomatic patients [22], and therefore the 1 in 1700 rate for colonoscopy might actually be an underestimation. In the case of a perforation, patients may experience severe abdominal pain during the procedure; however, this is not always the case, and they may be asymptomatic. If a perforation is identified during the test, the insufflation should be stopped immediately and the tube disconnected from the insufflator to vent the CO_2 from the patient. A pre-approved perforation policy should then be implemented and may include: (1) a member of staff remaining with the patient to provide support whilst another confirms the perforation with a consultant radiologist; (2) intravenous access being established if it is not already so; (3) reassurance to, and monitoring of, the patient; and (4) the surgical team should be contacted to review the images and determine whether the patient must be admitted. If a small localised perforation is detected then the patient may be allowed to leave the hospital. This will likely entail monitoring the patient for 24–48 h (dependent on local policies). However, management may need to be tailored to the individual patient [40] with fol-

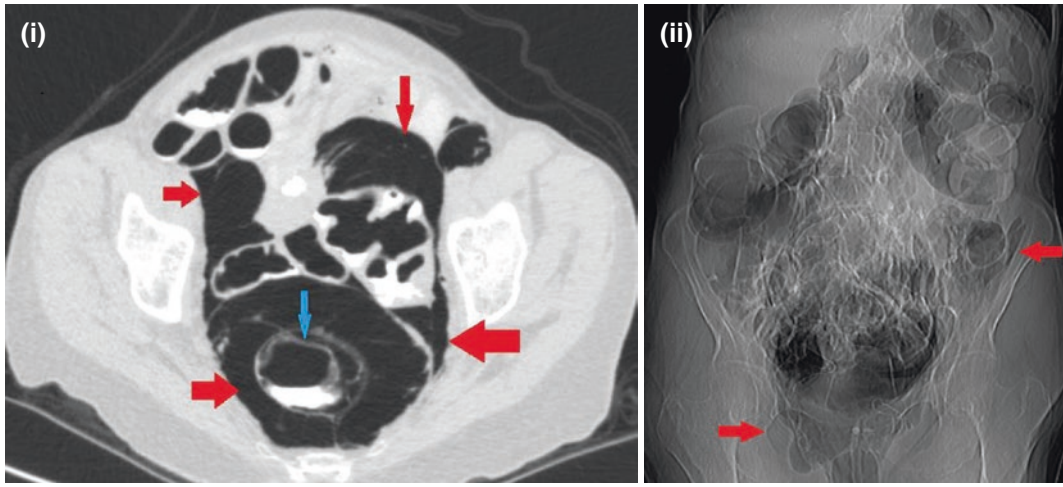

Fig. 8.8 (**i**) A supine CTC with faecal tagging. A large amount of mesorectal and retroperitoneal gas can be seen (*red arrows*) and the rectosigmoid wall can be seen clearly (*blue arrow*). (**ii**) Scout taken prior to the scan. On review, the free gas can already be seen on this image (*red arrows*)

low-up and treatment adjusted according to their clinical status.

A review by Pickhardt [22] of known CTC perforations showed that only one cancer-related CTC perforation required any surgical intervention, with the rest managed conservatively, which may include rest, dietary restrictions, and antibiotics.

During the procedure, and before a patient leaves the CT scanning room, radiographers are in an ideal position to review all images for adequate distension and colonic perforation. Radiographers therefore need to be adequately trained and deemed competent to do so. However, Burling et al. [2] showed that four out of nine patients with perforation at CTC were subtle and asymptomatic and were only discovered 4–6 h later when the study was formally reported. Therefore, verbal or written guidance should be given to CTC patients before they leave the scan room regarding symptoms of perforation (e.g., severe abdominal pain, increasingly painful abdominal discomfort, sweating and nausea or just generally very unwell) and what course of action to take should they develop these symptoms post-procedure.

To ensure safe working practice, local policies for the occurrence of perforation during or post-CTC should be developed prior to implementation of a CTC service. This will guide radiographers and radiologists in the appropriate management of patients should perforation be identified at the time of the scan, or later when reported.

8.4 Antispasmodic Drugs

Currently, the UK and Europe predominantly use hyoscine butylbromide (Buscopan®, Boehringer Ingelheim, Germany) as an antispasmolytic during imaging of the colon. However, it is not licensed in several countries including the United States of America (USA). The latter previously used Glucagon® as an alternative [41], but due to its cost and side effects, it is now rarely used [42] and is no longer recommended for use in the UK during CTC [3]. Drotaverine® has been reported as comparable to Buscopan® in Bulgaria [43]. Double-contrast barium enemas identified the benefit of the use of Glucagon®, but its use in CTC has not shown the same effect [44]. In 2001, the Joint Formulary Committee [45] found that Buscopan® was safer and cheaper than Glucagon. However, its efficacy in CTC examinations has not been conclusively proven [41]. Some research has shown it does not routinely improve distension when compared to patients with no antispas-

molytic [25] but does aid distension in patients with sigmoid diverticular disease [46]. Others have shown improved adequacy rates of CTC when Buscopan® is used [5, 6] and that significant colonic distension is better in patients who had received antispasmodics compared to those without [47]. Buscopan® works by relaxing the smooth muscle in the bowel wall, minimising peristalsis and spasm, but it does commonly have minor side effects of blurred vision and a dry mouth, which usually dissipate after 20 min. Buscopan® can therefore limit activities post-examination due to visual disturbance [45]. Thus, it should be recommended to patients to be cautious with activities such as driving until their vision has fully restored to normal. More major side effects are precipitation of urinary retention, glaucoma, angina attack, and cardiac ischaemia [45].

In the UK, a Patient Group Directive (PGD) can allow named radiographers to administer Buscopan® during CTC, enabling a more efficient workflow. The staff must have had adequate training in administration (either IV or intramuscular), know the contraindications to administration (untreated narrow angle glaucoma, myasthenia gravis, tachycardia, prostatic enlargement with urinary retention or paralytic ileus) [48] and maintain a regular audit of administration [3]. There is currently one alternative insufflator also available, which markets that it warms the CO_2 to 42.5–48.5 °C, reducing the likelihood of spasm in the colon [49], and therefore its use negates the need for antispasmodics. However, there have been no independent trials confirming this.

8.5 Intravenous Contrast

The use of intravenously administered contrast to enhance the bowel wall during CTC has been discussed since the procedure was first proposed [50]. The European consensus statement in 2013 by ESGAR [51] gave guidance to radiologists (Table 8.1) although the consensus panel did not conclusively agree on all the statements issued. In the UK, it is not usually advised to administer IV contrast to asymptomatic individuals [23] or screening programme patients (imaged within the NHS Bowel Cancer programme), unless there is a specific indication [3] or evidence (such as cancer) [3, 34] on the CTC ideally identified in the first position scanned.

Table 8.1 ESGAR statements on intravenous contrast use in CTC [51]

Intravenous (IV) contrast is not routinely required for colonic evaluation—but improves evaluation of the extracolonic organs
Oral tagging agents do not preclude the use of IV contrast
IV contrast should be administered to all patient with known colorectal cancer to facilitate staging
In symptomatic patients without known cancer, routine administration of IV contrast should be based on clinical indications or if pathology identified on unenhanced scans
If IV contrast used—administer in portal venous phase
Full-dose scan protocol to be used with IV contrast
IV contrast should be preferably administered in the supine position

Research by Morrin et al. [52] showed the use of IV contrast has no effect on the detection of small polyps but increases the ability to detect medium and large polyps. They did state that despite IV contrast being used, very flat lesions can still be missed. Yau et al. [53] believe that the use of IV contrast does not increase the detection rate of clinically significant findings within symptomatic patients. The use of IV contrast for symptomatic patients can increase the detection of incidental findings, for example, liver lesions such as cysts or haemangioma. Unfortunately, these findings often result in further clinic appointments and additional investigations such as ultrasound or magnetic resonance imaging (MRI). Lung et al. [5] released audit data of 4355 CTC examinations, of which 26% were given IV contrast and 46% of patients had extracolonic findings with 11% needing follow-up, of which only 2% had findings suggestive of extracolonic cancer. Only one patient with renal cancer who did not receive IV contrast would have benefitted from its use. Their conclusion was that IV contrast should be 'judicious, rather than routine', as its small benefit might be offset by

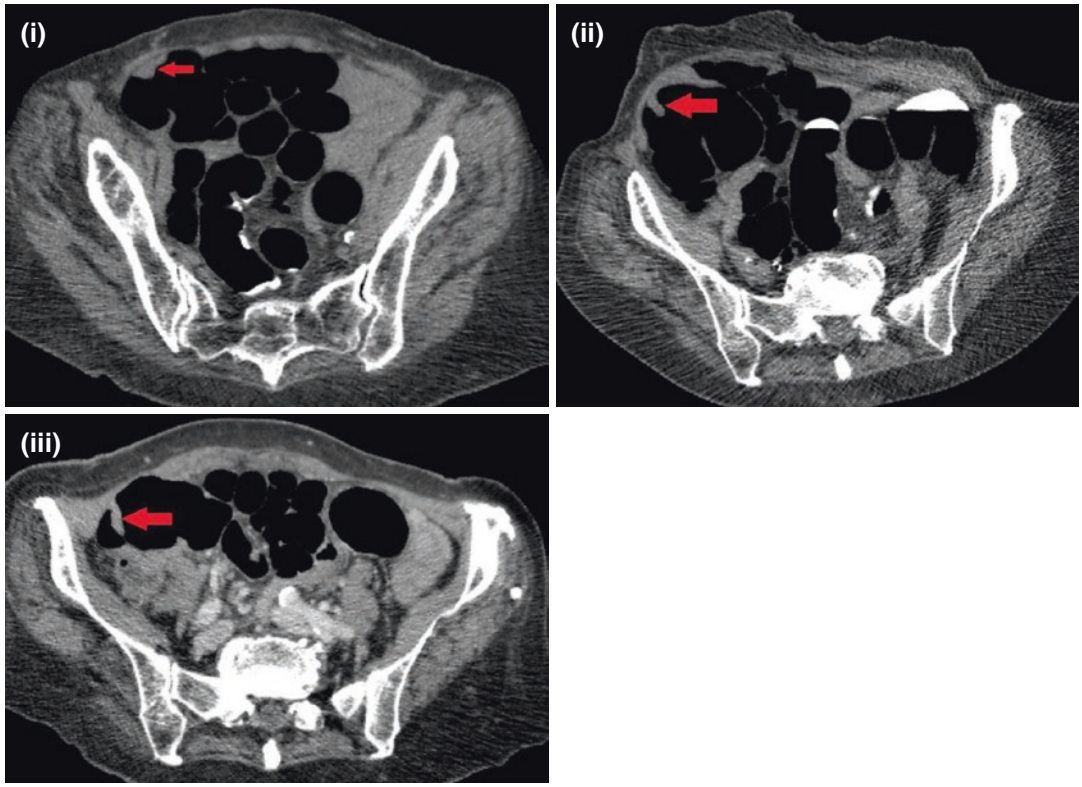

Fig. 8.9 (**i**) A supine scan was acquired. A small amount of faecal tagging can be seen in the sigmoid colon. (**ii**) On review of the prone sequence by the radiographer, the subtle thickening (*red arrow*) in the caecum opposite the ileocaecal valve raised a red flag, which was then identified on the previous supine image (**i**) (*red arrow*). (**iii**) A full-staging scan including chest was then performed in the supine position. Subsequently, the patient underwent colonoscopy which confirmed the presence of a laterally spreading tumour. Comparison of (**i**) and (**iii**) demonstrates a difference in density due to the higher mAs value used, but the tumour does not enhance with the contrast (*red arrow*)

the associated risks [5]. Gross extracolonic findings (ECFs) can be visible even without IV contrast. Subtle pathology with and without contrast may be visualised as shown in Fig. 8.9(i, ii, and iii). However, patients suspected of having colorectal cancer on CTC images should have IV contrast for staging (if the patient has an appropriate eGFR, no previous allergic reaction and no known iodine allergy) to identify invasion of pericolic fat planes and adjacent organs, and for metastases in sites such as the liver or lungs [3, 52]. Figures 8.10, 8.11, 8.12, 8.13, and 8.14(ii) demonstrate colonic and ECFs with and without IV contrast.

Nonionic IV contrast is thought to be almost completely excreted by the kidneys within 24 h of administration [54] and has been shown to

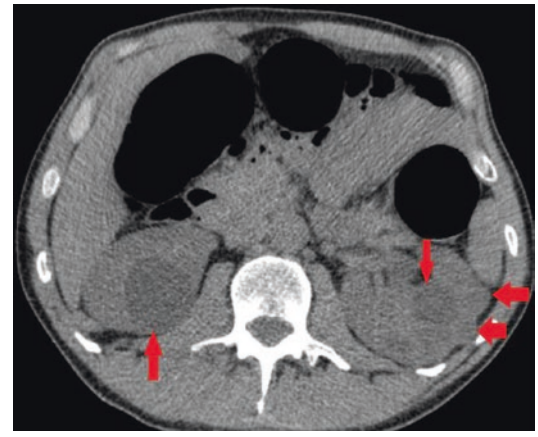

Fig. 8.10 A normal well-prepared and distended colon. Incidental finding of multiple cysts (*red arrows*) in the kidneys meant that the patient was referred for a kidney ultrasound which confirmed these to be benign cysts

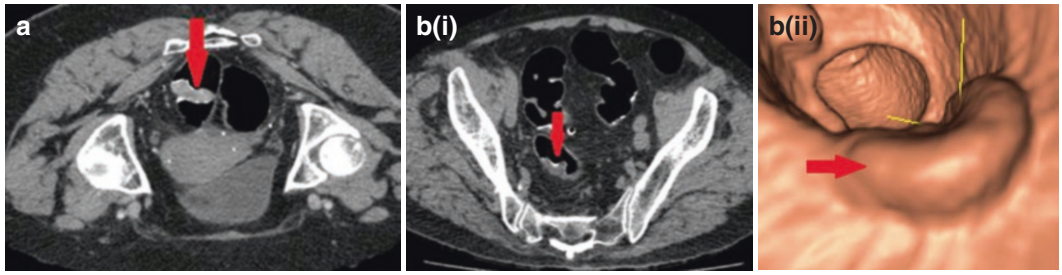

Fig. 8.11 (**a**) Prone scan. Patient #1 had faecal tagging and IV contrast. A saddle-shaped lesion with central depression can be seen in the sigmoid colon (*red arrow*). (**b**) (**i**) Supine scan. Patient #2 had faecal tagging and no IV contrast due to poor renal function. A centrally depressed lesion (*red arrow*) can also be seen in the sigmoid colon even without IV contrast. (**b**) (**ii**) Patient #2. 3D endoluminal rendering created by the CTC software. The raised edge (*red arrow*) and central depression can be seen protruding into the lumen of the colon

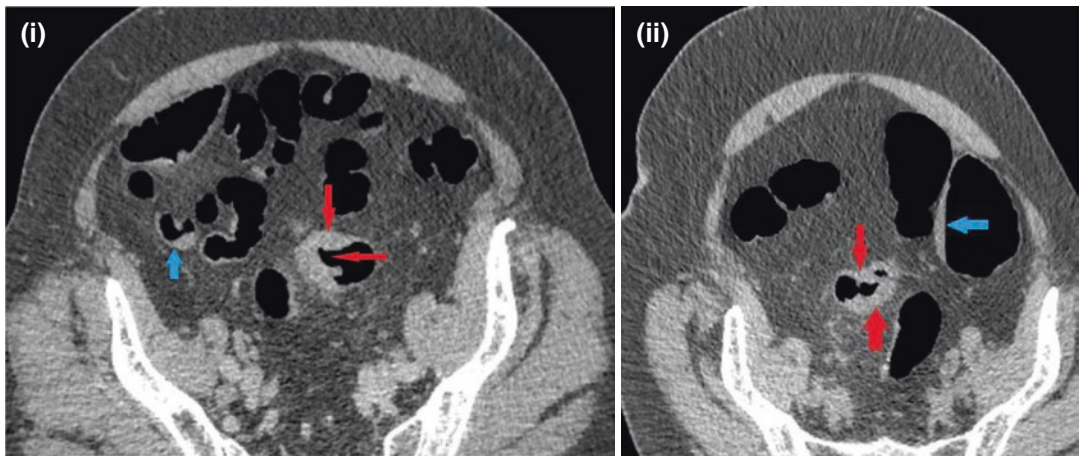

Fig. 8.12 (**i**) Supine image with IV contrast after a failed colonoscopy. A patient, with a known sigmoid cancer identified at colonoscopy which could not be passed with the scope, was sent for a staging CTC to enable visualisation of the rest of the colon. *Red arrows* show the location the endoscopist could not pass. (**ii**) Right decubitus position. The patient had been sent Gastrografin® as bowel preparation regime, but there was limited compliance with only half being taken, therefore small pools of untagged fluid can be seen in both (**i** and **ii**) (*blue arrows*). A sigmoid hemi-circumferential (semi-annular) cancer can be seen on both images (*red arrows*). Even though (**i**) is with IV contrast, there is only a small amount of vascular enhancement, and the cancer does not look dissimilar in density to (**ii**)

have a minimal effect on renal function with some diabetic patients showing a small rise in creatinine levels postinjection [55]. Adequate hydration should be advised both pre- and post-test. Manufacturers advise special consideration in the use of IV contrast in patients with pre-existing renal impairment, diabetes mellitus, Waldenström macroglobulinemia, or myelomatosis [55]. The incidence of notable i.v. contrast reactions occur in 0.5% of patients [56, 57], but some have reported 3–4% [52]. Most major reactions occur within the first 15 min of the injection, so it is advised by most manufacturers to maintain venous access and observe the patient during this time. It is best practice (though not always achievable) to advise patients to remain within the hospital afterwards for a further 30 min [18]. This is especially important if a patient is a high-risk one, such as an asthmatic, sensitive to medications or had a previous mild reaction to IV contrast and therefore may warrant premedication with corticosteroids prior to the CTC study. CT departments that make use of IV contrast should have adequate medication, equipment,

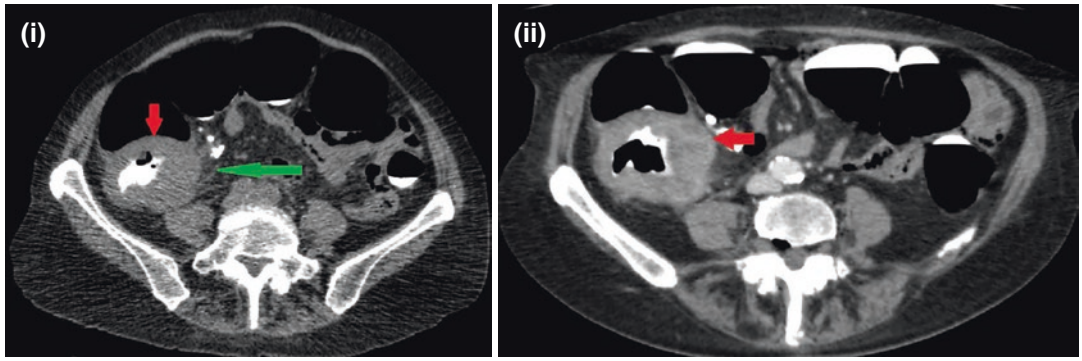

Fig. 8.13 (**i**) Supine image of a patient presented with a right-sided mass and anaemia. The patient was given Gastrografin® tagging to take at home the day before. A large circumferential mass in the caecum is shown. The cancer can be seen clearly even without IV contrast (*solid red arrow*). Pericolic fat stranding can also be seen (*green arrow*). The patient was then positioned in the prone position, the CO_2 gas was continued, IV contrast was given and an arterial chest and then portal venous phase CTC abdomen and pelvis area were taken. (**ii**) The cancer enhances (*solid red arrow*)

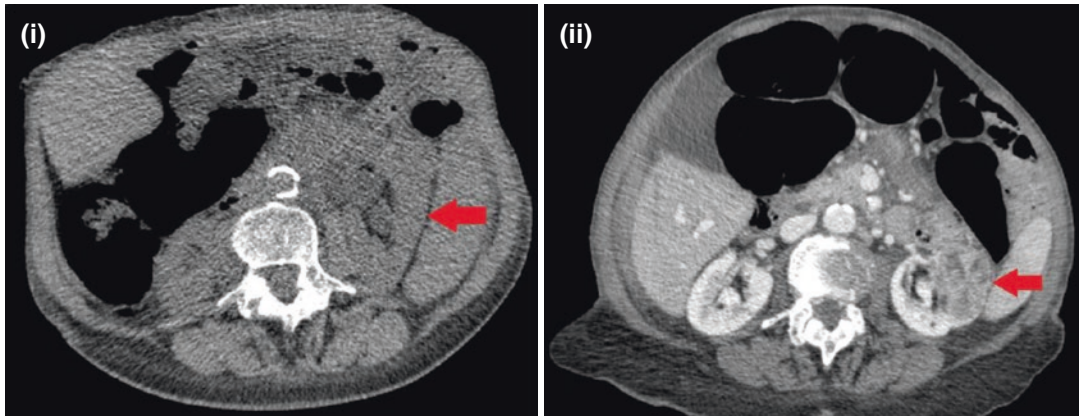

Fig. 8.14 (**i**) Patient with anaemia, weight loss, and change in bowel habit referred for a CTC. The image was acquired as a very low dose-prone sequence as the patient was to have IV contrast on second sequence due to anaemia. The left kidney (*red arrow*) looks larger than the right, but at a very low dose, the pathology is very hard to see. (**ii**) Supine image with IV contrast shows good distension in the transverse colon. The left kidney shows a renal cell carcinoma (*red arrow*) which was the likely cause for the patient's anaemia symptoms

and a protocol of what to do should a contrast reaction (mild or major) occur.

Institutions vary in the volume of IV contrast and type that should be given; therefore, it is recommended to follow your institutional policy for choice of contrast, but the abdomen must be scanned in a portal venous phase. Some studies, however, have looked at the use of arterial phased staging at CTC as a preoperative work-up to help surgically map CRC found at OC, which can then guide surgeons to the margins of relevant vessels needing to be resected [58, 59]. When deciding on the use of IV in contrast in a CTC service, the lead CTC radiologist should take into consideration the cost, the risks of contrast use and the clinical referral reason for the examination. The 2021 joint guidance for CTC standards of practice of the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiology recommends that perforation rate, and patient experience/safety should be continuous auditable outcomes [3] (see Chap. 27).

Key Messages

- Faecal tagging is proven to increase the sensitivity and specificity of the CTC examination and is recommended by many gastrointestinal imaging professional bodies such as the UK Bowel Cancer Screening Programme (BCSP), BSGAR (British Society of Gastrointestinal and Abdominal Radiology), ACR (American College of Radiology) and ESGAR (European Society of Gastrointestinal and Abdominal Radiology).
- No overall preparation has been proven to be the best. The preparation of choice must be safe to the patient, have effective bowel cleansing and faecal tagging action, be well tolerated by a high patient demographic and be cost effective to the department.
- Correct procedure and departmental protocols must be in place to meet current safety standards in bowel preparation.
- CO_2 is recommended to achieve colonic distension using an automated insufflator.
- Colonic perforation from CTC is rare but appropriate department perforation policy guidelines must be agreed and in place for a safe service.
- The use of an antispasmolytic (e.g., Buscopan) is key to obtaining optimal colonic distension and is recommended by current UK and European guidance.
- The use of intravenous contrast in CTC is not recommended in the ESGAR standards and the UK BCSP in the first instance in every type of CTC referral. It may have a role in visualising significant incidental extracolonic pathology, and the degree of metastatic disease when intracolonic pathology is identified.
- Patient experience and adverse incidents such as perforation rates should be continuous audited outcomes.

8.6 Summary

To achieve a good CTC, it is recommended to use faecal tagging, antispasmodics, and an automated insufflator. Careful prescreening by the team for allergies, renal function and mobility before administration of any contrast media or medications is essential. The type of medication, batch number, volume, and expiry dates of any oral or IV medication administered prior or during the CTC should be adequately recorded. This may be on the referral letter which is scanned into a PACS system, hospital radiology system or within the CTC report. Staff should be appropriately trained in the management of adverse reactions and perforations. Any untoward event such as an IV contrast reaction, a vasovagal attack due to the CO_2, an angina attack due to the antispasmodic or a colonic perforation should also be clearly documented. The reflective practice of a team debrief post-event will allow for junior colleagues to learn what went well, and what could be done differently the next time, and is an important part of every radiographer's continued professional development. Having appropriate policies and protocols in place before starting your CTC service will guide you in what to do in these events, should they occur.

References

1. Edwards JT, Mendelson RM, Fritschi L. Colorectal neoplasia screening with CT colonography in average-risk asymptomatic subjects: community based study. Radiology. 2004;230:459–64.
2. Burling D, Halligan S, Slater A, Noakes MJ, Taylor SA. Potentially serious adverse events at CT colonography in symptomatic patients: national survey of the United Kingdom. Radiology. 2006;239:464–71. https://doi.org/10.1148/radiol.2392051101.
3. British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiologists (RCR). Standards of practice for computed tomography colonography (CTC) Joint guidance from the British Society of Gastrointestinal and Abdominal Radiology and The Royal College of Radiologists. 2021. https://www.rcr.ac.uk/publication/standards-practice-computed-tomography-colonography-ctc-joint-guidance-british-society. Accessed 25 Nov 2022.
4. Atkin W, Dadswell E, Wooldrage K, Kralj-Hans I, von Wagner C, Edwards R, Yao G, et al. Computed tomographic colonography versus colonoscopy for investigation of patients with symptoms suggestive of colorectal cancer (SIGGAR): a multicentre randomised trial. Lancet. 2013;381:1194–202.

5. Lung P, Burling D, Kallarackel L, Muckian J, Ilangovan R, Gupta A, Marshall M, Shorvon P, Halligan S, Bhatnagar G, et al. Implementation of a new CT colonography service: 5 year experience. Clin Radiol. 2014;69:597–605.
6. Duxbury O, Burling D, Muckian J, Lung P, Obaro A, Smith K, Plumb A. Meeting the new joint British Society of Gastrointestinal and Abdominal Radiology and Royal College of Radiologists CT colonography standards: a 6-year experience. Clin Radiol. 2021;76(9):665–73.
7. Bayer plc. Gastrografin® gastroenteral solution summary of product characteristics. https://www.medicines.org.uk/emc/product/1126/smpc#:~:text=Gastrografin%20does%20not%20exert%20a,is%20absorbed%20following%20oral%20administration. Accessed 25 Nov 2022.
8. Wilson S, Thompson J. Comparison of two meglumine-diatrizoate based bowel preparations for computed tomography: comparison of patient symptoms and bowel preparation quality. Radiography. 2020;26(4):290–6.
9. ACR-SAR-SCBT-MR practice parameter for the performance of computed tomography (CT) colonography in adults. 2019. https://www.acr.org/-/media/ACR/Files/Practice-Parameters/ct-colonog.pdf. Accessed 3 Nov 2022.
10. Park SH, Yee J, Kim SH, Kim YH. Fundamental elements for successful performance of CT colonography (virtual colonoscopy). Korean J Radiol. 2007;8:264–75. https://doi.org/10.3348/kjr.2007.8.4.264.
11. Spada C, Stoker J, Alarcon O, et al. Clinical indications for computed tomographic colonography: ESGE and ESGAR guideline. Endoscopy. 2014;46:897–908. https://www.esge.com/clinical-indications-for-computed-tomographic-colonography-esge-esgar-guideline/
12. Lefere PA, Gryspeerdt SS, Dewyspelaere J, Baekelandt M, Van Holsbeeck BG. Dietary fecal tagging as a cleansing method before CT colonography: initial results polyp detection and patient acceptance. Radiology. 2002;224:393–403. https://doi.org/10.1148/radiol.2241011222.
13. Utano K, Takayanagi D, Nagata K, Aizawa M, Endo S, Nemoto T, Nemoto D, Isohata N, Lefor AK, Togashi K. A novel volume-reduced CT colonography regimen using hypertonic laxative (polyethylene glycol with ascorbic acid): randomized controlled trial. Eur Radiol. 2019;29(10):5236–46. https://doi.org/10.1007/s00330-019-06127-6.
14. Scalise P, Mantarro A, Pancrazi F, Neri E. Computed tomography colonography for the practicing radiologist: a review of current recommendations on methodology and clinical indications. World J Radiol. 2016;8(5):472–83. https://doi.org/10.4329/wjr.v8.i5.472.
15. NHS National Patient Safety Agency: Rapid Response Report NPSA/2009/RRR012: Reducing risk of harm from oral Bowel cleansing solutions. 2009. https://www.cas.mhra.gov.uk/ViewandAcknowledgment/ViewAlert.aspx?AlertID=101157. Accessed 25 Nov 2022.
16. EMC. Picolax. https://www.medicines.org.uk/emc/product/915. Accessed 25 Nov 2022.
17. The Royal College of Radiologists. Standards for intravascular contrast agent administration to adult patients. 3rd ed. London: The Royal College of Radiologists; 2015. https://www.rcr.ac.uk/search-v2?search=standards%20for%20intravascular%20contrast%20agent. Accessed 25 Nov 2022
18. The Royal Australian and New Zealand College of Radiologists®. RANZCR Iodinated Contrast Guidelines V2.3. 2018. https://www.ranzcr.com/search/ranzcr-iodinated-contrast-guidelines. Accessed 25 Nov 2022.
19. Zalis ME, Perumpillichira JJ, Magee C, Kohlberg G, Hahn PF. Tagging-based, electronically cleansed CT colonography: evaluation of patient comfort and image readability. Radiology. 2006;239:149–59.
20. Kim MJ, Park SH, Lee SS, et al. Efficacy of barium-based fecal tagging for CT colonography: a comparison between the use of high and low density barium suspensions in a Korean population—a preliminary study. Korean J Radiol. 2009;10:25–33. https://doi.org/10.3348/kjr.2009.10.1.25.
21. Blakeborough A, Sheridan MB, Chapman AH. Complications of barium enema examinations: a survey of UK Consultant Radiologists 1992–1994. Clin Radiol. 1997;52:142–8.
22. Pickhardt PJ. Incidence of colonic perforation at CT colonography: review of existing data and implications for screening of asymptomatic adults. Radiology. 2006;239:313–6.
23. Burling D. International collaboration for CT colonography standards. Clin Radiol. 2010;65:474–80. https://doi.org/10.1016/j.crad.2009.12.003.
24. Shinners TJ, Pickhardt PJ, Taylor AJ, Jones DA, Olsen CH. Patient-controlled room air insufflation versus automated carbon dioxide delivery for CT colonography. AJR. 2006;186:1491–6.
25. Nagata K, Fujiwara M, Shimamoto T, Iida N, Mogi T, Mitsushima T. Colonic distention at CT colonography: randomized evaluation of both IV hyoscine butylbromide and automated carbon dioxide insufflation. AJR. 2015;204:76–82. https://doi.org/10.2214/AJR.14.12772.
26. Fenton AM, Hammill SC, Rea RF, Low PA, Shen WK. Vasovagal syncope. Ann Intern Med. 2000;133:714–25.
27. Ciolina M, Iafrate F, Iussich G, Regge D, Iannitti M, Baldassari P, Pichi A, Correale L, Laghi A. Potential complications at CT colonography in asymptomatic and symptomatic patients: national survey of Italy. European Congress of Radiology-ECR. 2012. https://epos.myesr.org/poster/esr/ecr2012/B-0869. Accessed 25 Nov 2022.
28. Neri E, Caramella D, Vannozzi F, Turini F, Cerri F, Bartolozzi C. Vasovagal reactions in CT colonography. Abdom Imaging. 2007;32:552–5.

29. De Gonzalez AB, Kim KP, Yee J. CT colonography: perforation rates and potential radiation risks. Gastrointest Endosc Clin N Am. 2010;20:279–91. https://doi.org/10.1016/j.giec.2010.02.003.
30. Harned RK, Consigny PM, Cooper NB, Williams SM, Woltjen AJ. Barium enema examination following biopsy of the rectum or colon. Radiology. 1982;145:11–6.
31. Kozarek RA, Earnest DI, Silverstein ME, Smith RG. Air-pressure-induced colon injury during diagnostic colonoscopy. Gastroenterology. 1980;78:7–14.
32. Tzelepis GE, Nasiff L, McCooL FD, Hammond J. Transmission of pressure within the abdomen. J Appl Physiol. 1996;81:1111–4.
33. Woltjen JA. A retrospective analysis of cecal barotrauma caused by colonoscope air flow and pressure. Gastrointest Endosc. 2005;61:37–45.
34. Public Health England. The radiology clinical and professional group for the NHS bowel cancer screening programme (BCSP). Bowel cancer screening: guidelines for CTC imaging. 2021. https://www.gov.uk/government/publications/bowel-cancer-screening-imaging-use/bowel-cancer-screening-guidelines-for-ctc-imaging. Accessed 25 Nov 2022.
35. Sosna J, Blachar A, Amitai M, Barmeir E, Peled N, Goldberg SN, Bar-Ziv J. Colonic perforation at CT colonography: assessment of risk in a multicenter large cohort. Radiology. 2006;239:457–63.
36. Sosna J, Bar-Ziv J, Libson E, Eligulashvili M, Blachar A. CT colonography: positioning order and intracolonic pressure. AJR. 2008;191:175–80. https://doi.org/10.2214/AJR.07.3303.
37. Bellini D, Rengo M, De Cecco CN, Iafrate F, Hassan C, Laghi A. Perforation rate in CT colonography: a systematic review of the literature and meta-analysis. Eur Radiol. 2014;24:1487–96. https://doi.org/10.1007/s00330-014-3190-1.
38. NHS Bowel Cancer Screening Programme (BCSP). Bowel cancer screening: having a colonoscopy. 2021. https://www.gov.uk/government/publications/bowel-cancer-screening-colonoscopy/bowel-cancer-screening-having-a-colonoscopy-fit. Accessed 25 Nov 2022.
39. NHS England Guidance. Bowel cancer screening: having a CT colonography (CTC) scan. 2022. https://www.gov.uk/government/publications/bowel-cancer-screening-having-a-ct-colonography-ctc-scan/nhs-bowel-cancer-screening-programme-having-a-ct-colonography-ctc-scan. Accessed 25 Nov 2022.
40. Baccaro LM, Markelov A, Wilhelm J, Bloch R. Pneumoperitoneum after virtual colonoscopy: causes, risk factors, and management. Am Surg. 2014;80:549–54.
41. Taylor SA, Halligan S, Goh V, Morley S, Bassett P, Atkin W, Bartram CL. Optimizing colonic distention for multi-detector row CT colonography: effect of hyoscine butylbromide and rectal balloon catheter. Gastrointest Imaging. 2003;229:1151. https://doi.org/10.1148/radiol.2291021151.
42. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Radiol. 2014;18(1):607. https://doi.org/10.4102/sajr.v18i1.607.
43. Kristev AD, Sirakov NV, Getova DP, Katcarov VI, Sirakov VN, Stefanov RS, Turiiski VI, Velkova KG. Comparing hyoscine and drotaverine effects on colon in CT colonography. Cent Eur J Med. 2011;6:234–42.
44. Morrin MM, Farrell RJ, Keogan MT, Kruskal JB, Yam CS, Raptopoulos V. CT colonography: colonic distention improved by dual positioning but not intravenous glucagon. Eur Radiol. 2002;12:525–30.
45. Joint Formulary Committee. Antispasmodics. In: Mehta DK, editor. The British national formulary. 41st ed. London: Royal Pharmaceutical Society of Great Britain and British Medical Association; 2001. p. 34–5.
46. Bruzzi JF, Moss AC, Brennan DD, MacMathuna P, Fenlon HM. Effect of IV Buscopan as a muscle relaxant in CT colonography. Eur Radiol. 2003;13:364–70.
47. Sakamoto T, Utsunomiya D, Mitsuzaki K, Matsuda K, Kawakami M, Yamamura S, Urata J, Arakawa A, Yamashita Y. Colonic distention at screening CT colonography: role of spasmolytic agents and body habitus. Kurume Med J. 2014;61:9–15. https://www.jstage.jst.go.jp/article/kurumemedj/61/1.2/61_MS64002/_pdf
48. Ingelheim B. Professional leaflet: buscopan® ampoules 20 mg/mL solution for injection. 2008.
49. VIMAP Technologies. VMX-1020A data sheet. https://vimap-medical.org/home/insufflators/. Accessed 25 Nov 2022.
50. Amin Z, Boulos PB, Lees WR. Technical report: spiral CT pneumocolon for suspected colonic neoplasms. Clin Radiol. 1996;51:56–61.
51. Neri E, Halligan S, Hellström M, Lefere P, Mang T, Regge D, Stoker J, Taylor S, Laghi A, ESGAR CT Colonography Working Group. The second ESGAR consensus statement on CT colonography. Eur Radiol. 2013;23:720–9. https://doi.org/10.1007/s00330-012-2632-x.
52. Morrin MM, Farrell RJ, Kruskal JB, Reynolds K, McGee JB, Raptopoulos V. Utility of intravenously administered contrast material at CT colonography. Radiology. 2000;217:765–71.
53. Yau TY, Alkandari LA, Haaland B, Low W, Tan CH. Is intravenous contrast necessary for detection of clinically significant extracolonic findings in patients undergoing CT colonography? BJR. 2014;87(1036):20130667. https://doi.org/10.1259/bjr.20130667.
54. Huynh K. Baghdanian AH, Baghdanian AA, Sun DS, Kolli KP, Zagori RJ. Updated guidelines for intravenous contrast use for CT and MRI. Emergency Radiology. 2020;27(2):115–126. https://doi.org/10.1007/s10140-020-01751-y.

55. GE Healthcare. Professional leaflet: Visipaque® Iodixanol. Last revised April 2019. (Cited 2022 Nov 25). Available from https://www.gehealthcare.co.uk/-/jssmedia/18ab300e4cc54c8faaad8c0eb9d9c3eb.pdf?la=en-gb.
56. Kurabayashi T, Ida M, Fukayama H, Ohbayashi N, Yoshino N, Sasaki T. Adverse reactions to nonionic iodine in contrast-enhanced computed tomography: usefulness of monitoring vital signs. Dentomaxillofac Radiol. 1998;27:199–202. https://doi.org/10.1038/sj/dmfr/4600347.
57. Yasuda R, Munechika H. Delayed adverse reactions to nonionic monomeric contrast-enhanced media. Invest Radiol. 1998;33:1–5.
58. Hiroishi A, Yamada T, Morimoto T, Horikoshi K, Nakajima Y. Three-dimensional computed tomographic angiography with computed tomographic colonography for laparoscopic colorectal surgery. Jpn J Radiol. 2018;36:698–705. https://doi.org/10.1007/s11604-018-0775-7.
59. Cadi M, Manceau G, Lansier A, Rahmi G, Taïeb J, Karoui M. Computed tomography colonography angiography (CTC-A) prior to colectomy for cancer: a new tool for surgeons. J Visc Surg. 2021;159(2):136–43. https://doi.org/10.1016/j.jviscsurg.2021.10.003.

9 Preparation of CTC Patient: Diet, Bowel Preparation, the Role of Tagging, and Methods of Colonic Insufflation

Joel H. Bortz

9.1 Introduction

There are several CT colonography (CTC) components. Each one contributes to a successful examination: from patient preparation to performance and interpretation of the results [1]. Pickhardt [1] underscores that every part of the technical component of a CTC examination is interconnected. The final outcome will therefore be negatively impacted if there is a weak link in a CTC examination chain.

There is consensus in the literature that cathartic bowel preparation, and tagging agents are pivotal in CTC [2–5]. Studies have been done to assess 1, 2, or 3-day preparation; non-cathartic unrestricted diet; limited bowel preparation; liquid diet; low-fibre diet; cathartic bowel preparation together with tagging agents; and wet bowel preparation, for example [3, 6–8]. Comparative studies have been done of nonionic iohexol and ionic diatrizoate as tagging agents in CTC as part of a cathartic bowel regime [9]. Literature reports that iohexol (Omnipaque) is more palatable for patients [10, 11]; and diatrizoate (Gastrografin) has an unpleasant taste [2].

Two critical components are necessary to achieve a successful CTC: an adequately cleansed bowel and good distension of the colon [4]. Patient co-operation is necessary in order to achieve these two components. When a CTC is booked, it is important that patients are informed of the importance of the use of cathartic agents to cleanse the bowel, the role of tagging, and that the examination does require insertion of a rectal catheter to allow for distension of the colon. As discussed in Chap. 8 at the time of booking a CTC, each patient must be asked about known allergies or previous reactions to iodinated contrast media. Patients need to be informed that an anaesthetic is not required; it is not necessary for someone to accompany them to the procedure, which takes on average 20 min. It is important to emphasise that they must ensure that they are well hydrated. It is essential that an appropriately trained person explains to patients the importance of adhering to a liquid diet and taking the bowel preparation medication at the correct times.

During the Covid-19 pandemic, patients were assured that CTC, compared to colonoscopy, is a socially distanced and minimally invasive study with a very low risk of transmission of infection [12]: patients should always be told this when they make an appointment for CTC examinations.

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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The following abbreviations are used in this chapter

- CO_2: carbon dioxide
- CRC: colorectal cancer
- OC: optical colonoscopy
- 2D: two-dimensional

9.2 Bowel Preparation

Bowel preparation has evolved over the years. It is important to have an adequately cleansed bowel with good distension of the colon with CO_2 (carbon dioxide) in CTC examinations. There are many ways to perform CTC, but it is advisable to choose a method used at an institution that has published evidence of consistently producing outstanding results, and to then follow the published recommendations. The author has adopted the technique used by Professors Pickhardt and Kim from the University of Wisconsin [13]. These practitioners have shown the importance of bowel preparation including tagging agents and the use of CO_2 instead of room air for optimal visualisation of the colon. A weak link in any of these parameters can cause a poor CTC result.

9.3 Colonic Preparation

Bowel preparation is controversial in terms of patients' compliance [14, 15]. A primary barrier, to achieving optimal colorectal cancer (CRC) screening with either CTC or optical colonography (OC), is many patients' aversion to bowel cleansing [16, 17]. A CTC study requires both bowel cleansing and tagging agents (Fig. 9.1a–c). Tagging agents, such as 250 mL of 2.1% w/v Readi-Cat [4] and 50 mL nonionic iohexol (Omnipaque) [9, 18] are used. The barium tags stool in the colon; the Omnipaque tags the residual fluid in the bowel [18].

Cathartic bowel preparation is required for CTC, and OC with same-day polypectomy [6]. There are many different bowel preparations available, and most work well. A standard protocol is not available as opinions vary as to which is

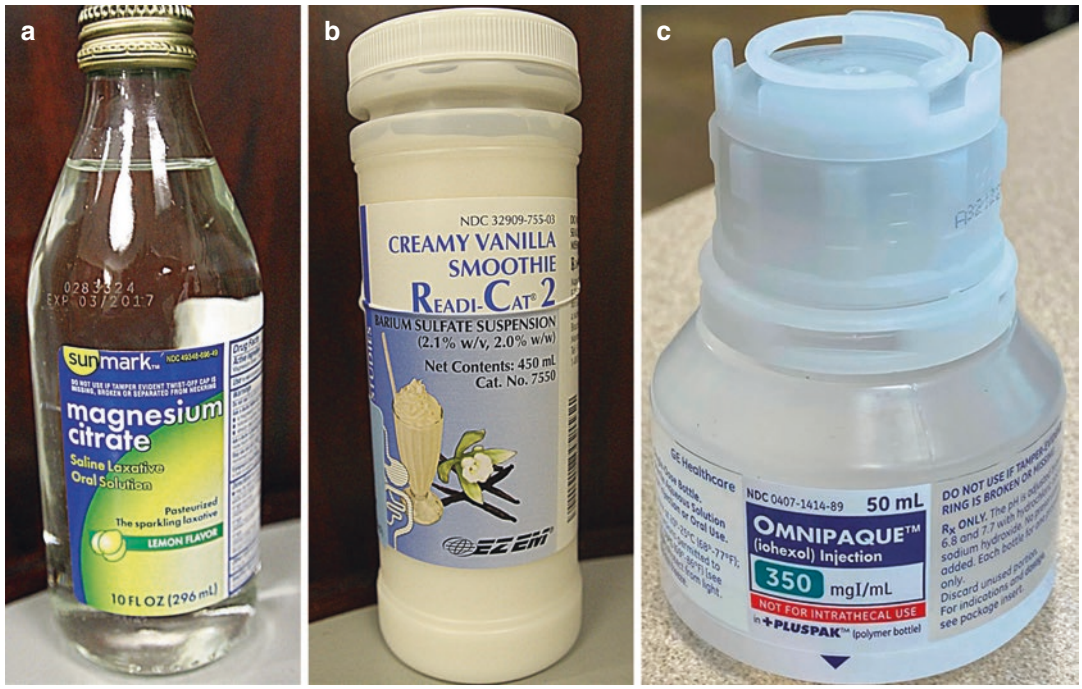

Fig. 9.1 (**a**) Magnesium citrate for bowel preparation. 2 × 296 mL bottles required. (**b**) Readi-Cat 2 to tag stool. Only 250 mL required. Remaining 200 mL to be discarded by the patient. (**c**) Omnipaque 50 mL to tag residual fluid

the best preparation. When CTC was first introduced in 1994, sodium phosphate (NaP) was the agent of choice. Patients were not adverse to its usage. The findings of a 2007 study showed that effective bowel cleansing could be achieved using either 90 mL or 45 mL sodium phosphate [19]. There were reports that its usage could have contributed to isolated cases of acute phosphate nephropathy [20]. A blinded study in 2010 that compared magnesium citrate (MgC) and sodium phosphate for catharsis resulted in the former being preferred for CTC bowel preparation [21]. A 2014 study undertaken to compare the efficacy of replacing sodium phosphate with magnesium citrate showed there had not been any compromise of the overall CTC examination quality [22]. Magnesium citrate remains the front-line CTC cathartic agent (see Fig. 9.1a). The regimen consists of 2 × 296 mL bottles compared with only one bottle of sodium phosphate. Significant clinical electrolyte imbalances are less likely with magnesium citrate compared to sodium phosphate. Fluid intake is essential to avoid dehydration [2].

There are two types of preparation: 'dry' preparation and 'wet' preparation [2]. A 'dry' preparation for CTC means that less residual fluid is present hence better visualisation of the colon wall [2]. It is thought that low-volume regimens ('dry' preparations) are superior to high-volume ones ('wet' preparations). An example of the latter is polyethylene glycol (PEG: ***Klean-Prep***®) [23]. Since PEG is a 'wet' preparation it is an electrolyte lavage preparation. It functions as an osmolar agent by increasing the water content of stool and inducing elimination [2]. Many patients are adverse to the available agents for bowel cleansing; hence, there is continual research being undertaken to find a cathartic agent that can (1) reduce residual fluid in the bowel, and (2) be positively accepted by patients.

A new formulation, called Suprep (OSS®) was introduced into the OC market in 2010 [24]. It is a low-volume oral sulphate solution. One dose of OSS Suprep consists of 17.5 g sodium sulphate, 1.6 g magnesium sulphate, 3.1 g potassium sulphate, and flavouring agents in an aqueous liquid form supplied in a 177 mL plastic bottle [24]. Sulphate is a poorly absorbed anion, and OSS does not alter electrolyte balance [25]. The recommended OC regimen consists of 2 × 177 mL bottles in a split dose to adequately cleanse the colon for OC examinations. Bannas et al. [26] undertook a trial using a single bottle regime (177 mL) for colonic cleansing. They were of the opinion that a single-bottle regime, together with an ionic iodinated oral contrast medium of sodium diatrozoate/megulumine diatrozoate (Gastrografin), would act as an additional mild cathartic agent. Five different cathartic regimes were employed in the trial, namely

- Single dose of 45 mL NaP
- Double dose NaP (2 × 45 mL) separated by 3 h
- Double dose of MgC (2 × 296 mL) separated by 3 h
- PEG. Four litres (4 L) divided into 16 × 237 mL taken every 10 min
- Single bottle OSS purgation regimen. The 177 mL oral sulphate solution was diluted with 296 mL water before ingestion
- To tag residual stool and fluid, respectively, all of the patients were given 250 mL Readi-Cat 2, and 60 mL Gastrografin the evening before the CTC examination

The authors used an automated QA software tool to determine volume and attenuation of residual colonic fluid. According to Bannas et al. [26], the findings of their 2014 trial were that the OSS Suprep regime at that time was superior to any other previously used cathartic agents for CTC bowel preparation. There was less residual fluid compared with the other agents, and the fluid attenuation value increased.

Below is the bowel preparation that the author uses.

9.4 Recommended Bowel Preparation Including Diet

For a successful examination, bowel preparation should consist of a well-established CTC standard protocol [27]. The author's recommended proto-

Table 9.1 Patient preparation

Ensure clean bowel	Prep day	Day of CTC
Hydration: Patient to drink 3–4 L (4 quarts) of clear liquid day before CTC ***TIP***: If liquid can be seen through and there is nothing floating in it, then it may be consumed ***Approved clear liquid*** • Tea/coffee; iced tea; apple/white grape/white cranberry juice; lemonade; powerade; soda/diet soda; coconut water; vitamin water; jell-O/popsicles; clear broth or consommé ***Not approved*** • Orange juice; tomato juice; grapefruit juice; prune juice	• No solid foods day before the CTC and prior to CTC • Adequate hydration to be maintained: clear liquid throughout the day to be consumed until midnight thereafter nil per mouth • Diabetic patients to test blood glucose level more often and to drink clear liquid that contains sugar if less than 70 mg/dL	• Nil per mouth until completion of CTC • Patients on daily medications may take as prescribed with small sips of water
NB: No solid foods day before CTC. Fasting after midnight	Patients on medications to take them 1 h before or 1 h after taking the magnesium citrate	Patients who have not had bowel movements or could not finish the bowel prep kit should be requested to reschedule the CTC for a later day
Bowel prep kit • Bisacodyl (dulcolax) tablets 5 mg × 2 • Magnesium citrate 2 × 296 mL bottles • Barium sulphate 2.1% w/v (250 mL) to tag remaining stool • Iohexol (Omnipaque) (50 L) to tag remaining fluid	***Step 1*** • At 11:00: Bisacodyl (dulcolax) tablets to be taken with 1 glass (8 ounces) clear liquid ***Step 2*** • At 14:00: one bottle of (296 mL) of magnesium citrate to be swallowed followed with at least 4–6 cups clear liquid ***Step 3*** • At 17:00: 250 mL barium sulphate to be drunk followed by the remaining bottle of magnesium citrate ***Step 4*** • At 20:00: 50 mL of undiluted iohexol (Omnipaque) to be swallowed OR can be mixed with 1 glass of clear liquid; the entire amount must be swallowed (not necessary to drink this quickly)	• The patient may commence eating solids and resume usual medication schedule if the CTC study is normal or if a same day OC is not feasible – ***NOTE***: If a same day OC is feasible then patient to continue fasting as an anaesthetic will be required. Someone will have to accompany the patient home. Patients cannot drive home after an OC

col is as follows. Bowel preparation commences the day before the scheduled examination and a 24 h liquid diet is required (Table 9.1 presents a list of permitted liquids). Dry bowel preparation is routine. The protocol is: (1) at 11:00 2 × 5 mg bisacodyl (Dulcolax) tablets are ingested with one glass (8 ounces/234 mL) clear fluid, (2) 296 mL solution of magnesium citrate ingested at 14:00 and a further 296 mL at 17:00 on the day before the study, (3) tagging agent 250 mL of 2.1% w/v Readi-Cat® is ingested at 17:00 (it stains any remaining stool), and (4) at 20:00 50 cc iohexol (Omnipaque) is ingested to stain any residual fluid white [18]. Patients are required to adhere to a 1-day clear liquid diet to aid bowel catharsis as well as to ensure hydration because of osmotic fluid loss [19]. In 2022, it was necessary to make changes to this bowel preparation protocol. There

were supply chain and production issues of iohexol during Covid-19 pandemic [28]. In view of the shortage use was made of Gastrografin; patients found the taste to be unpleasant. In July 2022, magnesium citrate oral laxative was recalled in the United States of America (USA), Canada, and Panama due to microbial contamination [29]. The result of this recall was that the above 1-day preparation protocol was changed to a 2-day protocol of liquid diet and additional Dulcolax tablets; patients were not happy with this revised protocol and bowel cleansing was not as good as using magnesium citrate.

The protocol includes nil per mouth from midnight. If a patient has had breakfast in error, another CTC appointment must be arranged. It is important for a patient to be fully briefed on all requirements when a CTC is booked. An appropriately trained person must carefully explain to the patient the importance of adhering to a liquid diet and taking the bowel preparation medication at the correct times (steps 1 and 2 in Table 9.1). The times to take the medication in these steps, and the tagging ones, must be labelled on the bottles. Patients must be informed that it is essential they adhere to all the steps for bowel preparation including no solid foods as indicated in Table 9.1. Consumption of solid food before a CTC will result in stool in the colon. Figure 9.2(i) is an example of a patient not following instructions. The patient ate snacks the evening before the CTC; there was stool in the caecum and the examination had to be rebooked.

The patient must be informed that onset of bowel action is variable: it may occur after 30 min or be delayed for up to 4 h. Tagging is an integral part of the colonic preparation (steps 3 and 4 in Table 9.1).

Nonionic Omnipaque contrast medium is likely safer than Gastrografin [9]. A comparative study of these two contrast media reported that patients found the latter to have an unpleasant taste [9]. Gastrografin is a hypertonic oral contrast medium which has been used for decades in gastrointestinal radiology [30]. It is used as a tagging agent in CTC primarily to tag and stain residual fluid white so that any submerged polyps can be easily identified [4]. Some patients are however reluctant to ingest the oral contrast medium for two reasons. It contains iodine and/or they may have had a prior reaction to injected contrast media. Anaphylactoid reactions have been reported in the literature, especially when Gastrografin has been aspirated [31]. The main contraindications for its use would be known hypersensitivity to iodine. Asthmatic patients need to be careful as they may experience bronchospasm. Patients with hyperthyroidism should avoid Gastrografin [30]. In the vast majority of patients, the contrast medium is administered without reported problems. However, it is essential that cognisance should be taken of a patient's history of allergy or previous reactions to contrast media.

Barium does not adhere to the colonic wall; it coats the surfaces of polyps making them more conspicuous and easier to diagnose [27]. This may reduce the false-positive rate on CTC. Both Omnipaque and Gastrografin stain residual fluid white which aids in 2D evaluation of submerged polyps. Since Gastrografin is hypertonic, it also emulsifies the stool adherent to the bowel wall thus causing a secondary catharsis [27]. Figure 9.2(ii)–(iv) illustrates the importance of tagging residual fluid.

It is sensible to shift to PEG for the extremely small percentage of patients who are in poor health due to cardiac or renal disease, or hypertensive patients taking angiotensin-converting-enzyme inhibitors (ACE inhibitors) to avoid fluid or electrolyte shift. PEG has an unpleasant taste and a large volume needs to be consumed. In view of this, patients usually do not adhere strictly to its correct use [4].

9.4.1 Non-cathartic Options for CTC

Patient adherence may improve with a non-cathartic preparation, but there are trade-offs [32]. The findings of a 2012 study, comprising 605 patients who did not have cathartic agents, showed accurate detection of adenomas ≥10 mm or larger, but less accurate detection for lesions <10 mm in size [33]. Patient preparation comprised a low-

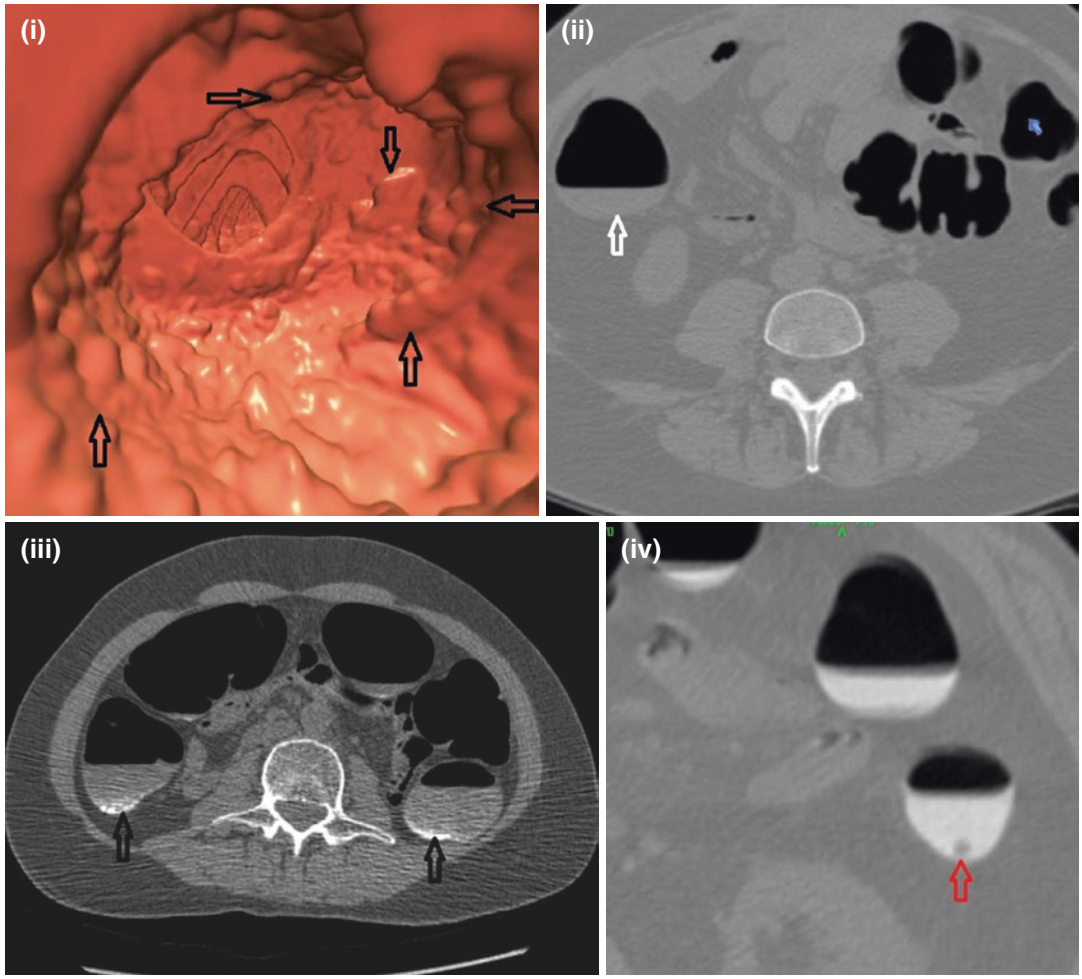

Fig. 9.2 (**i**) 3D view shows excessive stool (open black arrows) in the caecum due to poorly prepared bowel as patient ate snacks in the evening before the study. (**ii**) 2D axial view showing unopacified fluid (open white arrow) due to lack Omnipaque as a tagging agent. (**iii**) 2D axial view shows barium (open black arrows) at the bottom of the non-pacified fluid due to lack of Omnipaque. (**iv**) 2D axial view showing visualisation of a submerged polyp (open red arrow) in opacified residual fluid

fibre diet as well as barium and Gastrografin for stool and fluid tagging. The study employed electronic cleansing as well as CTC computer-aided detection (CAD) software, respectively. Electronic cleansing may cause significant artefacts (see Chap. 12), and 2D (two-dimensional) reading is required. Feedback from the patients was positive in terms of a laxative-free CTC. A downside to a laxative-free study is that a same-day OC cannot be performed if the CTC findings reveal an adenoma ≥10 mm [33]. A cathartic-free regime would probably result in an increase in screening compliance. Furthermore, risks associated with purgative preparations would be avoided, particularly in patients with known cardiac and renal insufficiency. However, according to Pickhardt [6] there are disadvantages of non-cathartic screening protocols, namely

- Laxative-free regimes still require patient preparation; tagging agents are required to tag stool and residual fluid.
- A reduction in accuracy could lead to missed lesions and overuse of colonoscopy.
- Lack of cathartic preparation precludes same-day optical colonoscopy.
- 2D reading is essential because large amounts of stool are present in the bowel.

- Electronic cleansing produces its own artefacts which further complicate reading of the CTC study.

9.5 CTC Colonic Insufflation

There are two methods to insufflate the colon during CTC studies. Room air or CO_2 can be insufflated using either a handheld device (manual insufflation) or an automated pressure-controlled insufflator [4, 34]. Informed consent forms must include the benefits and risks of both methods. Informed consent is discussed in Chap. 3. It is also important to consider the use of room air versus CO_2, and the potential risks of perforation in CTC studies.

9.5.1 Carbon Dioxide Versus Room Air for Colonic Insufflation

The advantage of using CO_2, compared to room air, is its rapid absorption from the colon by normal breathing. Its resorption is 150 times faster through the colon wall compared to room air. The main components of air are nitrogen and oxygen [35]. Literature reports that CO_2 is absorbed across the intestinal mucosa 160 times more rapidly than nitrogen and 13 times more rapidly than oxygen [36]. Patients therefore experience less cramps during and after a CTC study when CO_2 is used [4]. This holds true for patients during and post colonoscopy [35]. Abdominal pain during CTC is less of a feature with CO_2 than room air: the former is rapidly resorbed following the procedure resulting in much reduced post-procedure distension and pain [37, 38]. CO_2 may cause bloating for a short period [4].

9.5.2 Manual Insufflation Using Room Air or Carbon Dioxide

Manual insufflation requires the use of a handheld air-bulb insufflator. Room air and CO_2 can both be used to distend the colon in a CTC study; room air is free whereas there are costs involved in the use of CO_2. Irrespective of which negative contrast medium is used the success of a CTC depends on an adequately distended and clean colon [39]. Introducing room air or CO_2 into the colon requires many puffs of a handheld device. According to Sosna et al. [40], each puff of a device will introduce approximately 40 cc of air; at least 50 puffs will be required to introduce 2 L of air. Of importance is that the pressure at which the air is introduced is unknown [40]. The danger of perforating the bowel under these circumstances far exceeds that of the gentle measured pressure and volume attained with an automated pressure-controlled CO_2 insufflator. The intracolonic pressure produced by manual insufflation may vary greatly depending on the force used to compress the bulb of the puffer. Pressures varied from 41 to 148 mmHg in an industrial study performed in 2002 [41]. An intracolonic pressure above 140 mmHg can lead to perforation of the caecum [42]. During manual insufflation, perforation can be caused by the use of either room air or CO_2. The medico-legal ramifications of using manual insufflation are self-evident.

9.5.3 Automated Pressure-Controlled Insufflation with Carbon Dioxide

A successful CTC study requires optimal distension of the colon [2, 4, 6]. Optimal distension means that during a fly-through, there are no breaks in the well-distended colon segments. An automated pressure-controlled device has more advantages than disadvantages when compared with manual insufflation [4]. Several vendors supply automated CTC insufflators. Training is often necessary to operate an insufflator and to understand pressure and volume readings on the dials. It is essential to check that there is sufficient CO_2 in the cylinder before commencing a CTC study.

The intracolonic pressure, which is indicated on the dial of an automated CO_2 insufflator, is constantly monitored (see Fig. 9.3a(i) and (ii)). The CO_2 is introduced very gently into the colon until 1 L has been insufflated. The pressure is then gradually increased to 20 mmHg or higher if necessary, usually to a maximum pressure of

25 mmHg. There are newer automated CO_2 insufflators that provide a range to 35 mmHg. There are also some insufflators that can be used at pressures >35 mmHg. The important factor to bear in mind is that the pressure should gradually be increased. It has been shown that using constant pressure infusion of CO_2 has been as effective in colon distension in stenosing as well as in non-stenosing carcinomas [42]. Kim et al. [42] in their study also checked for colonic perforation 24 h later in 65 patients who had undergone biopsies immediately before their respective CTC studies. No perforations occurred in these patients. According to literature, the risk of perforation is minimal when constant-pressure automated CO_2 is used [43]. Unlike a handheld device, an automated insufflator can be switched on and off to control insufflation. The amount of CO_2 used can be accurately recorded. Such a facility is not available with handheld devices.

A recently launched insufflator (VMX-1020A Vimap Technologies®) includes an option to warm the CO_2 during colonic insufflation. This product allows for temperature ranges from 30 to 47 °C (Fig. 9.3b(i) and (ii)). The temperature can be selected as a constant setting or adjusted. This warming option was included by the manufacturer to relax the colon wall (personal communication with Nicolas Costovici, Vimap Technologies). Studies using warmed humidified CO_2 in laparoscopic procedures have been done. The findings of a study by Farley et al. [44]

Fig. 9.3 (**a**) (**i**) Close-up view of pressure controlled insufflator (PROTOCO2L—Bracco®). Installation pressure set at 15. Rectal intraluminal pressure at 19 mmHg. Left upper dial shows total volume readout of CO_2 = 1.5 L. (**a**) (**ii**) Automated CO_2 colonic insufflator (VMX 1020 A—Vimap Technologies®).

Fig. 9.3 (**b**) (**i**) Close-up view of the Vimap gauge. Installation pressure at 21 mmHg. Volume of CO_2 12.5 L. Rate of introduction at 2.5 L/min. Temperature gauge for CO_2 at 39 °C. Note these settings are for demonstration purposes only and were not used during a CTC study. (Courtesy Vimap Technologies). (**b**) (**ii**) Cross-section view of the CO_2 warming mechanism in the VMX 1020 A insufflator. (Courtesy Vimap Technologies)

were that the use of warmed gas did not significantly result in less postoperative pain than patients undergoing laparoscopic cholecystectomy with standard CO_2 insufflation. Glew et al. [45] found that warmed humidified CO_2 did increase dissipation of residual gas following laparoscopy. There are some endoscopy insufflators that include warming the carbon dioxide from a gas cylinder or from a wall-mounted outlet.

9.6 Perforation Risks

Colonic perforation during CTC is rare [43]. Most of the recorded cases of colonic perforation were associated with the use of manual insufflation, and generally occurred in symptomatic patients, or in those with underlying disease, such as inflammatory bowel disease, colon cancer, and diverticulosis [46]. Another cause of perforation has been attributed to the usage of a large gauge rigid rectal catheter used in barium enema examinations. Current practice is the routine use of small gauge soft rectal catheters (e.g., 20–25 French gauge) in CTC examinations.

CTC should not be performed soon after colonoscopic polypectomy, snare polypectomy, or biopsy to reduce perforation risks. The findings of a 1984 study underscored that no perforations occurred when barium enema examinations were performed within 72 h post biopsy or colonoscopic polypectomy [47]. A 2006 study by Dachman did not support these findings [48]. He showed that it takes a week for granulation tissue formation in most surgical wounds; during this period, an injured colonic wall is weak thus would not be able to withstand high intracolonic pressure as occurs during insufflation. To minimise the rare risk of perforation, the current practice is that there should be a waiting period of 2–4 weeks before performing CTC. If a deep biopsy or polypectomy has recently been performed, it is advisable to wait at least 4 weeks before proceeding with the CTC to allow the mucosa to heal [4].

Patient preparation is important in terms of best practice and standards. The 2021 joint guidance for CTC standards of practice of the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiology includes bowel preparation and insufflation for clinical audit [49] (see Chap. 27).

Key Messages

- Hydration is mandatory: patients to drink 3–4 L (4 quarts) of clear liquid 24 h before a CTC study.
- Cathartic agents are essential to cleanse the bowel; good visualisation of a stool-free colon is required for a successful CTC study.
- Tagging of stool and residual fluid is pivotal for an accurate study.
- Well-distended colon is required.
- Carbon dioxide is an integral component in CTC; it is safe, rapidly absorbed and does not cause cramping.
- Check that there is sufficient CO_2 in the cylinder before commencing a CTC examination.
- Automated pressure-controlled carbon dioxide insufflation using a small rectal catheter has been shown to reduce the rare risk of perforation.
- CTC should not be performed soon after colonoscopic polypectomy, snare polypectomy, or biopsy to reduce perforation risks.
- Anaesthesia is not required; therefore, it is not necessary for someone to accompany a patient to a CTC study.
- Cognisance to be taken of patients with previous history of adverse reactions to contrast media.
- Patients with hyperthyroidism should avoid Gastrografin.
- Patients with known cardiac or renal insufficiency could be compromised with ‘dry’ preparations; a non-cathartic regime is an option.
- Bowel preparation should be included in clinical audits.

9.7 Summary

There are two crucial components to achieve a successful CTC: an adequately cleansed bowel and good distension of the colon. An automated pressure-controlled CO_2 insufflation results in a well-distended colon. Pain and cramping are not associated with the use of CO_2 to distend the bowel. The risk of perforation is very rare in CTC studies. However, to reduce any risk of perforation a CTC should not be performed soon after colonoscopic polypectomy, snare polypectomy, or biopsy. Furthermore, a small gauge soft rectal

catheter should be used. Patients with hyperthyroidism should avoid Gastrografin.

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References

1. Pickhardt PJ. Imaging and screening for colorectal cancer with CT colonography. Radiol Clin N Am. 2017;55:1183–96.
2. Yee J, Weinstein S, Morgan T, Alore P, Aslam R. Advances in CT colonography for colorectal screening and diagnosis. J Cancer. 2013;4(3):200–9.
3. Pickhardt PJ. Screening CT colonography: how I do it. AJR Am J Roentgenol. 2007;189(2):290–8.
4. Bortz JH. CT colonography: an approach for a successful examination. S Afr J Radiol. 2014;18(1):607. https://doi.org/10.4102/sajr.v18i1.607.
5. Kim B, Park SH, Hong GS, et al. Iohexol versus diatrizoate for fecal/fluid tagging during CT colonography performed with cathartic preparation: comparison of examination quality. Eur Radiol. 2015;25(6):1561–9. https://doi.org/10.1007/s00330-014-3568-0.
6. Pickhardt PJ. Colonic preparation for computed tomographic colonography: understanding the relative advantages and disadvantages of a noncathartic approach. Mayo Clin Proc. 2007;82(6):659–61.
7. Johnson CD, Manduca A, Fletcher JG, MacCarty RL, et al. Noncathartic CT colonography with stool tagging: performance with and without electronic stool subtraction. AJR Am J Roentgenol. 2008;190:361–6.
8. Liedenbaum MH, Denters MJ, de Vries AH, van Ravesteijn VF, et al. Low-fiber diet in limited bowel preparation for CT colonography: influence on image quality and patient acceptance. AJR Am J Roentgenol. 2010;195:W31–7.
9. Johnson B, Hindshaw JL, Robbins JB, Pickhardt PJ. Objective and subjective intrapatient comparison of iohexol versus diatrizoate for bowel preparation at CT colonography. AJR Am J Roentgenol. 2016;206(2):1202–7.
10. McNamara MM, Lockhart ME, Fineberg NS, Berland LL. Oral contrast media for body CT: comparison of diatrizoate sodium and iohexol for patient acceptance and bowel opacification. AJR Am J Roentgenol. 2010;195:1137–41.
11. Pollentine A, Ngan-Soo E, McCoubrie P. Acceptability of oral iodinated contrast media: a head-to-head comparison of four media. Br J Radiol. 2013;86:20120636. https://doi.org/10.1259/bjr.20120636.
12. Moreno CC, Yee Y, Ahmed FS, Barish MA, Brewington C, Dachman AH, Gollup MJ, Kim DH, McFarland E, Pickhardt PJ, Reddy S, Zalis M, Chang KJ. CT colonography's role in the Covid-19 pandemic: a safe (r), socially distanced total colon examination. Abdom Radiol. 2021;46(2):486–90. https://doi.org/10.1007/s00261-020-02674-5.
13. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009.
14. Summers R. The elephant in the room: bowel preparation for CT colonography. Acad Radiol. 2009;16(7):777–9. https://doi.org/10.1016/j.acra.2009.04.001.
15. Hara AK, Kuo MD, Blevins M, Chen M, et al. National CT colonography trial (ACRIN 6664): comparison of three full-laxative bowel preparations in more than 2500 average-risk patients. AJR Am J Roentgenol. 2011;196(5):1076–82. https://doi.org/10.2214/AJR.10.4334.
16. Harewood GO, Wiersema MJ, Melton LJ 3rd. A prospective controlled assessment of factors influencing acceptance of screening colonoscopy. Am J Gastroenerol. 2002;97(12):3186–94.
17. Beebe TJ, Johnson CD, Stoner SM, Anderson KJ, Limburg PJ. Assessing attitudes towards laxative preparation in colorectal cancer screening and effects on future testing: potential receptivity to computed tomographic colonoscopy. Mayo Clin Proc. 2007;82(6):666–71.
18. Bortz JH, Munro L. Does the everyday lifestyle diet of patients for screening CT colonography impact on their bowel cleaning and perceptions of a 1-day liquid diet? S Afr Radiogr. 2018;56(2):11–7.
19. Kim DH, Pickhardt PJ, Hinshaw JL, et al. Prospective blinded trial comparing 45-mL and 90-mL dose of oral sodium phosphate for bowel preparation before computed tomographic colonography. J Comput Assit Tomogr. 2007;31(1):53–8.
20. Markowitz GS, Stoke MB, Radhakrishnan J, D'Agati VD. Acute phosphate nephropathy following oral sodium phosphate bowel purgative: an under recognised cause of chronic renal failure. J Am Soc Nephrol. 2005;16(11):3389–96.
21. Borden ZS, Pickhardt PJ, Kim DH, et al. Bowel preparation for CT colonography: blinded comparison of magnesium citrate and sodium phosphate for catharsis. Radiology. 2010;254(1):138–44.
22. Bannas P, Bakke J, Munoz de Rio A, Pickhardt PJ. Intra-individual comparison of magnesium citrate and sodium phosphate for bowel preparation at CT colonography: automate volumetric analysis of residual fluid for quality assessment. Clin Radiol. 2014;69:1171–7.
23. Macari M, Lovelle M, Pedrosa I, et al. Effect of different bowel preparation on residual fluid at CT colonography. Radiology. 2001;218(1):274–7.

24. OSS: Suprep Bowel Prep Kit, Braintree Laboratories, Braintree, MA.
25. Di Palma JA, Rodriguez R, McGowan J, et al. A randomised clinical study evaluating the safety and efficacy of a new, reduced-volume, oral sulphate colon-cleansing preparation for colonoscopy. Am J Gastroenterol. 2009;104(9):2275–84.
26. Bannas P, Bakke J, Patrick JL, Pickhardt JP. Automated volumetric analysis for comparison of oral sulphate solution (SUPREP) with established cathartic agents at CT colonography. Abdom Imaging. 2015;40(1):11–8. https://doi.org/10.1007/s00261-014-0186-x.
27. Kim DH, Hinshaw JL, Lubner MG, Munoz del Rio A, Pooler BD, Pickhardt PJ. Contrast coating for the surface of flat polyps at CT colonography: a marker for detection. Eur Radiol. 2014;24(4):940–6. https://doi.org/10.1007/s00330-014-3095-z.
28. Grist TM, Canon CL, Fishman EK, Kohi MP, Mossa-Basha M. Short-, mid-, and long-term strategies to manage the shortage of iohexol. Radiology. 2022;304(2):289–93. https://doi.org/10.1148/radiol.221183.
29. Vi-Jon, LLC expands voluntary nationwide recall of all flavors and lots within expiry of magnesium citrate saline laxative oral solution due to microbial contamination. 2022. https://www.fda.gov/safety/recalls-market-withdrawals-safety-alerts/vi-jon-llc-expands-voluntary-nationwide-recall-all-flavors-and-lots-within-expiry-magnesium-citrate. Accessed 30 Sept 2022.
30. Gastrografin®. Oral solution. Sodium amidotrizoate 100 mg/mL, meglumine amidotrizoate 660 mg/mL. Gastrografin Australian Approved Product Information from 2009.
31. Miller SH. Anaphylactoid reaction after administration of diatrizoate meglumine and diatrizoate sodium solution. AJR Am J Roentgenol. 1997;168:959–61.
32. Pickhardt PJ. CT colonography: does it satisfy the criteria for colorectal screening test? Expert Rev Gastroenterol Hepatol. 2014;8(3):211–3.
33. Zalis ME, Blake MA, Cai W, et al. Diagnostic accuracy of laxative-free computed tomographic colonography for detection of adenomatous polyps in asymptomatic adults: a prospective evaluation. Ann Intern Med. 2012;156:692–702.
34. RANZCR. Requirements for the practice of computed tomography colonography (CTC). Sydney: The Royal Australian and New Zealand College of Radiologists; 2013. p. 6.
35. Singh R, Neo EN, Nordeen N, Shanmuganathan G, et al. Carbon dioxide insufflation during colonoscopy in deeply sedated patients. World J Gastroenterol. 2012;18(25):3250–3. https://doi.org/10.3748/wjg.v18.i25.3250.
36. ASGE Technology Committee. Methods of luminal distention for colonoscopy. Gastrointest Endosc. 2013;77(4):519–25. https://doi.org/10.1016/j.gie.2012.09.025.
37. Burling D, Taylor SA, Halligan S, Gartner L, et al. Automated insufflation of carbon dioxide for MDCT colonography: distension and patient experience compared with manual insufflation. AJR Am J Roentgenol. 2006;186:96–103. https://doi.org/10.2214/ajr.04.1506.
38. Shinners TJ, Pickhardt PJ, Taylor AJ, Jones DA, Olsen CH. Patient-controlled room air insufflation versus automated carbon dioxide delivery for CT colonography. AJR Am J Roentgenol. 2006;186(6):1491–6. https://doi.org/10.2214/ajr.05.0416.
39. Burling D, Taylor SA, Halligan S. How to get the colon distended? In: Lefere P, Grypspeerdt S, editors. Virtual colonoscopy. Berlin: Springer; 2006. p. 51–60.
40. Sosna J, Bar-Ziv J, Libson E, Eligulashvili M, Blachar A. CT colonography: positioning order and intracolonic pressure. AJR Am J Roentgenol. 2008;191:W175–80. https://doi.org/10.2214/ajr.07.3303.
41. Williams R. CO_2 hand bulb colon distention used with CT colonography. New York: E-Z-E-M Inc.; 2002.
42. Kim SY, Park SH, Choi EK, et al. Automated carbon dioxide insufflation for CT colonography: effectiveness of colonic distention in cancer patients with severe luminal narrowing. AJR Am J Roentgenol. 2008;190(3):698–706. https://doi.org/10.2214/AJR.07.2156.
43. Pickhardt PJ. Incidence of colonic perforation at CT colonography: review of existing data and implications for screening of asymptomatic adults. Radiology. 2006;239(2):313–6.
44. Farley DR, Greenlee SM, Dirk R, et al. Double-blind, prospective, randomised study of warmed, humidified carbon dioxide insufflation vs standard carbon dioxide for patients undergoing laparoscopic cholecystectomy. Arch Surg. 2004;139(7):739–44. https://doi.org/10.1001/archsurg.139.7.739.
45. Glew PA, Campher MJJ, Pearson K, Schofield JC, Davey AK. The effect of warm humidified CO_2 on the dissipation of residual gas following laparoscopy in piglets. J Am Assoc Gynecol Laparosc. 2004;11(2):204–10.
46. Sosna J, Blacher A, Amitai M, et al. Colonic perforation at CT colonography: assessment of risk in a multicenter large cohort. Radiology. 2006;239(2):457–63.
47. Culp CE, Carlson HC. Is there a safe interval between diagnostic invasive procedures and the barium study of the colorectum? Gastrointest Radiol. 1984;9:69–72.
48. Dachman AH. Advice for optimising colonic distention and minimising risk of perforation during CT colonography. Radiology. 2006;239:317–21.
49. The joint guidance for CTC standards of practice of the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiology. 2021. https://www.rcr.ac.uk/system/files/publication/field_publication_files/bfcr201-standards-of-practice-for-computed-tomography-colonography-ctc.pdf. Accessed 29 Sept 2022.

10 CTC Technique and Image Interpretation Methods

Joel H. Bortz

10.1 Introduction

CTC has been identified as a valid screening test for CRC [1, 2]. It has demonstrated both cost-effectiveness [3] and a high degree of acceptance among patients [4]. Screening of asymptomatic individuals can reduce CRC mortality [1]. Removal of an advanced adenoma may reduce the incidence of CRC [1].

There have been significant changes in the performance of a CTC study since it was first used by Vining in 1994 [5]. The main changes being in computer hardware and software, and CTC technique. Initially, it took hours to process images, but technological advances in computers now allow us to generate vast numbers of images in real-time [6]. CT scanners have advanced from single-slice to super-fast multidetector CT (MDCT) scanners that can scan up to 320 slices per second. It is not necessary to use super-fast MDCT scanners for CTC studies; good studies can be performed on 16-slice up to 64-slice MDCT scanners. Advances in CT hardware have resulted in shorter scanning times. Breath holds of 5 s for the scout film and 10 s for abdominal scans are the norm now. A 2003 study by Pickhardt et al. [2] brought about changes to CTC technique. Two tagging agents are used: 2% w/v barium sulphate to tag stool and iohexol (Omnipaque) to tag remaining fluid (see Table 9.1 in Chap. 9). In the study by Pickhardt et al. [2], two tagging agents were administered to all participants (patients) prior to the CTC procedure. The author uses 2% w/v barium sulphate to tag stool and iohexol (Omnipaque) to tag remaining fluid (see Table 9.1 in Chap. 9). Apart from tagging stool, barium has been shown to also lightly cover a polyp, thereby making it more conspicuous on 2D (two-dimensional) viewing. A useful tip is to scroll carefully through the polyp to assess if soft tissue is present underlying the barium. A fairly recent paper underscores that contrast coating of a flat polyp can act as a marker for detection (Fig. 10.1) [7].

The relatively high-density barium has several disadvantages thus its use is not recommended for routine use in CTC examinations. If 40% w/v barium sulphate is used for a CTC study, this does not include a cathartic bowel cleansing or fluid tagging [8]. The use of 40% w/v barium sulphate will prevent a same-day optical colonoscopy (OC) examination being performed. Electronic cleansing (EC) is not currently routinely performed because it may cause a large number of artefacts that could make interpretation difficult [8]. Part of the surface mucosa may be electronically removed and could result in missed lesions. Promising results have been reported in the use of deep learning electronic cleansing for single, and dual-energy CTC to resolve EC caused artefacts [9].

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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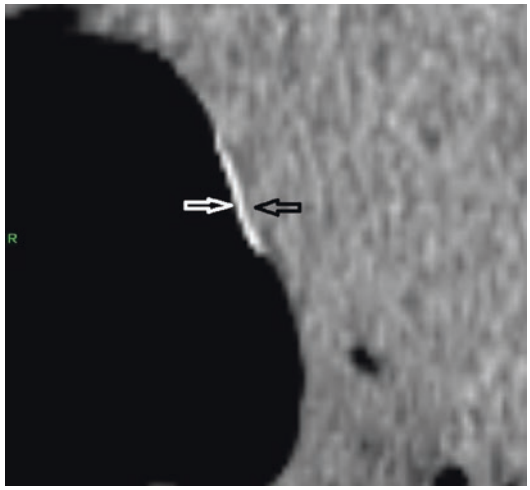

Fig. 10.1 2D axial view showing flat lesion in caecal pole. Note the thin layer of barium (open white arrow) covering the soft tissue (open black arrow)

CTC examinations are straightforward when a clean bowel and an adequately distended colon are imaged with an MDCT scanner. The role of CT software is important in CTC: clinically significant polyps can be readily detected with dedicated software [10]. All CTC components must be in place to perform a successful examination. This entails (1) patient compliance in terms of bowel preparation, (2) an adequately distended colon, (3) the use of at least a 16-slice MDCT scanner, and (4) interpretation of images using a dedicated 3D platform. These components are interdependent. A deficiency in any of them can cause a poor CTC result [11]. Chapter 9 focuses on bowel preparation, the role of tagging, and the use of automated-carbon dioxide (CO_2) insufflation. CTC technique and methods of interpreting images are the main focus in this chapter.

The following abbreviations are used in this chapter

- AI: artificial intelligence
- CAD: computer-aided detection
- CCE: colon capsule endoscopy
- CO_2: carbon dioxide
- CRC: colorectal cancer
- ECFs: extracolonic findings
- ICV: ileocaecal valve
- LLD: left lateral decubitus
- MDCT: multidetector computed tomography
- MPR: multiplanar reformation
- OC: optical colonoscopy
- RLD: right lateral decubitus
- TD: translucent display
- 3D: three-dimensional
- 2D: two-dimensional
- UK: United Kingdom
- USA: United States of America

10.2 Indications and Contraindications

Table 10.1 presents indications and contraindications for CTC. These must be covered when informed consent is obtained from patients.

Table 10.1 Indications and contraindications for CTC

Indications	Contraindications
• Screening of asymptomatic adults at average risk for colorectal cancer • Following failed or incomplete optical colonoscopy • Asymptomatic patients with a positive family history • All patients on anticoagulant therapy needing colorectal screening • Surveillance following resection of polyps or cancer • Surveillance of unresected 6–9 mm polyps detected at CTC • Unexplained gastrointestinal (GI) bleeding; iron deficiency anaemia; unexplained GI symptoms	• Active inflammatory bowel disease (e.g., Crohn's disease; ulcerative colitis) • Routine follow-up of inflammatory bowel disease • Recent deep endoscopic biopsy or polypectomy—wait 4–6 weeks before performing a CTC • Known or suspected colonic perforation • Any symptomatic acute colitis (e.g., patient has abdominal pain, diarrhoea with passage of blood or mucus) • Colon containing inguinal hernia • Acute diverticulitis—wait 6 weeks post-conservative treatment before performing a CTC • Acute diarrhoea • Pregnancy • Hereditary polyposis or non-polyposis cancer syndrome • Known or suspected bowel obstruction

10.3 Colonic Classifications

A C0–C4 classification is used when reporting CTC findings. Table 10.2 presents the colonic classifications. For example, as shown in Table 10.2 a non-diagnostic study would be classified as C0 and a normal colon or benign lesion as C1. If a polyp or possibly an advanced adenoma were noted in the study, the classification would be C3. A revised C-RAD classification is work in progress and should be published in the near future.

Table 10.2 Colonic classifications

C0	Inadequate study
C1	Normal colon or benign lesion; continue routine screening every 5 years • No visible abnormalities of the colon • No polyp ≥6 mm • Lipoma or inverted diverticulum • Non-neoplastic findings, for example, colonic diverticula
C2	Small polyps. Surveillance or colonoscopy recommended • Small polyp 6–9 mm: 1 or 2 (i.e. <3 in number)
C3	Polyp, possibly advanced adenoma: follow-up colonoscopy recommended • Polyp ≥10 mm • Polyps ≥3.6–9 mm (↑ risk of developing advanced adenoma)
C4	Colonic mass, likely malignant; surgical consultation recommended • Malignant appearing colonic mass detected, which may compromise bowel lumen or demonstrate extracolonic invasion, such as lymphadenopathy or distant metastases

Adapted from [12]

10.4 Positioning and Introduction of CO_2

Before commencing a CTC examination, the patient is sent to the restroom/lavatory as the rectum must be emptied of any residual fluid [11]. The patient is requested to remove all clothing and wear a disposable gown with the opening at the back. Ensure there are no metal objects on the patient. Record any prosthetics as these could cause artefacts on the final image.

As discussed in Chap. 9, the colon is distended with CO_2. The author uses an automated pressure-controlled CO_2 insufflator. It is essential to check that there is sufficient CO_2 in the cylinder before commencing a study.

Most times, a CTC study only requires a 180° two-view series: supine and prone. A 90° two-view CTC study that comprises supine and right lateral decubitus (RLD) may not clear the ileocaecal valve (ICV) of fluid. The RLD series is therefore used for obese patients, and poor colon distension as well as single or multiple breaks in the colon outline. The transverse colon is often compressed, with resultant non-filling of the segment, in obese patients in the prone position. Figure 10.2a(i) and (ii) illustrate the value of an RLD when there are multiple breaks in the two-view scans. Figure 10.2b is a synopsis of the CTC technique described below.

The patient is positioned feet first in a left lateral position in the scanner. A sterile disposable soft small-gauge rubber rectal catheter (25F or smaller) is then gently inserted into the rectum and the balloon is insufflated with 20–25 cc of air employing a 2-way connection (3-way connec-

tion catheters are no longer available in the USA; they are available in the UK) as shown in Fig. 10.2c. Important to check that the catheter is in the rectum and not the vagina before commencing insufflation in all female patients.

The automated pressure-controlled CO_2 insufflator is switched on and the pressure set to 15 mmHg to enable the CO_2 to gently flow at low pressure into the descending colon until one litre (1 L) of CO_2 has been introduced [11]. The amount of CO_2 is indicated on the gauge. Figure 10.2d is a close-up view of the dials of an insufflator (PROTOCO$_2$L—Bracco). At this point, turn the patient prone and then immediately onto the right side to fill the proximal transverse and ascending colon. The pressure at this stage may be increased to 20 mmHg to distend the colon. When the volume reaches 2 L, return the patient to the supine position and commence scanning. For all scans, instruct the patient to inhale, then exhale, and suspend breathing during scanning. Scanning is performed in exhalation as this elevates the diaphragm and allows the colon and flexures to expand [11]. The first breath hold (5 s) allows acquisition of the scout film. Once this film is reviewed, inform the patient that a full supine scan of the abdomen will commence. Duration of breath hold depends on the type of CT scanner used. The higher the scanning rating, the shorter the breath hold. For example, a patient needs to maintain a 10 s breath hold with a 16-slice scanner, whereas a longer breath hold would be necessary with a 4-slice scanner (see Chap. 4 for advances in CT scanners).

The CO_2 insufflator is switched off whilst the patient is turned prone. This is done because elderly and obese patients may have trouble turning prone and the intracolonic pressure rises rapidly, often above 60 mmHg, thereby triggering the machine alarm [11]. The deflation manoeuvre

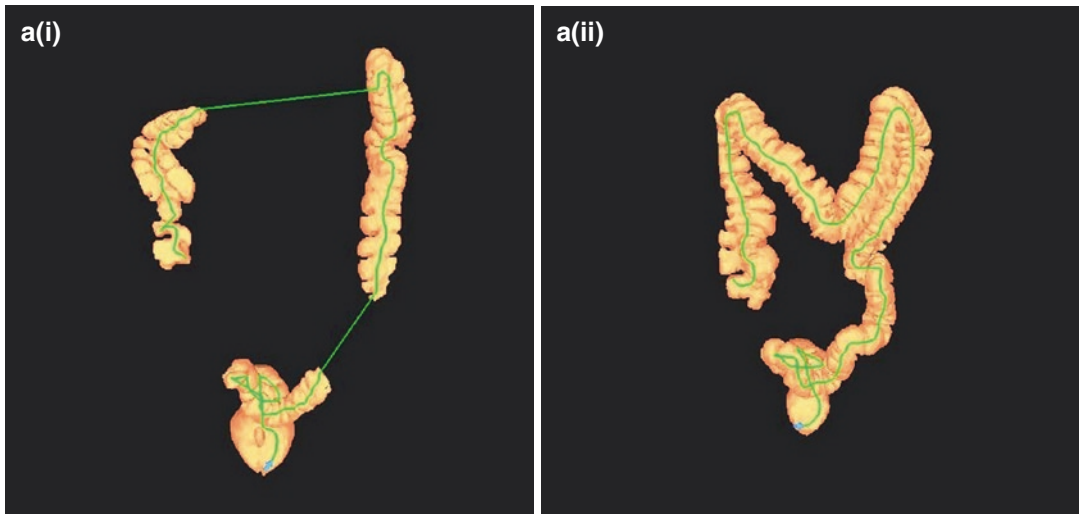

Fig. 10.2 (**a**) (**i**) Colon view showing breaks in colon filling. (**a**) (**ii**) Complete filling of colon in the RLD scan.(**b**)

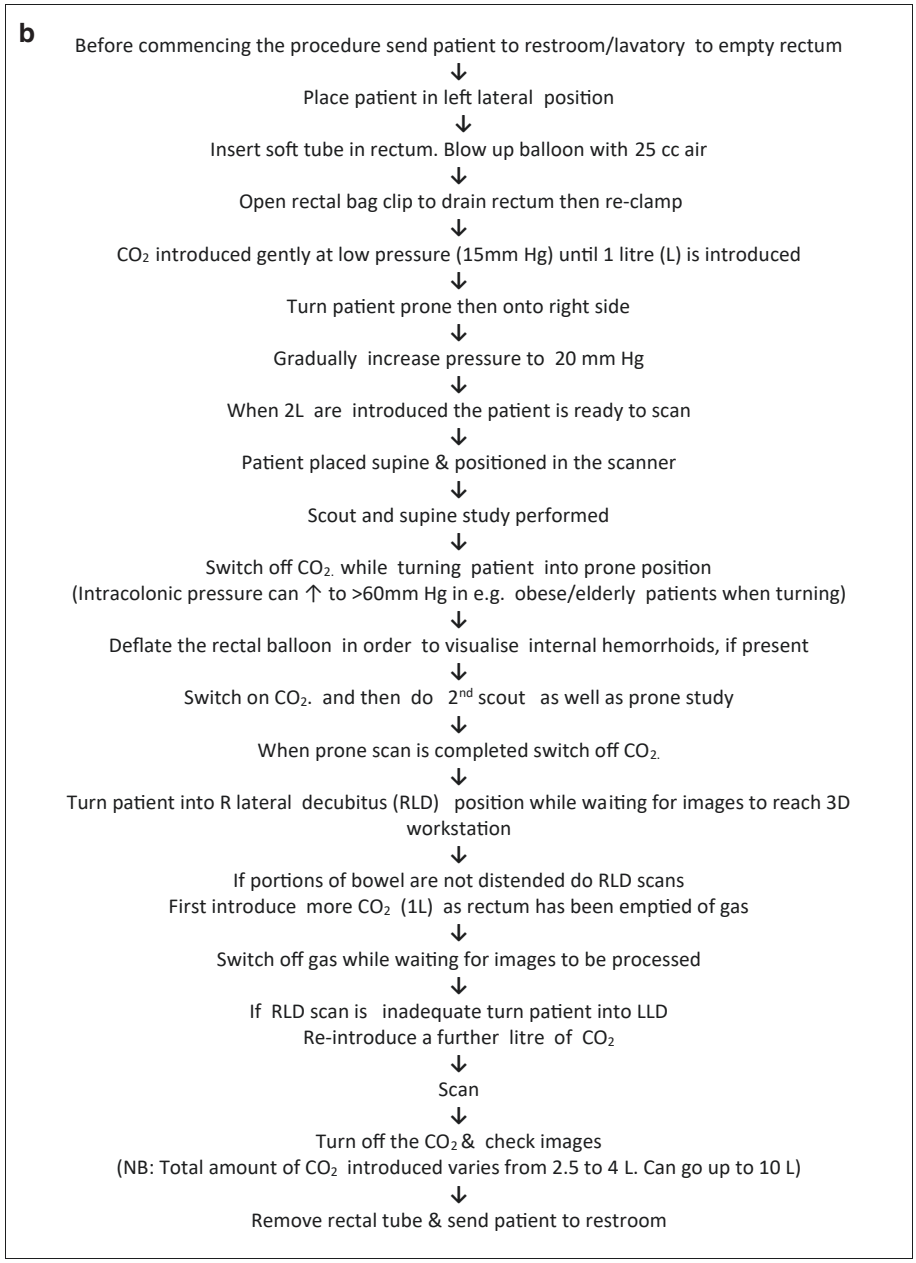

Fig. 10.2 Schematic presentation of CTC technique.

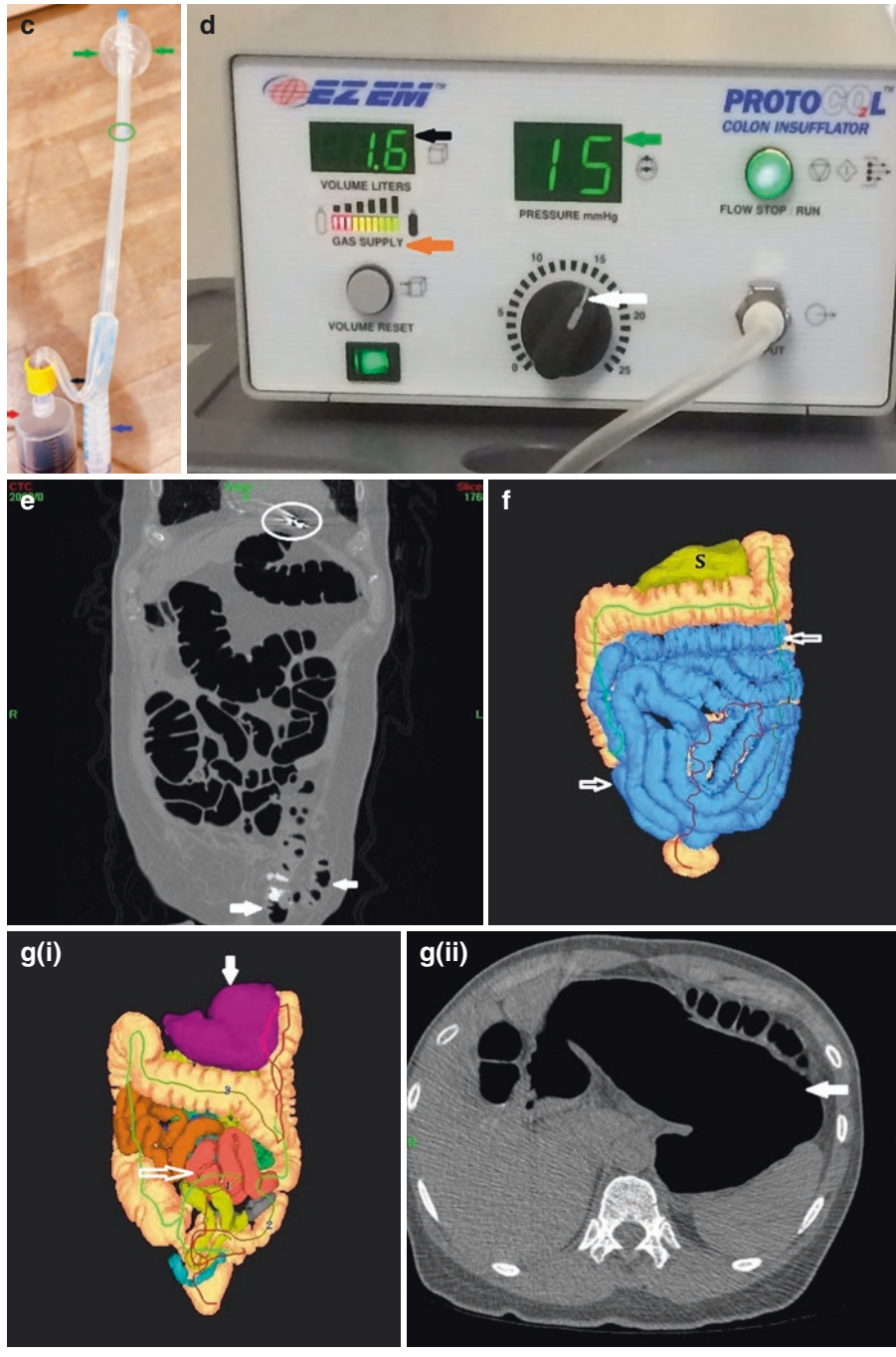

Fig. 10.2 (**c**) Green arrows indicate inflated balloon. The catheter must not be inserted into the rectum beyond the blue dot (green circle). Black arrow indicates the port through which 25 cc of air is injected to inflate the balloon. Syringe containing room air (red arrow). Connection between rectal tube and tube from CO_2 insufflator (blue arrow). (**d**) Close-up of CO_2 insufflator. Black arrow = litres of CO_2 insufflated (1.6 L). Green arrow = pressure in mmHg (15 mmHg) recording rectal pressure, and the white arrow on back dial shows the insufflation pressure at start of procedure. These two readings may be discordant when rectal pressure increases above 15 mmHg and no flow of CO_2 can occur. Orange arrow indicates volume of CO_2 in the cylinder. (**e**) 2D coronal view shows sigmoid colon in left inguinal region (white arrows). Note the pacemaker wires (white circle). (**f**) Colon-map showing air in small bowel (open white arrows). *S* stomach. (**g**) (**i**). Air in stomach (closed white arrow). Note excessive air in small bowel (open white arrow). (**g**) (**ii**) 2D axial view of stomach distension (arrow)

is used by some radiologists after completion of the supine scan by emptying the rectum of air and then re-inflating for the prone scan; this reduces the incidence of pain [13]. From time to time, it may not be possible for some patients to turn into the prone position: a lateral decubitus view will be required instead. Ensure when scanning in the prone position that a pillow, which is placed under the patient's chest, does not impinge on the abdomen [11].

Before introducing CO_2 the balloon is deflated when the patient is in the prone position. This is done for two reasons: to obtain a full scan series without an inflated balloon, as it may obscure good visualisation of the distal rectum, and to better visualise internal haemorrhoids, if present (see Chap. 13). When the balloon is deflated, the CO_2 insufflator is switched on. The patient is positioned for scanning. A scout film is taken on exhalation and breath hold of about 5 s. The abdominal scan usually takes 10 s. When the prone scan is completed, the insufflator is switched off. The patient is turned into the RLD position whilst the images are examined by either a radiologist or appropriately trained radiographer. The reason for placing the patient in this position is because an RLD series may be required. On average, the acquisition and assessment of a two-view CTC study takes no more than 5 min. A CTC study requires on average between 15 and 20 min' room time. Note that extracolonic structures are also imaged during scanning. If a patient is poorly prepared, and there is a lot of faecal material in the large bowel which is felt to make the study non-diagnostic (C0), then the radiologist/radiographer has not completed the examination unless a full report is given on any extracolonic findings that may be present.

Adequate distension does not imply complete distension of all segments in all cases. Should areas of poor distension be identified in the same areas in both the supine and prone positions, in particular the sigmoid colon in cases of diverticular disease, then the patient is ready to be scanned in the RLD position. The main reason for an additional view is because moderate or severe diverticular disease (see Chap. 16) usually results in inadequate distension of the sigmoid colon. Scanning on breath hold can recommence. Whilst waiting for the images to be processed, the CO_2 is switched off. In a rare case where the RLD is unable to distend the appropriate area, the patient is turned into the left lateral decubitus (LLD) position. The CO_2 is switched on and the patient re-scanned. Occasionally, it may happen that a four-view series fails to distend the colon adequately. The author then takes another supine scan because the bowel may have relaxed to allow for adequate distension.

Pain is not a feature of CTC. In the event of a patient complaining of pain early on in the procedure, it is important to immediately check the inguinal regions for possible bowel herniation (Fig. 10.2e) [11]. If no herniation is evident, then the most likely cause of pain is underlying diverticular disease (see Chap. 16). As stated previously, it is essential in female patients to check that the catheter is in the rectum and not the vagina.

If a spasmolytic is used, it may relax the ICV and result in the small bowel filling with air (Fig. 10.2f). Occasionally, the valve may be incompetent without the use of a spasmolytic. Carbon dioxide refluxes into the small bowel, and it may rapidly reach the stomach (Fig. 10.2g(i) and (ii)). When this occurs, the patient usually complains of nausea and often breaks into a sweat. It is essential to instruct the patient to burp as this causes immediate relief [11].

10.5 Evaluation of Polypoidal Lesions

There are clues that allow differentiation between a polypoidal lesion and stool: 2D and 3D (three-dimensional) views are complementary. The former is the most useful method for making the distinction. When a polypoidal lesion is observed on 3D endoluminal fly-through, it is important to ascertain whether it is a polyp or stool. The latter can mimic a polyp; particularly in patients with sub-optimal bowel preparation. The following steps should be performed.

- Evaluate the lesion using 2D viewing and check for the presence of air within the lesion. If air is present, it is stool and not a polyp.
- Note the position of the lesion during postural change. Does it move or not?
- Use translucent display (TD) software, if available. TD enables one to evaluate below the surface of the mucosa.

It is important to evaluate a polypoidal lesion by performing 2D viewing with multiplanar views. The position of a polypoidal lesion, in both the supine and prone views, must be checked. If there is movement due to postural change, then this favours stool rather than polyp. Most typically, stool will move to the opposite wall when a patient is turned from the supine to the prone position. Beware of the pedunculated polyp on a long stalk which may move with postural change [11]. A sessile polyp does not move with postural change; sessile polyps are fixed to the colon wall or haustral folds thus they do not shift in position. However, a paper by Laks et al. [14] showed that 27% of polyps moved from an anterior location to a posterior one relative to the colonic surface when a patient turned from the supine to prone position. In other words, the polyps appeared to be mobile, but the polyp mobility was related to positional changes of the colon due to lax mesentery. Therefore, the shift in polyp location is not true mobility of the polyp. A further caveat to this is that occasionally a polyp is noted to move in position. It is not the polyp that moves, but the segment of the colon in which it lies. Bowel segments that may move are the sigmoid colon, which may be redundant, the transverse colon, and the ascending colon (see Chap. 11). The structure would favour stool and not a polyp if movement is detected. In most cases, stool moves, but occasionally it may be adherent to the colon wall.

To distinguish between stool and polyp on 2D viewing the following observations can be made

- Areas of internal gas, or areas of high attenuation, indicate the lesion is residual faecal matter and not a polyp.
- Polyps are homogenous in attenuation.
- Morphology of a lesion. Small polyps and cancers may have lobulated rounded borders.
- Residual faecal material may look similar. However, if it shows irregular angulated borders or geometric pattern it is residual faecal material.
- Mobility of a lesion. Stool tends to move to the dependent surface of the mucosa in 180° postural change. Pedunculated polyps, and occasionally soft tissue polyps, may move depending on what section of the colon they are present in.

The colon is not a fixed structure; positional abnormalities are common [15]. The sigmoid colon, transverse colon, and caecum are located in the peritoneal cavity. These bowel segments may be on a long mesentery, which allows them to rotate on the mesentery. The rectum, descending colon, and ascending colon are located in the extra-peritoneal space. Portions of the ascending colon, however, are frequently mobile.

It is important during 2D viewing to check for the presence of air within the lesion (Fig. 10.3a). If air is evident this would confirm that stool is the cause of the lesion. Stool is favoured if there is mixed heterogeneity within the polypoidal lesion. Stool is a potential CTC pitfall in image interpretation; hence, it is covered in greater detail in Chap. 12.

A 3D TD is a Viatronix software tool. It provides a semi-transparent view in different colours beneath the surface [16]. The software's different colour attenuation values are: red indicates soft tissue; white indicates high attenuation values, such as barium; green indicates negative values in the fat attenuation range; and blue indicates negative values, such as air [17]. The use of TD allows for visualisation of the composition of a polypoidal lesion. On TD a polyp will have a high intensity (red) centre, surrounded by a thin layer of green (fatty tissue) and a blue layer which is air as shown in Fig. 10.3b(i). If the lesion is stool, the high intensity is usually of mixed density. As discussed in Chap. 9, barium tags stool in the colon. In most cases, if barium makes up the entire polypoidal lesion, then this

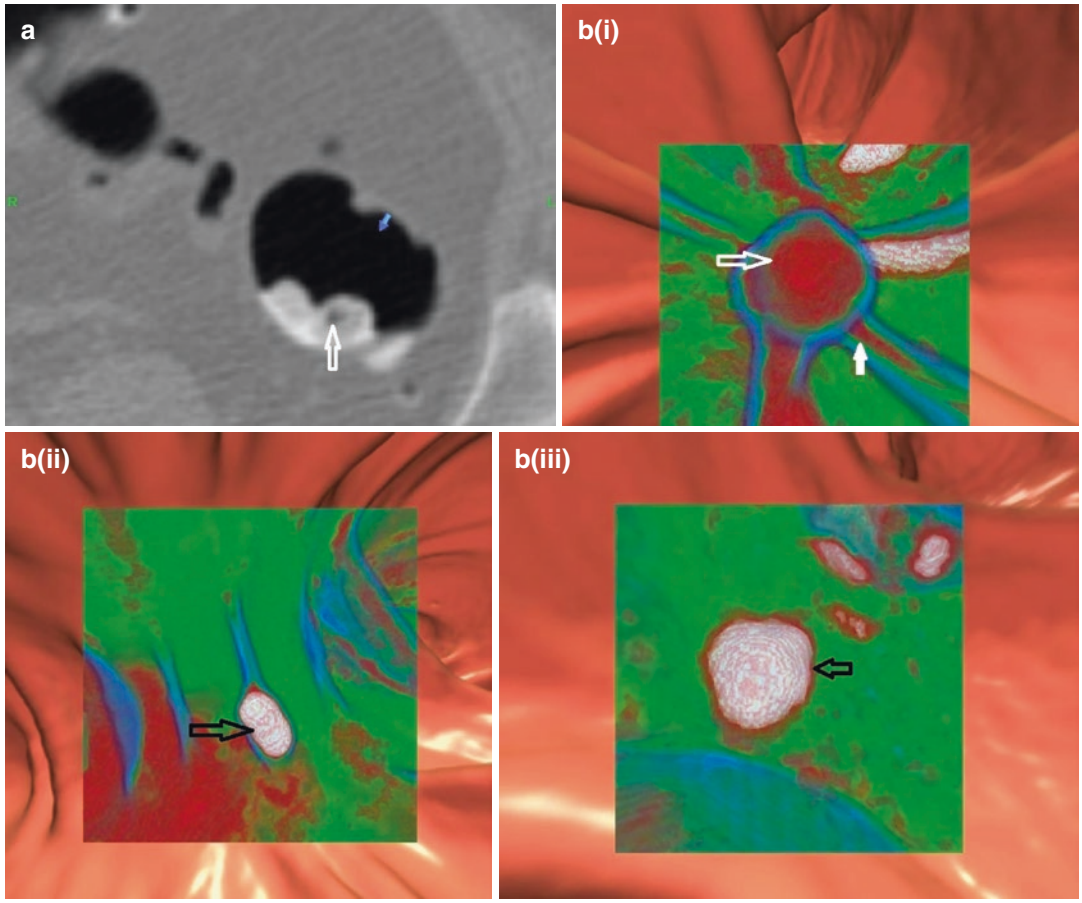

Fig. 10.3 (**a**) 2D view shows air in stool (white arrow). (**b**) (**i**) Translucent display (TD) of a pedunculated polyp showing high intensity red centre (open white arrow) as well as high intensity stalk (closed white arrow). Blue = air. Green = fatty tissue. (**b**) (**ii**) TD shows barium covered stool which simulates a polyp on 3D (open black arrow). (**b**) (**iii**) TD showing stool covered with barium (open black arrow)

indicates stool as shown in Fig. 10.3b(ii) and (iii). A TD image that shows a white interior is barium/stool. Barium tends to coat a polyp superficially, making it more conspicuous. Barium cannot get into the centre of a lesion.

The above process may seem to be complicated, but in fact it is an easy one. It can be performed in less than a minute. Measurement of polyps is described in detail in Chap. 14.

10.6 Diagnostic CTC Following Incomplete OC

Failure to reach the caecum during OC represents an incomplete or failed examination. The percentage of OC studies which may be incomplete shows a wide variation from 0.4 to 15% [18, 19]. Reasons for a failed OC might include older patients, female gender, colon length, number of acute angle bends and flexures, advanced diverticular disease, prior abdominal surgery, occlusive cancers, benign strictures, colon containing hernias, intestinal malrotation, and poor bowel preparation (see Chap. 20). From a CTC perspective, this group of patients is the most challenging [11]. They would have predominantly been prepared for an OC using a 'wet' preparation, such as PEG, which results in a large amount of residual colonic fluid, as discussed in Chap. 9. These patients would not have been given pre-procedural contrast or fluid tagging, making it more challenging to exclude false positives, such as stool adherent to the wall.

CTC has been the procedure of choice following an incomplete study as it could be performed as a same-day study on patients who had a failed or incomplete OC. This meant that there was no need for two separate bowel preparations. Patients were referred for a same-day CTC when they were fully conscious. In the absence of tagging agents (barium and Omnipaque), it was necessary to consider a compromise [11]. Recommendations for the use of CTC and bowel preparation steps in failed or incomplete OC cases are discussed in detail in Chap. 20.

Before commencing with patient preparation, it is important to establish whether a recent polypectomy or biopsy (superficial or deep) has been performed. Occasionally, with superficial biopsies, the CO_2 may track submucosally and result in pneumatosis coli [11]. If a deep biopsy or polypectomy has recently been performed, it is advisable to wait at least 4–6 weeks for proper healing of the mucosa before proceeding with the CTC to allow the mucosa to heal (see Table 10.1). Before beginning a CTC study, a pre-procedure low-dose CT scan is taken to assess whether free air is or is not present. It is important to first exclude the possibility of an OC-caused colonic perforation.

There have been rare reports of colonic perforation at CTC, especially in patients with obstructive lesions [20]. A retrospective clinical audit of 17,067 CTC examinations was conducted to determine the incidence of potentially serious adverse events; there were nine perforations (0.052%): four were asymptomatic and five symptomatic [20]. Figure 10.4a(i) to (iii) shows a CTC perforation. The 2021 joint guidance for CTC standards of practice of the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiology recommends that perforation rate should be a continuous auditable outcome [21] (see Chap. 27).

Approximately 50% of patients with colonic perforations do not have symptoms. The author performs a low-dose CT scan, comprising 10 mm slice thickness at 10 mm intervals, before inserting a rectal catheter [2]. The images are viewed and, if any extra-luminal air is present, a CTC is not performed. Figure 10.4b shows colonic perforation following an incomplete OC. The referring clinician must be immediately informed of this CT finding. If no free air is identified to suggest perforation, the scanning protocol in Fig. 10.2b is implemented.

Hough et al. [22] reported a total effective dose of 0.9 mSv for men and 1.2 mSv for women in low-dose abdomino-pelvic CT to exclude perforation. Alternative techniques may be used, such as a slice through the upper, middle, and lower abdomen. These increased gaps may be a trade-off for sensitivity. Professor Pickhardt (personal email correspondence, May 2014) stated that low-dose CT is preferred to erect plain-film radiographs. According to him, the latter only excludes free air whereas most perforations have contained extra-luminal gas, retroperitoneally or intramural [11].

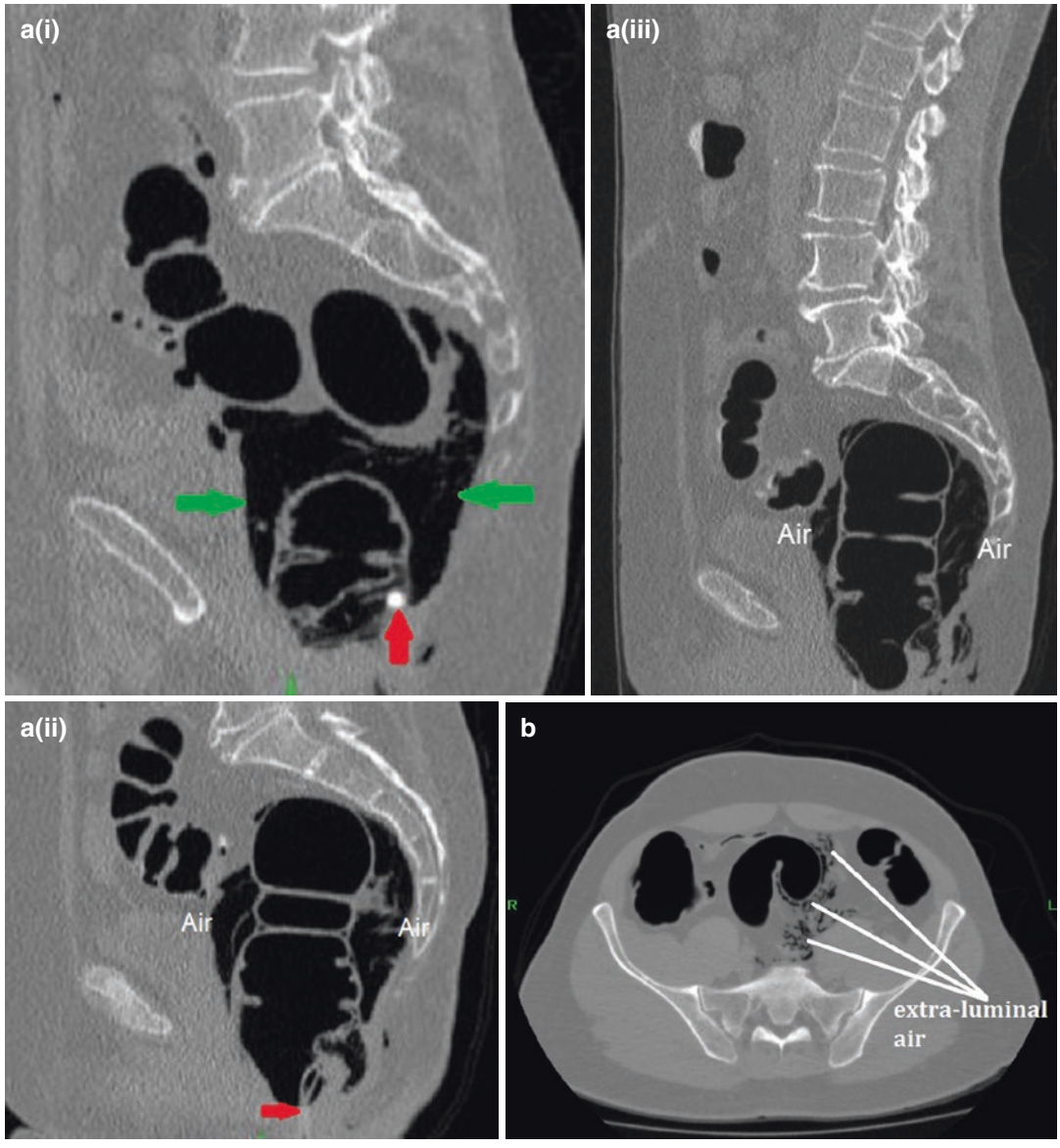

Fig. 10.4 (**a**) (**i**) Sagittal view showing tube/catheter tip (red arrow) exiting wall of rectum which is surrounded by air (green arrows). No intraperitoneal air noted. (**a**) (**ii**) Prone sagittal view showing rectum perforated by tube (red arrow). Air is surrounding the rectum anteriorly and posteriorly. (**a**) (**iii**) Prone sagittal view 1 h after removal of the tube. Far less air compared to (**i**). (**b**) 2D axial view shows extra-luminal air indicating colonic perforation following an optical colonoscopy

10.7 Diagnostic CTC Versus Colon Capsule Endoscopy Following Incomplete OC

In 2011, colon capsule endoscopy (CCE) was introduced, and a second-generation capsule has been available since 2014. The angle of view of images was increased from 156° to 172°. Two cameras are present and a full mucosal view is therefore obtained. The PillCam Colon 2 (Given Imaging Inc., Yoqneam, Israel) can photograph 4 FPS (frames per second) when stationary, and 35 FPS when moving. A 2015 study reported that CCE's sensitivity and specificity was 88% and 82%, respectively, in terms of identifying conventional adenomas 6 mm or larger [18]. The conclusion of another study, which compared CCE and CTC in patients with incomplete colonoscopy, was that both tools were of comparable efficacy in terms of colon evaluation [23]. A comparative study of the preference of patients who had undergone both an OC and CCE study found that they far preferred CCE [24]. Battery life is a disadvantage in CCE and a possible solution could be video compression [25]. Use of artificial intelligence (AI) algorithms in CCE may increase visualisation of complete colon mucosa [26]. Detection of lesions outside of the colon is a main advantage of CTC: this is not possible with CCE and OC. Chapter 20 includes patient preparation and a description of second-generation PillCam for CCE.

10.8 Tattooing to Identify Polyps and CRC Lesions During Endoscopy

Tattooing is the technique whereby lesions in the colon lumen can be marked during OC by injecting Indian ink into the submucosa of lesions [27]. It can be used to indicate the position of a lesion in any part of the colon for visualisation during laparoscopic surgery. It is useful for minimally invasive surgery [28]; it is a safe and relatively easy technique which helps to identify lesions that cannot be felt manually during laparoscopic surgery [27]. It is being used more frequently during OC when it is not possible to completely remove an identified polyp [27]: tattooing thus indicates the location of remnants when a follow-up OC is performed. Literature recommends that CRC lesions should be tattooed during a patient's first endoscopy [29]. The benefit of tattooing is that it has an accuracy rate of between 70 and 100% [30]. Tattooing is part of best practice in terms of patient outcomes [29].

10.9 Extracolonic Findings

CTC screening is usually performed in healthy asymptomatic individuals using supine and prone scans without intravenous (IV) contrast [1]. As a result of the scan views, extracolonic structures are visualised. An advantage of CTC, compared with other CRC screening tools, such as OC and CCE, is that it is able to detect incidental lesions external to the colon [1]. An automatic retrospective reconstruction of the supine series of all patients is performed for evaluation of extracolonic findings (ECFs). This consists of 5 mm sections at 3 mm intervals. It is important to remember that, when performing the prone series, there is often more coverage and certain lesions, such as those from lung cancer, may only be detected on prone imaging. ECFs are covered in Chap. 18 and examples of ECFs in incomplete and failed OC cases are presented in Chap. 20.

10.10 Interpretation

A successful CTC is not difficult to perform if the bowel is clean and the colon is well distended. There are two methods available to read the scans: 2D and 3D. Some proponents prefer using 2D as a primary approach with 3D reserved for problem-solving, whereas others prefer 3D as the primary method, with 2D for problem-solving [1, 31]. Readers need to be skilled in both interpretation methods. For 2D polyp detection, the window setting should be at a window width of 2000 and centred at 0 to −200 [16]. Soft tissue windows are set at 400 with a centre of 50. Sessile polyps have a round or ovoid morphology and are

of soft-tissue density. These should be visualised in both prone and supine scans as their position is not affected by postural change, except possibly the previously mentioned portions of the bowel which may be mobile. Stool, on the other hand, does move as previously discussed. Air is often visible in the stool, giving it a heterogeneous appearance. One must beware the pedunculated polyp on a long stalk in terms of postural change as evident in Fig. 10.5a(i) and (ii) [11].

According to Pickhardt et al. [31] primary 3D evaluation is preferable; they advocate the use of 2D for evaluation of polyp/stool differentiation. They maintain that this approach is easy, quick and extremely accurate. They conducted research on the accuracy of readers when using 2D compared with 3D [31]. Primary 2D CTC, according to them, is less sensitive than primary 3D CTC for polyp detection in low-prevalence screening cohorts.

All current systems allow improved 3D fly-through. The author's preference is a primary 3D system, such as the Viatronix V3D system (Stonybrook, New York), but there are other

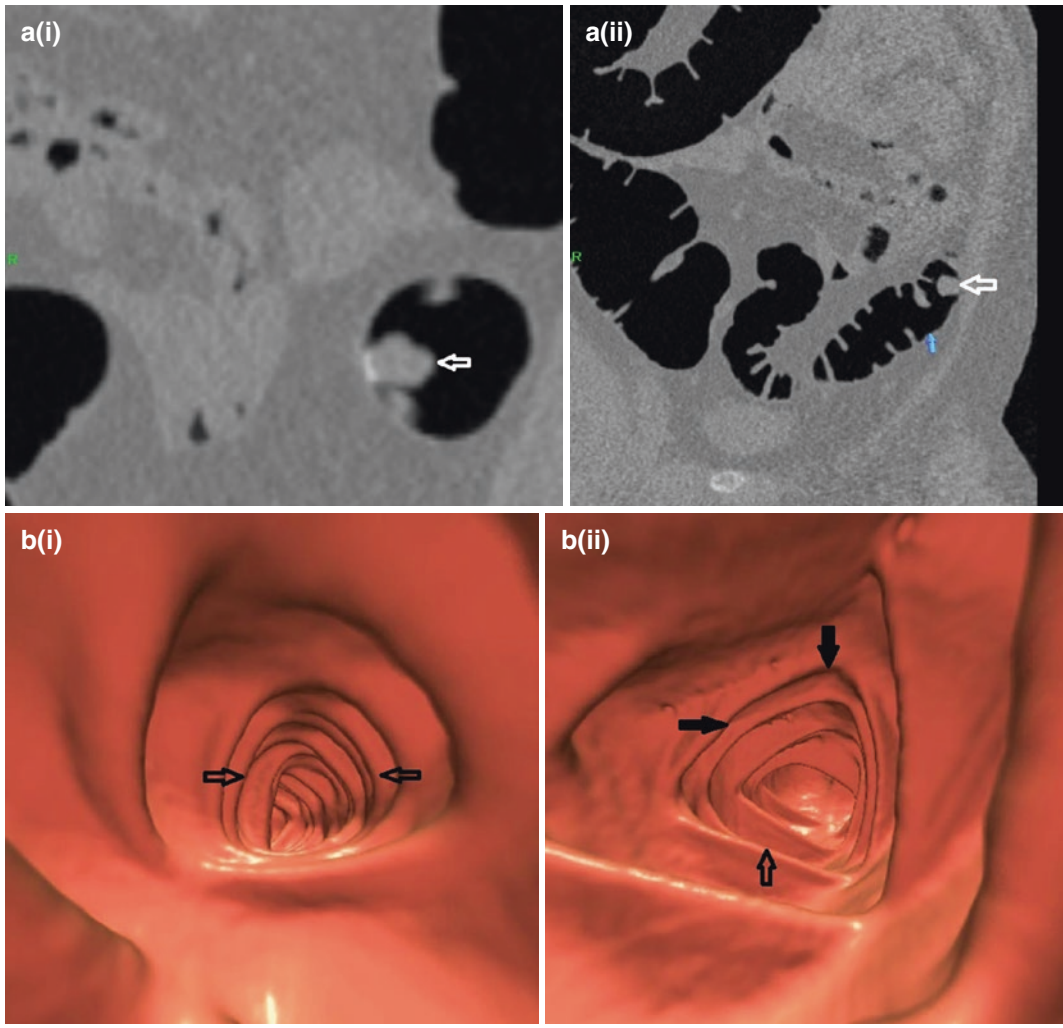

Fig. 10.5 (**a**) (**i**) 2D supine view shows pedunculated polyp on medial wall of colon (arrow). (**a**) (**ii**) 2D prone view shows movement of pedunculated polyp to the lateral wall of colon (arrow). (**b**) (**i**) 3D showing circular fold in descending colon (arrows). (**b**) (**ii**) 3D view showing triangular fold of ascending colon (arrows).

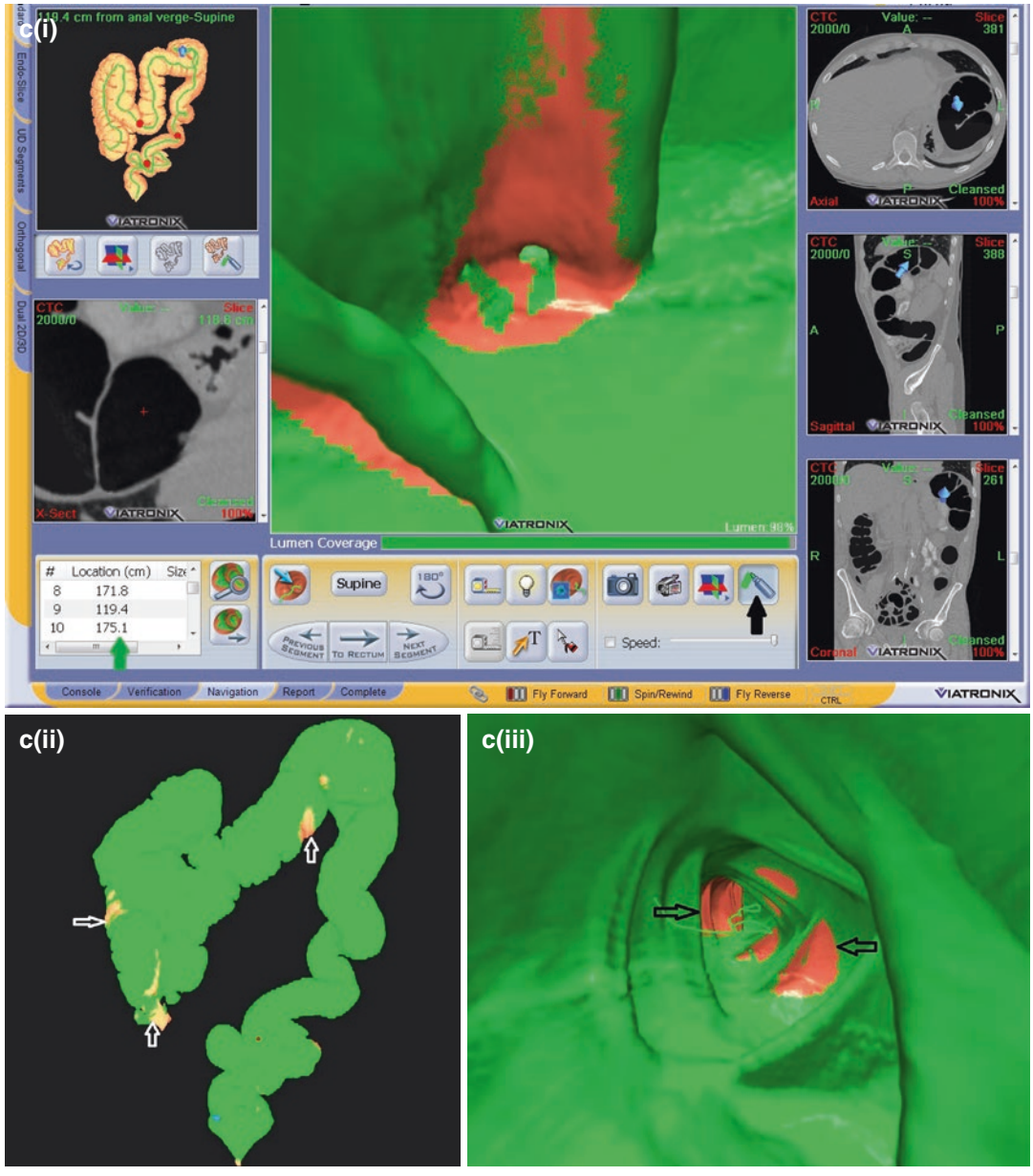

Fig. 10.5 (**c**) (**i**) Viatronix V3D workstation showing all the icons. Spray can icon (black arrow). Green arrow = location of total number of missed areas and their distance from anal verge (Image courtesy of Viatronix, Stony Brook, New York). (**c**) (**ii**) Colon view showing three missed areas (arrows): caecum, ascending colon and distal transverse colon. (**c**) (**iii**) 3D endoluminal view. Pink (arrows) indicates region not visualised (missed regions).

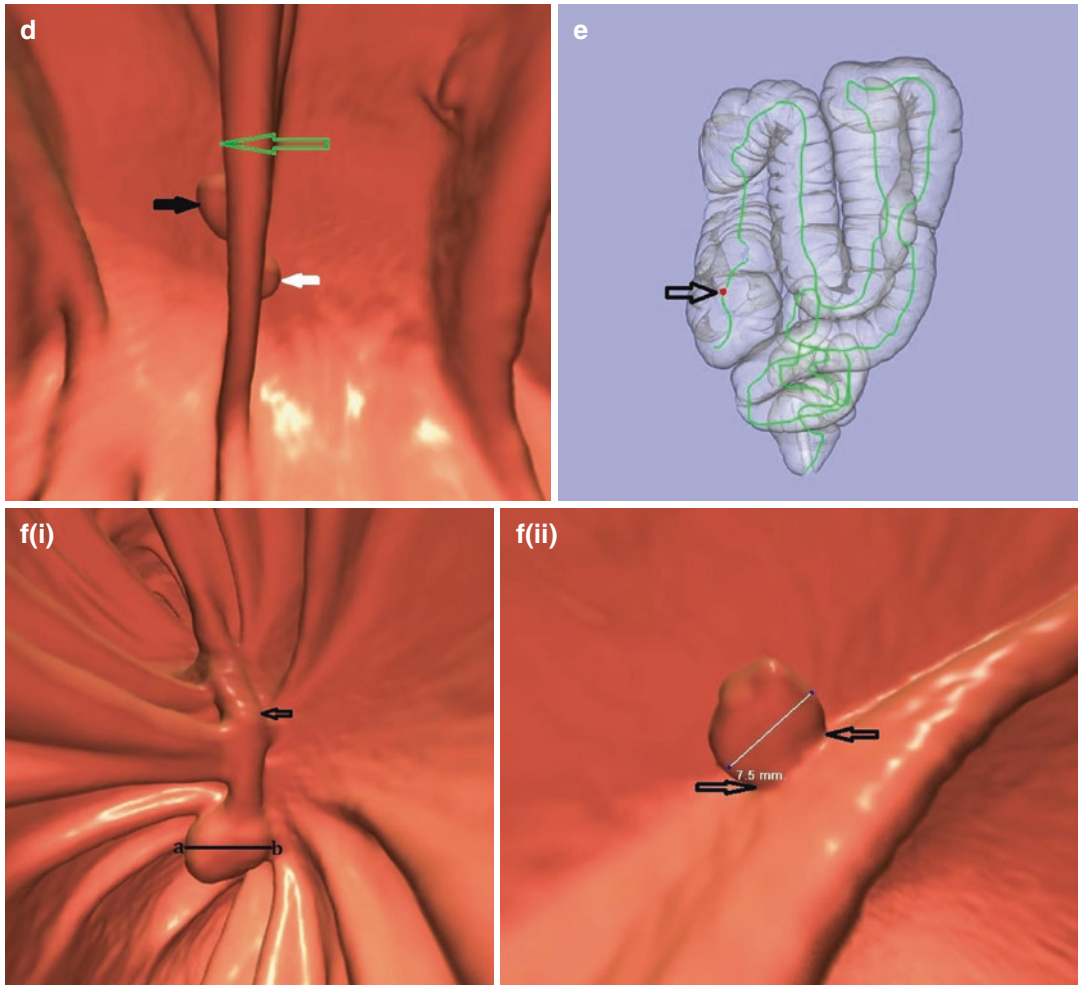

Fig. 10.5 (**d**) Black arrow points to a sessile polyp on posterior haustral fold. White arrow points to a smaller sessile polyp on anterior haustral fold. Open green arrow indicates flight from rectum to caecum. (**e**) Colon-map with a 'bookmark' red dot indicating site of lesion (open black arrow). Note green centreline. (**f**) (**i**) Pedunculated polyp (head = a–b). Long stalk (open black arrow). (**f**) (**ii**) 3D view of a small sessile polyp (diameter = 7.5 mm). Base of polyp (open black arrows)

options. The author's standard protocol is to perform supine and prone scans; additional views in the RLD and LLD may be required. Changing a patient's position by 180° allows shifting of pooled liquid, as well as movement of stool, from one wall to the opposite wall [11]. A retrograde fly-through from the rectum to the caecum covers only a maximum of 90% of colonic mucosa. This is the maximum percentage of mucosa visualised at OC on withdrawal of the scope. In CTC the total bowel mucosa is visualised four times: from the rectum to the caecum (retrograde navigation) and back from caecum to the rectum (antegrade navigation) in the supine position, and again in the prone series. This means that 100% of colonic mucosa is visualised.

For CTC interpretation the 3D surface-rendered image (colon-map) and automated centreline are essential for effective 3D evaluation. The centreline allows for an automated fly-through. The 3D map provides precise location in real-time, and allows for bookmarks to be placed indicating site of lesion. It also indicates relevant anatomy, such as an excessively tortuous portion of bowel (see Chap. 20). A centreline is automatically generated and continues in a retrograde fashion to the caecum and ICV. An icon is then clicked which reverses the fly-through from the caecum to the rectum [11]. The same is done in the prone study. It takes less than 2 min to perform this bidirectional flight.

The field-of-view (FOV) setting for Viatronix is 120° as this provides a good field of evaluation with no geometric distortion. Using a FOV of 120° allows for approximately 90% coverage for a single one-way fly-through. A second complete fly-through in the opposite direction allows for coverage of approximately 96%. The folds in the left colon (anal verge to splenic flexure) are usually circular; in the right colon (caecum to splenic flexure) they become triangular (Fig. 10.5b(i) and (ii)).

A 'missed region' tool is available on Viatronix whereby the operator can quickly flip through the unseen areas by clicking on an icon (Fig. 10.5c(i)). By doing this adds about an extra 30 s per study. To detect any lesions, which may have been missed, a click on the spray can icon colours the visualised areas of the bowel green (Fig. 10.5c(ii)). The regions that have not been visualised are pink (Fig. 10.5c(iii)). Clicking on the detect missed region icon takes the viewer automatically to the different missed regions until 100% of the bowel is visualised. Note that flying unidirectional only results in about 90% coverage of the colon.

A colour-density map is used to assess the density of any protrusions suggestive of polyps or stool that are encountered on the way. Polyps appear as red, barium appears white, and lipomas display as green coloration. The anterior surface of a colon fold faces the rectum and anus; the posterior surface of the fold faces the caecum and ICV (Fig. 10.5d). The anterior folds are seen on a retrograde fly-through from the rectum; the posterior ones are seen on the reverse fly-through from the caecum. A 'bookmark' or red dot can be placed on the colon outline to indicate the site of a polyp or carcinoma. The bookmark is useful if a subsequent OC needs to be done [11]. The red dot indicates the site of the lesion as well as the distance from the anal verge (Fig. 10.5e). The green line indicates the automated centreline.

How to manage polyps is important. Radiologists, and appropriately trained radiographers, need to have a working knowledge of polyp morphology and how to measure polyps, [21] as well as what recommendations to make when polyps are present. It is advisable to include the following disclaimer in all CTC reports: 'CTC is not intended for detection of diminutive polyps (≤5 mm), the presence or absence of which will not change the clinical management of the patient' [11]. A reporting template is included in Chap. 21.

Some software allows one to decide which view is best to measure polyps, and is covered in Chap. 14. The head of a pedunculated polyp is measured; the length of its stalk is not measured (Fig. 10.5f(i)). The largest diameter of a sessile polyp is measured (Fig. 10.5f(ii)). Polyps of 6–9 mm are termed small (see Table 10.2). A study is considered positive when a lesion ≥6 mm is detected. If there are three or more polyps in the 6–9 mm range, OC is recommended on the same day (see Table 10.2). If the polyp burden is one or two (i.e. <3 polyps), an option is a 3 year surveillance (see Table 10.2). If after three years there is an increase in polyp size, the patient can be referred for an OC. Most polyps, however, tend to regress in size. Polyps ≥10 mm are routinely removed. The chance of malignancy is <1% in an asymptomatic low-risk individual [32, 33].

A 2015 study, which involved 9336 adults, reported interesting results in terms of OC's status as the gold standard colon test [34]. The findings underscore that lesions are missed at OC. The study included discordant lesions (findings that were not confirmed with initial OC) and nonblinded lesions (endoscopist provided with advanced knowledge of specific polyp size, loca-

tion, and morphological appearance at CTC). The findings revealed that 144 patients (21.5%) of all discordant lesions were confirmed as false negative at OC, and that these were on average 8.5 mm ± 3 mm in diameter, and were more likely to be in the right colon. In summary, 21.5% of discordant polyps 6 mm or greater were detected at CTC, but not confirmed at subsequent OC [34]. These polyps were later proved to be true positives on CTC, even though the endoscopists had full advanced knowledge prior to the OC of the respective size, location, and CTC morphological appearance of the polyp. Furthermore, of the discordant lesions subsequent follow-up by OC, 40% proved to be CTC true-positive findings. The remaining balances were considered to be CTC false-positive findings as they were not detected at OC. A small percentage had follow-up CTC studies, and the lesions were again identified, which suggested that OC diagnosis of false positives was wrong. In terms of the false-negative findings at OC, 81% were subsequently found to be neoplastic (adenomas or serrated lesions); 43% were advanced lesions, and 89% of advanced lesions were located in the right colon [34]. In a nutshell the findings show that OC is not infallible nor the final arbiter. If a lesion ≥6 mm is detected at CTC, but not at OC, this does not always mean that CTC is wrong. Patient management should be a 3-year surveillance programme, or redo CTC in 3 years to check whether the lesion is still evident; if not present it was probably a false-positive CTC lesion. However, if the lesion is again identified, or if it has grown, then repeat OC is indicated. The characteristics of advanced adenomas should be known (see Table 10.3) [16, 33, 35].

Table 10.3 Criteria of advanced adenoma

• Any adenoma that is large (≥10 mm) and of any histological subtype, namely tubular, tubulovillous, or villous
• Any adenoma of any size that harbours high-grade dysplasia
• Any adenoma of any size that contains a significant villous component (≥25% of tubulovillous or villous histology)

Adapted [35]

10.11 Methods and Software to View CTC Images

CTC interpretation is underpinned by knowledge of both normal and abnormal anatomical variations. CTC produces 2D images comprising axial, multiplanar reformations (MPR) coronal, sagittal, and oblique views, and 3D endoluminal views. What is the best method to analyse data? There is consensus that readers need to be skilled in both 2D and 3D interpretation methods. Given the ongoing technological advances in imaging, there are new CTC display techniques also available, such as the 'filet' dissection' views where the colon is opened up to view for polyps, or the band view [36]. Virtual dissection (filet) view is an alternative 3D Viatronix software tool (Fig. 10.6). The colon is dissected open and flattened. A filet view's appearance is that of a pinned pathology specimen. These specimen type images suffer from geometric distortions thus polyps, especially in the flexure regions, become more difficult to identify. These new techniques speed up interpretation time, but there is distortion of the mucosal folds sometimes making polyp visualisation difficult.

It is important to evaluate polyps in terms of postural change (see Chap. 14). There is a range of available software. All systems today allow for an improved 3D fly-through. Available 3D software systems do not always produce comparative images. The software of independent manufacturers is often superior to that of CT manufacturers. A 2003 comparative study, which was undertaken to directly compare 3D endoluminal capabilities of three commercial systems, found that Viatronix V3D-Colon was the best in terms of an effective time-efficiency primary 3D evaluation [10]. However, technological advances in software over the years have improved and have resulted in several good options. Which is the best method for evaluation of polyps? The acid test is the one that furnishes the best specificity and sensitivity for detection of polyps <6 mm. Pickhardt et al. [2] analysed 1233 asymptomatic patients with 3D and 2D readings. Tagging was employed. Their results of detection of polyps were:

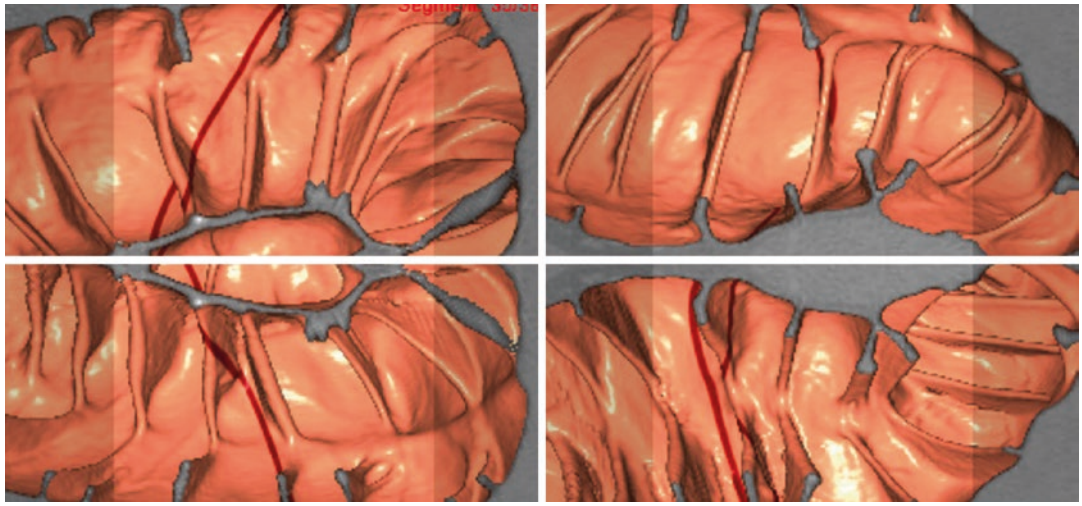

Fig. 10.6 Filet view. Its appearance resembles a pinned pathology specimen

- ≥6 mm 86% sensitivity
- ≥8 mm 93% sensitivity
- ≥10 mm 92% sensitivity.

Computer-aided detection (CAD) systems have become available [37, 38]. These systems are designed primarily to identify lesions that have been missed by the reader [39]. Reading time using CAD, especially by inexperienced readers, is usually longer [40]. CAD does have a role as either a primary or secondary reader depending on a reader's experience. Literature reports on the effectiveness of AI in accurate diagnosis of polyps in CTC examinations [41]. A pilot study using 3D deep learning in CTC for detection of serrated polyps produced a comparable performance to that of conventional CAD systems [42]. A detailed discussion of AI, machine learning and deep learning in imaging is presented in Chap. 25.

Key Messages

- Check volume of CO_2 in the cylinder before commencing the study.
- Patient must be sent to the restroom/lavatory to empty rectum of fluid before the CTC study commences.
- Patient preparation includes cathartic and tagging agents.
- If a patient complains of abdominal pain, check inguinal regions for possible bowel herniation.
- If a patient complains of nausea and breaks into a sweat this usually is due to air in the stomach: instruct the patient to burp as this causes immediate relief.
- The balloon is deflated when the patient is in the prone position to obtain a full scan series without an inflated balloon, as it may obscure good visualisation of the distal rectum, and to better visualise internal haemorrhoids, if present.
- Most centres do not undertake a same-day CTC study following incomplete OC. Protocol is to schedule for the next day. Patient remains on liquid diet for 24 h and tagging agents are administered.
- Before beginning a CTC study following a failed OC, a pre-procedure low-dose CT scan must be taken to assess whether free air is, or is not present. It is important to first exclude the possibility of an OC-caused colonic perforation.
- Image interpretation requires both 2D and 3D viewing.
- Areas of internal gas, or areas of high attenuation, indicate the lesion is residual faecal matter and not a polyp.

- Polyps are homogenous in attenuation.
- Residual faecal material may look similar. However, if it shows irregular angulated borders or geometric pattern it is residual faecal material.
- Mobility of a lesion. Stool tends to move to the dependent surface of the mucosa in 180° postural change. Pedunculated polyps, and occasionally soft tissue polyps, may move depending on what section of the colon they are present in.

10.12 Summary

Most CTC studies comprise a two-view series: supine and prone. A non-diagnostic study requires reporting of any extracolonic findings. Both 2D and 3D viewing is required to evaluate the colon. Software may include translucent display, checking missed colon regions, and virtual dissection options. CAD systems do have a role as either a primary or secondary reader, and AI has a role in interpretation of CTC images.

Acknowledgements Viatronix V3D workstation image courtesy of Viatronix, Stony Brook, New York.

References

1. Yee J, Weinstein S, Morgan T, Alore P, Aslam R. Advances in CT colonography for colorectal cancer screening and diagnosis. J Cancer. 2013;4(3):200–9. https://doi.org/10.7150/jca.5858.
2. Pickhardt PJ, Choi R, Hwang I, Butler JA, Puckett ML, Hildebrandt A, et al. Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. N Engl J Med. 2003;349(23):2191–200. https://doi.org/10.1056/NEJMoa031618.
3. Pickhardt PJ, Hassan G, Laghi A, et al. Cost-effectiveness of colorectal cancer screening with computed tomography colonography. The impact of not reporting diminutive lesions. Cancer. 2007;109(11):2213–21.
4. Gluecker TM, Johnson CD, Harmsen WS, Offord KP, et al. Colorectal cancer screening with CT colonography, colonoscopy and double-contrast barium enema examination: prospective assessment of patient perceptions and preferences. Radiology. 2003;227(2):378–84. https://doi.org/10.1148/radiol.2272020293.
5. Vining DJ, Gelfand DW, Bechtold RE, et al. Technical feasibility of colon imaging with helical CT and virtual reality. AJR. 1994;162:104.
6. Vining DJ. Virtual colonoscopy: a storm is brewing. Appl Radiol. 2008;37(11):12–6.
7. Kim DH, Hinshaw L, Lubner MG, Munoz de Rio A, Pooler BD, Pickhardt PJ. Contrast coating for the surface of flat polyps at CT colonography: a marker for detection. Eur Radiol. 2014;24(4):940–6. https://doi.org/10.1007/s00330-014-3095-z.
8. Pickhardt PJ. Screening CT colonography: how I do it. AJR. 2007;189(2):290–8. https://doi.org/10.2214/ajr.07.2136.
9. Tachibana R, Näppi JJ, Ota J, et al. Deep learning electronic cleansing for single- and dual-energy CT colonography. Radiographics. 2018;38(7):2034–50.
10. Pickhardt PJ. Three-dimensional endoluminal CT colonography (virtual colonoscopy): comparison of three commercially available systems. AJR. 2003;181(6):1599–606.
11. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Radiol. 2014;18(1):607. https://doi.org/10.4102/sajr.v18i1.607.
12. Zalis ME, Barish MA, Choi JR, Dachman AH, et al. CT colonography reporting and data system: a consensus proposal. Radiology. 2005;236(1):3–9. https://doi.org/10.1148/radiol.2361041926.
13. Dachman AH. Advice for optimising colonic distention and minimising risk of perforation during CT colonography. Radiology. 2006;239(2):317–21.
14. Laks S, Macari M, Bini E. Positional change in colon polyps at CT colonography. Radiology. 2004;231(3):761–6.
15. Saunders BP, Phillips RK, Williams CB. Intraoperative measurement of colonic anatomy and attachments with relevance to colonoscopy. Br J Surg. 1995;82(11):1491–3.
16. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009.
17. Bortz J. Inverted appendix: computed tomographic colonography diagnosis in a patient and lesson learned. S Afr J Radiol. 2015;19(1):748. https://doi.org/10.4102/sajr.v19i1.748.
18. Rex DK, Adler SN, Aisenberg J, et al. Accuracy of capsule colonoscopy in detecting colorectal polyps in a screening population. Gastroenterology. 2015;148(5):948–57.
19. Spada C, Hassan C, Munoz-Navos M, et al. Second generation colon capsule endoscopy compared with colonoscopy. Gastrointest Endosc. 2011;74(3):581–9.
20. Burling D, Halligan S, Slater A, Noakes M, Taylor S. Potentially serious adverse events at CT colonography in symptomatic patients: National Survey of the United Kingdom. Radiology. 2006;239:464–71. https://doi.org/10.1148/radiol.2392051101.

21. The joint guidance for CTC standards of practice of the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiology. 2021. https://www.rcr.ac.uk/system/files/publication/field_publication_files/bfcr201-standards-of-practice-for-computed-tomography-colonography-ctc.pdf. Accessed 29 Sept 2022.
22. Hough DM, Kuntz MA, Fidler JL, Johnson CD, et al. Detection of occult colonic perforation before CT colonography after incomplete colonoscopy: perforation rate and use of a low-dose diagnostic scan before CO_2 insufflation. AJR. 2008;191(4):1077–81. https://doi.org/10.2214/ajr.07.2746.
23. Spada C, Hassan C, Barbaro B, et al. Colon capsule versus CT colonography in patients with incomplete colonoscopy. A prospective, comparative trial. Gut. 2015;64(2):272–81.
24. Ismail MS, Murphy G, Semenor S, McNamara D. Comparing colon capsule endoscopy to colonoscopy; a symptomatic patient's perspective. BMC Gastroenterol. 2002;2(1):31. https://doi.org/10.1186/s12876-021-02081-0.
25. Kwack WG, Lim YJ. Current status and research into overcoming limitations of colon capsule endoscopy. Clin Endosc. 2016;49:8–15.
26. Deding U, Herp J, Havshoei A-L, et al. Colon capsule endoscopy versus CT colonography after incomplete colonoscopy. Artificial intelligence algorithms to identify complete colonic investigations. United Eur Gastroenterol J. 2020;8(7):782–9.
27. Alonso S, Pérez S, Argudo N, Latorraca JI, Pascual M, Álvarez MA, Seoane A, Barranco LE, Grande L, Pera M. Endoscopic tattooing of colorectal neoplasms removed by laparoscopy: a proposal for selective marking. Rev Esp Enferm Dig. 2018;110(1):25–9. https://doi.org/10.17235/reed.2017.5136/2017.
28. Yang M, Pepe D, Schlachta CM, Alkhamesi NA. Endoscopic tattoo: the importance and need for standardised guidelines and protocol. J R Soc Med. 2017;110(7):287–91. https://doi.org/10.1177/0141076817712244.
29. Nahid M, Shrestha AK, Imtiaz MR, Basnyat PS. Endoscopic tattooing for colorectal lesions: impact on quality of care and patient outcomes. Ann R Coll Surg Engl. 2020;102(8):594–7. https://doi.org/10.1308/rcsann.2020.0104.
30. Trakarnsanga A, Akaraviputh T. Endoscopic tattooing of colorectal lesions: is it a risk-free procedure? World J Gastrointest Endosc. 2011;3(12):256–60. https://doi.org/10.4253/wjge.v3.i12.256.
31. Pickhardt PJ, Lee AD, Taylor AJ, Michel SJ, et al. Primary 2D versus primary 3D polyp detection at screening CT colonography. AJR. 2007;189:1451–6. https://doi.org/10.2214/ajr.07.2291.
32. Pickhardt PJ, Kim DH. Colorectal cancer screening with CT colonography: key concepts regarding polyp prevalence, size, histology, morphology, and natural history. AJR. 2009;193(1):40–6. https://doi.org/10.2214/ajr.08.1709.
33. Johnson CD, Chen M, Toledano AY, Heiken JP, et al. Accuracy of CT colonography for detection of large adenomas and cancers. N Engl J Med. 2008;359(12):1207–17. https://doi.org/10.1056/NEJMoa0800996.
34. Pooler BD, Kim DH, Weiss JM, Matkowskyj KA, Pickhardt PJ. Colorectal polyps missed with optical colonoscopy despite previous detection and localization with CT colonography. Radiology. 2016;278(2):422–9. https://doi.org/10.1148/radiol.2015150294.
35. Kim DH, Pickhardt PJ, Taylor AJ. Characteristics of advanced adenomas detected at CT colonographic screening: implications for appropriate size thresholds for polypectomy versus surveillance. AJR. 2007;188(4):940–4.
36. Lee SS, Park SH, Kim JK, Kim N, et al. Panoramic endoluminal display with minimal image distortion using circumferential radial ray-casting for primary three-dimensional interpretation of CT colonography. Eur Radiol. 2009;19:1951–9. https://doi.org/10.1007/s00330-009-1362-1.
37. Lawrence EM, Pickhardt PJ, Kim DH, Robbins JB. Colorectal polyps: stand-alone performance of computer-aided detection in a large asymptomatic screening population. Radiology. 2010;256(3):791–8. https://doi.org/10.1148/radiol.10092292.
38. Halligan S, Mallett S, Altman DG, et al. Incremental benefit of computer-aided detection when used as a second and concurrent reader of CT colonographic data: multiobserver study. Radiology. 2011;258(2):469–76. https://doi.org/10.1148/radiol.10100354.
39. De Haan MC, Pickhardt PJ, Stoker J. CT colonography: accuracy, acceptance, safety and position in organized population screening. Gut. 2015;64(2):342–50. https://doi.org/10.1136/gutjnl-2014-308696.
40. Helbren EL, Plumb AA, Taylor SA. The future developments in gastrointestinal radiology. Frontline Gastroenterol. 2012;3(Supp 1):i36–41. https://doi.org/10.1136/flgastro-2012-100121.
41. Rasouli P, Moghadam AD, Eslami P, et al. The role of artificial intelligence in colon polyps detection. Gastroenterol Hepatol Bed Bench. 2020;13(3):191–9.
42. Näppi J, Pickhardt PJ, Kim D, Hironaka T, Hiroyuki Y. Deep learning of contrast-coated serrated polyps for computer-aided detection in CT colonography. SPIE Med Imaging Proc. 2017;10134:114–20. https://doi.org/10.1117/12.2255634.

Anatomy of the Colon: Rectum to Ileocaecal Valve

11

Joel H. Bortz

11.1 Introduction

Most colon cancers, apart from inherited genetic disorders, such as hereditary non-polyposis colorectal cancer, arise from a pre-existing polyp which develops over a period of 10–15 years into a cancer [1]. The primary aim of CTC screening is therefore to detect potentially suspicious lesions, such as polyps, to reduce the risk of them developing into colorectal cancer [2–5]. In order to interpret CTC images, a reader must know the normal anatomy of the colon and normal variants and malrotation of the bowel. CTC studies are part of the management of asymptomatic and symptomatic patients, it is essential that a generated report includes identified normal anatomy and, if present, normal variants, extrinsic impressions on the colon lumen, and all identified pathology. This is important for clinical audits in terms of best practice (see Chap. 27). Both 2D and 3D images are used to interpret the scans performed. Computer-aided diagnosis (CAD) software systems could also be used by readers [4, 6, 7] (see Chap. 10). Artificial intelligence (AI) could also be used (see Chap. 25).

The following abbreviations are used in this chapter.

- CTC: CT colonography
- ICV: ileocaecal valve
- MPR: multiplanar reformation
- 3D: three-dimensional
- 2D: two-dimensional

11.2 Anatomy of the Bowel Wall

There are four layers of the wall of colon: (1) mucosa (epithelial/innermost) layer comprising connective tissue and a thin muscle layer (muscularis); (2) submucosa comprising connective tissue, nerves, and lymphatics; (3) muscularis propria (muscle layer) consisting of two bands, namely circular and longitudinal; (4) serosa is the outermost layer present from sigmoid to caecum.

The proximal colon develops from the midgut, and its blood supply is the superior mesentery artery (SMA). The distal colon develops from the hindgut; its blood supply is the inferior mesentery artery (IMA). The proximal colon has a multilayered capillary network; the distal colon has a single layered capillary network [8]. It is important to know the layers of the bowel wall because cancers confined to the mucosa, without penetration into the submucosa or muscular layer, have a good prognosis (see the adenocarcinoma sequence in Chap. 15).

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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11.3 Colon Anatomy

The colon length in adults varies from 150 cm (5 feet) to 180 cm (6 feet) or up to 300 cm (10 feet) [9]. It is divided into six segments: rectum, sigmoid colon, descending colon, transverse colon, ascending colon, and caecum (Fig. 11.1).

The right colon extends from the caecal pole to the splenic flexure; the left colon extends from splenic flexure to the ano-rectal region. Note that CTC reports do not include the flexure regions as anatomical landmarks because there is a difference between CTC localisation of polyps and optical colonoscopy (OC) localisation of polyps. It is not possible to have a mirror image of the two procedures because the folds are pushed and pulled during an OC.

11.3.1 Rectum and Valves of Houston

The rectum commences at the mid-sacral level and ends in the anal canal; its average length is 15 cm, and it does not have haustral marking. The longitudinal taenia coli end at the rectosigmoid junction and continue only as a smooth muscle layer in the rectum [9]. The three valves of Houston (superior middle, and inferior) are in the rectum [10]. The valves are depicted as three semilunar folds in the rectum in a CTC study (Fig. 11.2 (i, ii)). In 50% of people, the superior

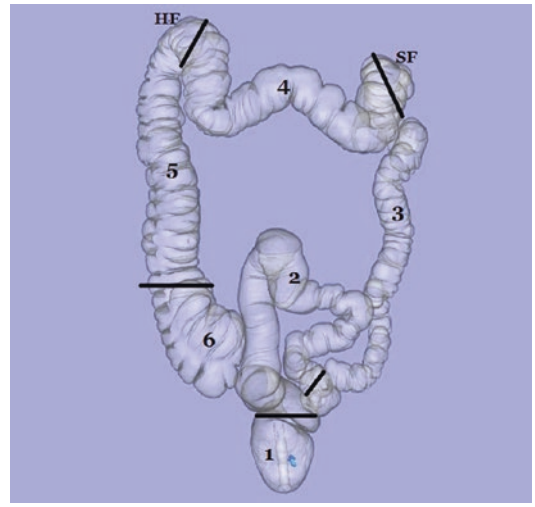

Fig. 11.1 Normal colon. Colon-map showing normal six segments of colon: 1 = rectum; 2 = sigmoid colon; 3 = descending colon; 4 = transverse colon; 5 = ascending colon; 6 = caecum. *SF* splenic flexure, *HF* hepatic flexure

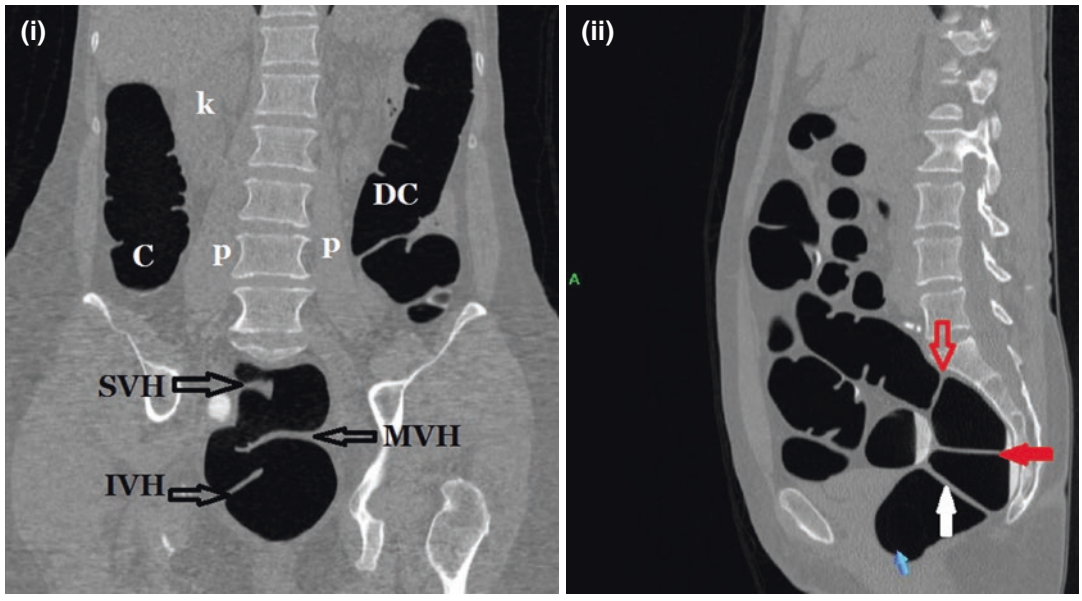

Fig. 11.2 Rectum. (**i**) 2D coronal view showing inferior valve of Houston (IVH), middle valve of Houston (MVH) and superior valve of Houston (SVH); (**ii**) 2D sagittal view showing the three valves of Houston in the rectum. IVH (white arrow); MVH (closed red arrow); SVH (open red arrow)

and inferior folds are located on the left side of the rectum; the middle valve is more prominent and is on the right. There is a reverse configuration in about 33% of people. The valves may be more variable in the rest of people (17%). The middle valve demarcates the level of the abdominal-peritoneal reflection anteriorly. It is usually located 8 cm from the anal verge and demarcates the middle and lower rectum. On a 3D fly-through, the haustral folds have a different configuration between the left and right colon. They have a typically rounded appearance on the left; on the right, their appearance is triangular.

11.3.2 Rectosigmoid Junction

This area is located anterior to the sacral promontory. It is clearly identified on coronal and sagittal multiplanar reformation (MPR) images where the rectosigmoid colon moves upward and anteriorly. The sigmoid colon has a loosely attached mesentery, which allows for mobility, and in some people it may be particularly tortuous and redundant. Figure 11.3a (i)–(iii) demonstrate a normal sigmoid colon. Figure 11.3b (i) and (ii) demonstrate a displaced sigmoid colon. The sigmoid colon is often smaller in calibre than the

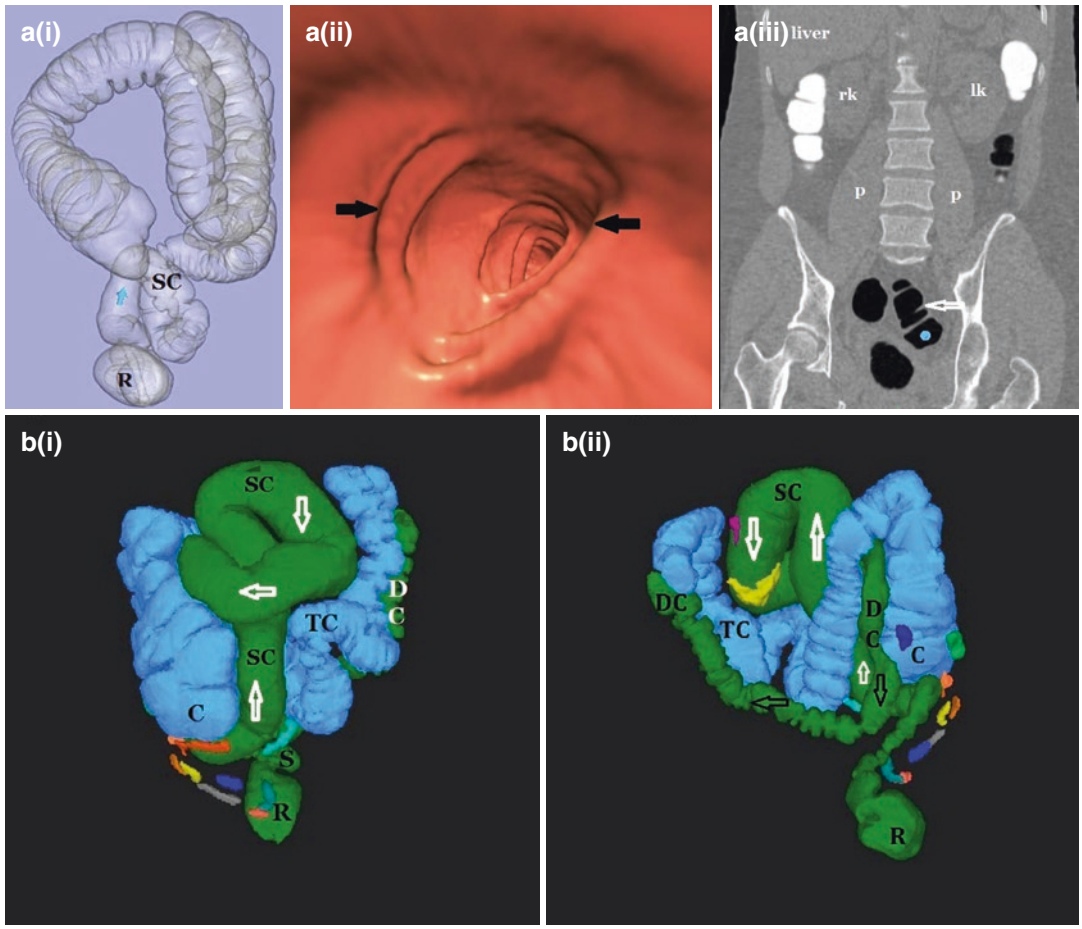

Fig. 11.3 Rectosigmoid. (**a**) (**1**) Colon-map showing sigmoid colon (SC) and rectum (R); (**ii**) 3D view shows circular folds (arrow) in sigmoid colon; (**iii**) 2D coronal view showing sigmoid colon (open white arrow). Psoas muscle (p); right kidney (rk); left kidney (lk). (**b**) (**i**) Supine colon-map showing grossly redundant sigmoid colon (S, SC and open white arrows). Rectum (R); descending colon (DC); transverse colon (TC); caecum (C); (**ii**) Prone colon-map showing grossly redundant sigmoid colon (SC and white arrows). Rectum (R); descending colon (DC);transverse colon (TC); caecum (C)

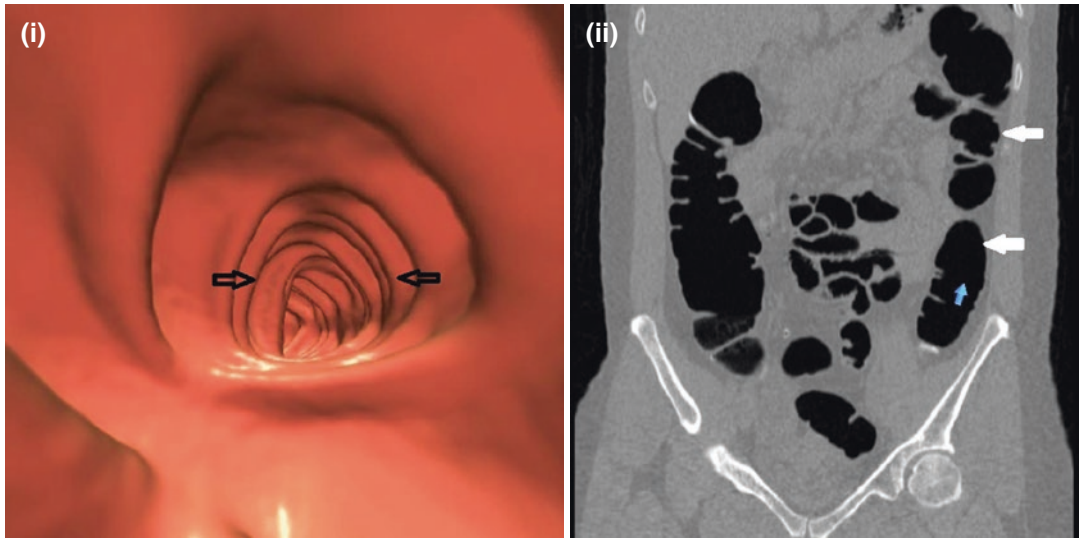

Fig. 11.4 Descending colon (**i**) 3D view of a circular fold in descending colon (open black arrows); (**ii**) 2D coronal view showing descending colon (white arrows)

rest of the colon. The sigmoid colon contains rounded haustral folds [3]. The junction between the sigmoid colon and the descending colon occurs when the colon assumes an upward course, best visualised in a coronal view.

11.3.3 Descending Colon

The descending colon is relatively fixed in position throughout its course as it is retroperitoneal. Circular folds are present in this segment on 3D views (Fig. 11.4 (i)). The rectum, sigmoid colon, and descending colon comprise the left colon (Fig. 11.4 (ii)).

11.3.4 Splenic Flexure

The splenic flexure represents the highest segment of the left colon (see Fig. 11.1). Ligaments from the diaphragm help fix this segment. It is found where the colonic lumen changes direction in a downward and posterior fashion. It is the transition point from the intraperitoneal transverse colon to the retroperitoneal descending colon (Fig. 11.5 (i, ii)).

11.3.5 Transverse Colon

The transverse colon extends from the splenic flexure to the hepatic flexure; the lumen of the transverse colon shows triangular folds on 3D (Fig. 11.6 (i)). It has a loose mesenteric attachment (Fig. 11.6 (ii)–(iv)); it often changes in position from supine to prone. It has better distension in the supine position. Often it can be partially compressed, particularly in obese patients, in the prone position during a CTC study; it then does not adequately fill with carbon dioxide. A right lateral decubitus view is then required should this occur [5].

11.3.6 Hepatic Flexure

The hepatic flexure is the highest point of the right colon lumen where the colon alters course in a downward fashion (Fig. 11.7 (i)–(iii)).

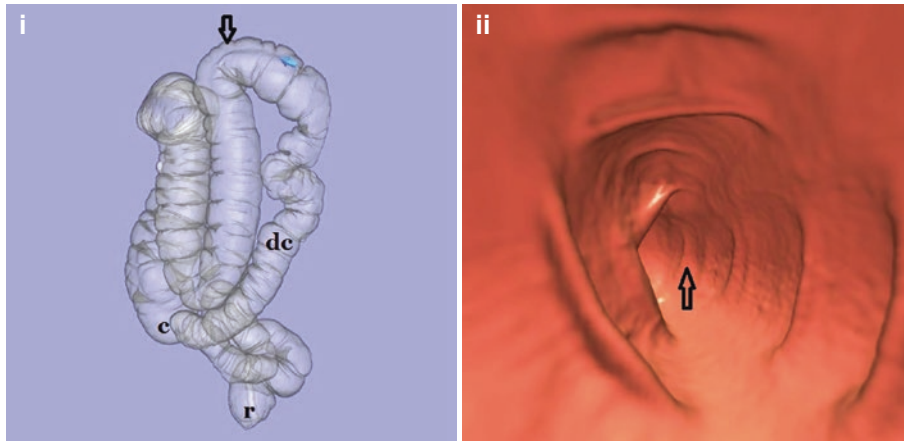

Fig. 11.5 Splenic flexure (**i**) Colon-map showing the splenic flexure (open black arrow). Rectum (r); descending colon (dc); caecum (c). (**ii**) 3D view of the splenic flexure (open black arrow)

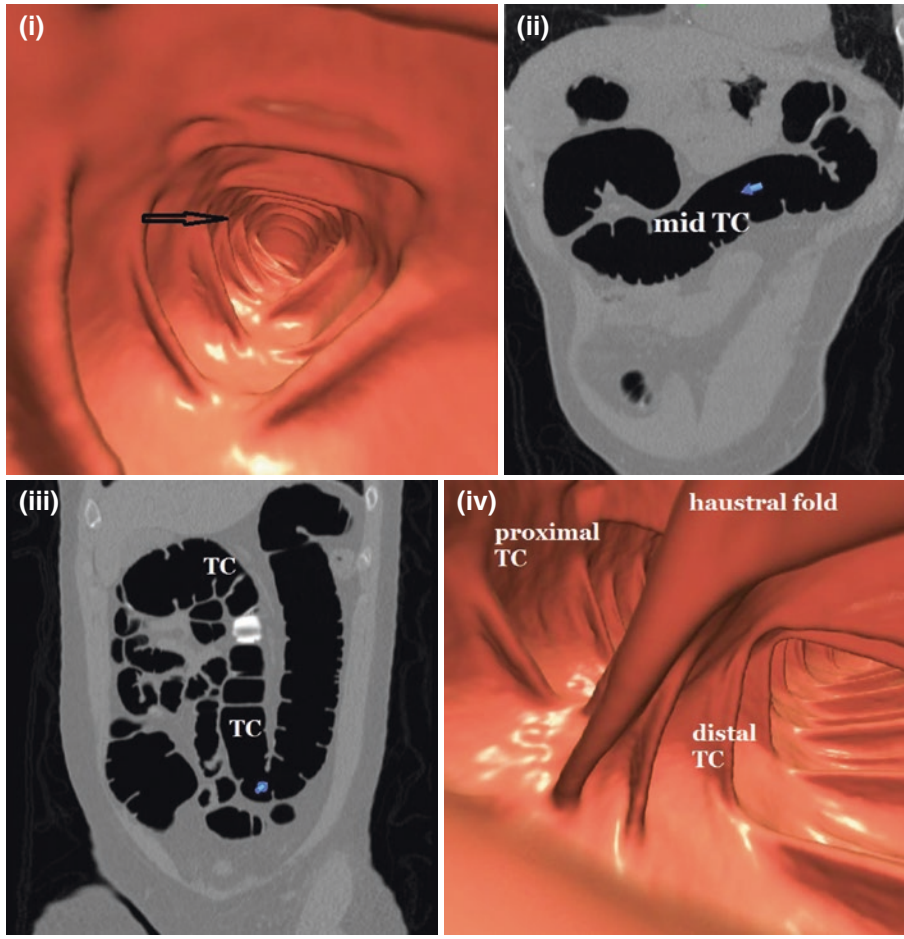

Fig. 11.6 Transverse colon (**i**) 3D view of a triangular fold in transverse colon (open black arrow); (**ii**) 2D coronal view of the mid-transverse colon (mid- TC); (**iii**) 2D coronal view showing mid-transverse colon (TC) dipping into pelvis; (**iv**) 3D showing view of mid-transverse colon with thickened haustral fold due to angulation between proximal and distal transverse colon (TC)

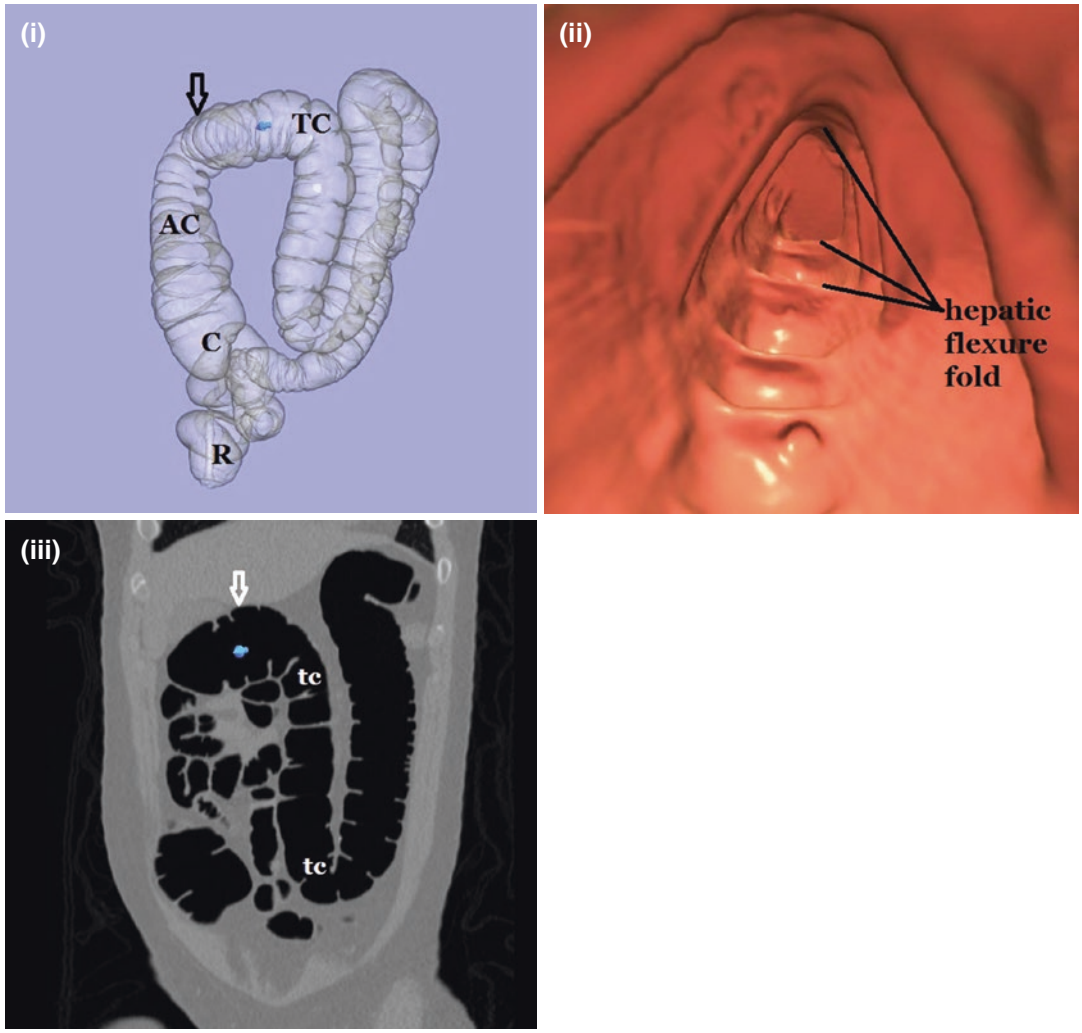

Fig. 11.7 Hepatic flexure **(i)** Colon-map showing hepatic flexure (open black arrow). Rectum (R); transverse colon (TC); ascending colon (AC); caecum (C); **(ii)** 3D showing triangular fold of hepatic flexure; **(iii)** 2D coronal view showing hepatic flexure (open white arrow)

11.3.7 Ascending Colon

The ascending colon is larger in diameter than the left colon. It is usually well distended on both supine and prone studies. However, there is often a gap between the hepatic flexure and the ascending colon (see Chap. 10). This is due to a collection of fluid in this location of the colon [3]. The folds have a triangular appearance (Fig. 11.8 (i)) and slightly thicker than those in the transverse colon. Figure 11.8 (ii) demonstrates a normal distended ascending colon.

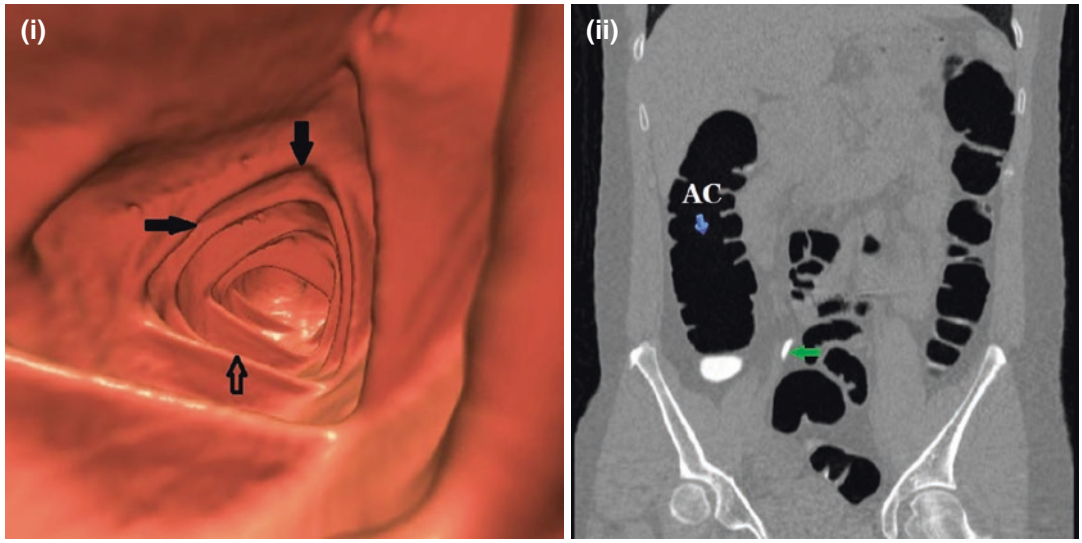

Fig. 11.8 Ascending colon (**i**) 3D view of a triangular fold in ascending colon (arrows); (**ii**) 2D coronal view showing ascending colon (AC). Green arrow = appendix

11.3.8 Ileocaecal Valve (ICV)

It is easy to identify the ICV valve because its position is constant relative to the terminal ileum and caecum. It demarcates the caecum from the ascending colon. The appearance of an ICV varies from a labial type with a slit-like elongated appearance to a more bulbous polypoidal or papillary type (Fig. 11.9a (i) and (ii)). A bulbous or papillary ICV causes a prominent polypoidal appearance with a central depression. A specific feature of the ICV is a depression or 'pit' orifice [3] where the terminal ileum empties into the right colon. This orifice may be visualised on both 2D and 3D views as shown in Fig. 11.9a (iii). An ICV on a CTC study may be open (patent) or closed. Figure 11.9b demonstrates a closed IVC. If it is open, then reflux of carbon dioxide may occur (Fig. 11.9c (i)–(iv)). The ICV is located postero-medially where the terminal ileum enters the caecum. An ICV may be completely replaced with fat (Fig. 11.9d (i) and (ii)). It may have a high intensity (red) on translucent display (TD) as shown in Fig. 11.9 (iii). Polyps or adenocarcinoma may occur on the surface of the ICV because it is covered by mucosa.

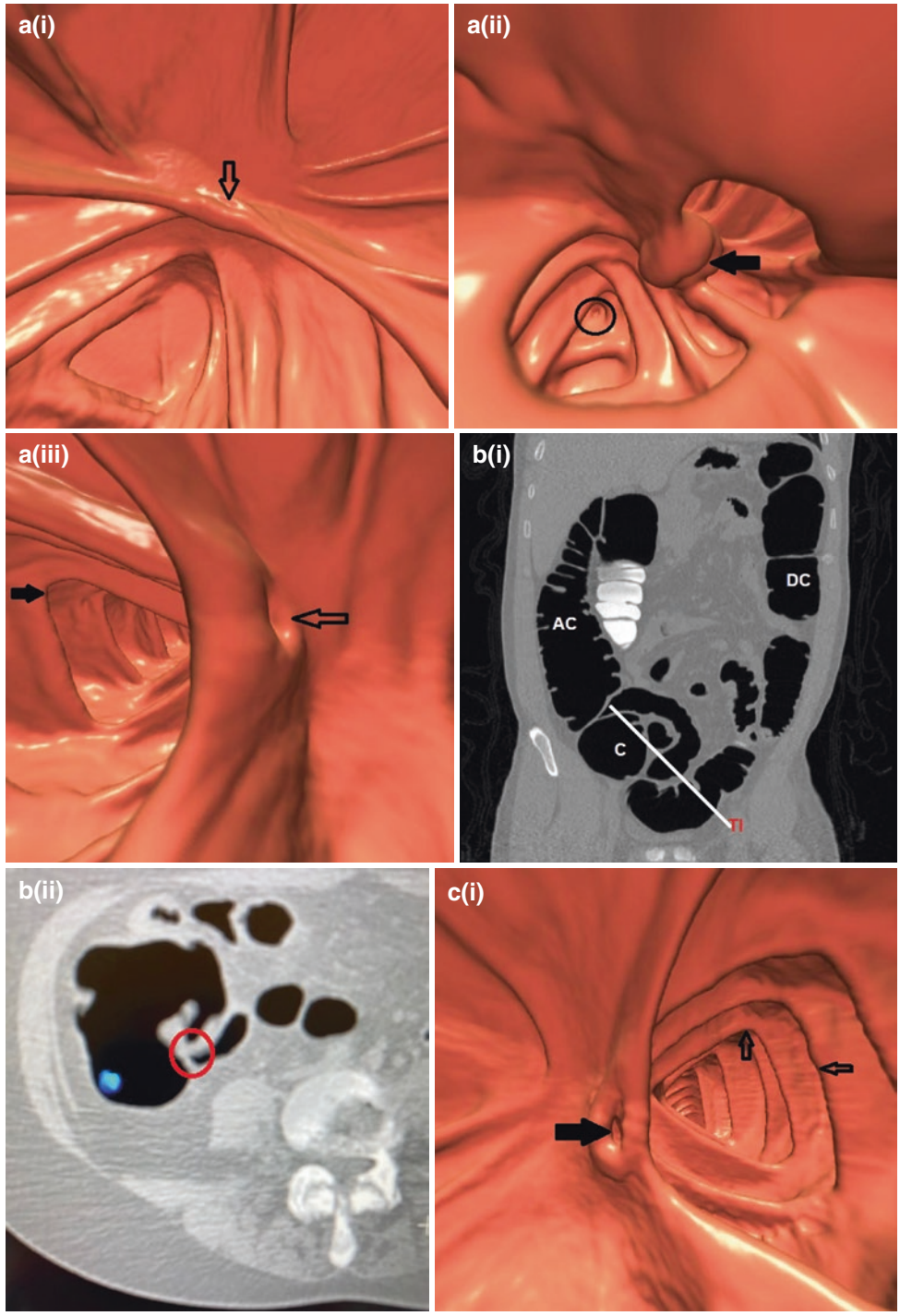

Fig. 11.9 Ileocaecal valve. (**a**) (**i**) 3D view shows labial ICV (open black arrow); (**ii**) 3D view of a bulbous ileocaecal valve (black arrow). Appendiceal orifice (circle); (**iii**) 3D view of ICV showing depression or 'pit' orifice (open black arrow) where the terminal ileum empties into right colon. Closed arrow = triangular folds. (**b**) (**i**) 2D coronal view of a closed ICV. Terminal ileum (TI); caecum (C); ascending colon (AC); descending colon (DC); (**ii**) 2D axial view of a closed ICV (red circle). (**c**) (**i**) 3D view showing patent ICV (closed black arrow) and triangular folds (open black arrows);

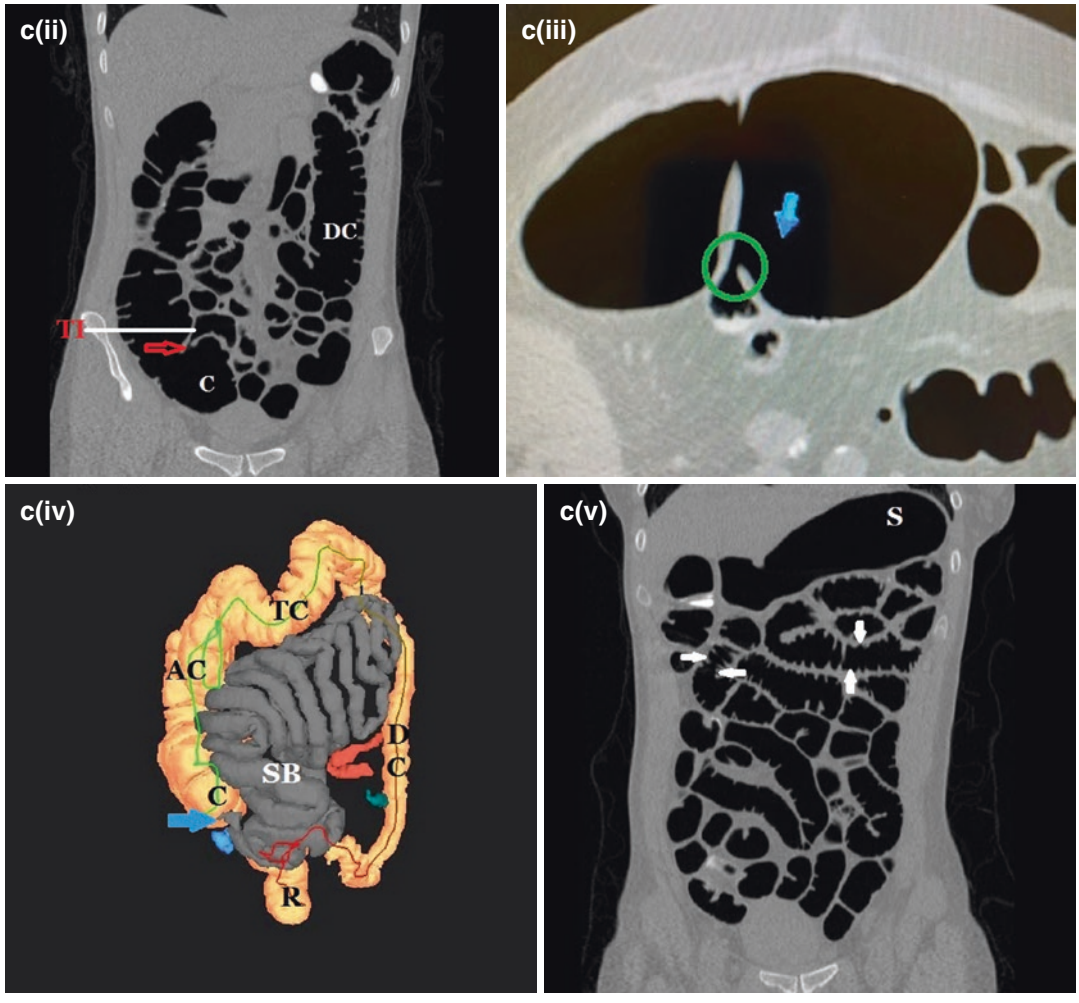

Fig. 11.9 (**ii**) 2D coronal view of a patent ICV (white arrow) with air in the terminal ileum (TI). Caecum (C); descending colon (DC); (**iii**) 2D axial supine view showing patent ICV (green circle); (**iv**) Colon- map showing reflux of gas into small bowel (SB grey) due to patent ICV (blue arrow); (**v**) 2D coronal view showing small bowel valvulae conniventes (open white arrows) and gas in stomach (S).

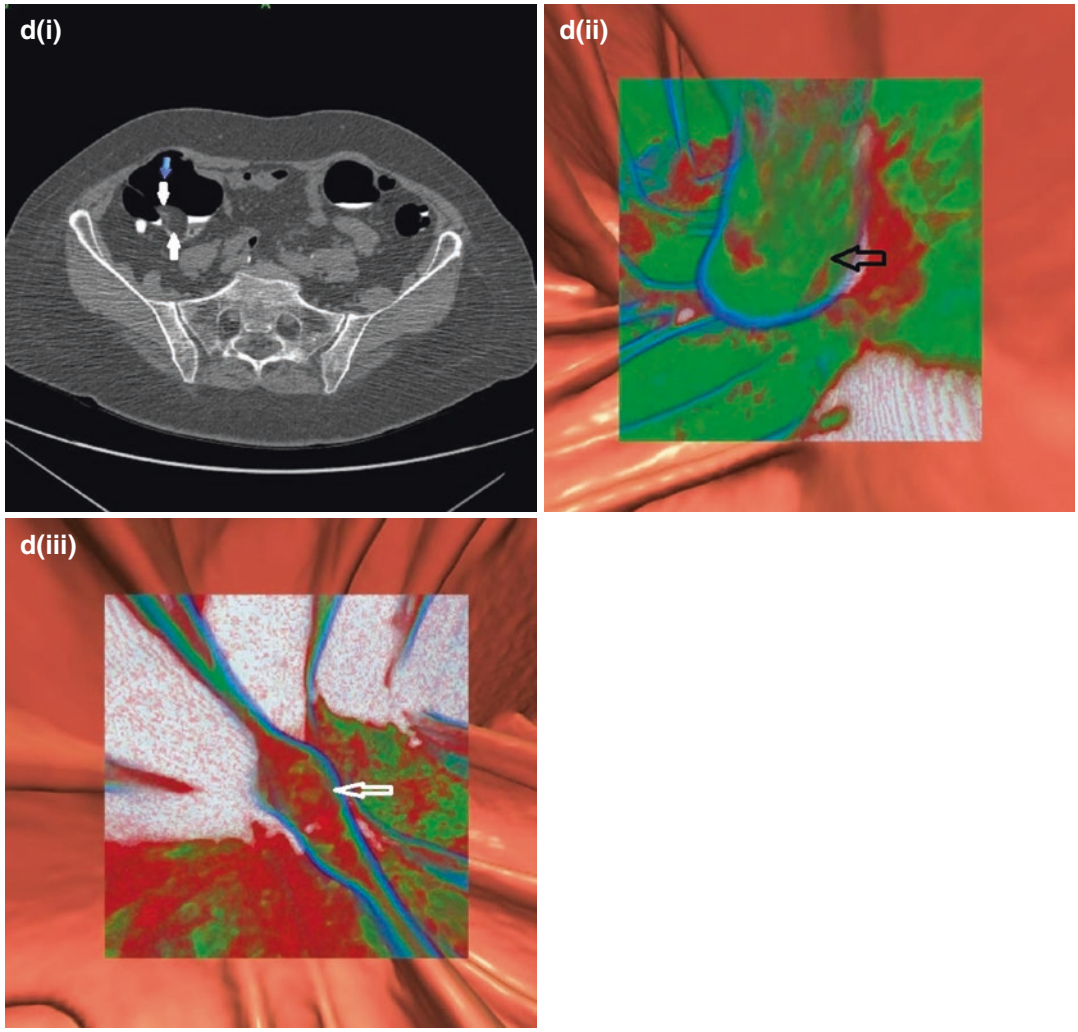

Fig. 11.9 (**d**) (**i**) 2D soft tissue axial view of a fatty ICV (white arrows); (**ii**) TD (translucent display) shows predominantly fatty ICV (green, open black arrow); (**iii**) TD shows high intensity ICV (red, open white arrow)

11.3.9 Caecum

This colon segment is proximal to the ICV; its configuration and position may change as shown in Fig. 11.10(i) and (ii). This occurs because 10% of people have no peritoneal fixation of the ascending colon thereby allowing for caecal mobility (Fig. 11.10 (iii) and (iv)). The caecum is more capacious than the ascending colon.

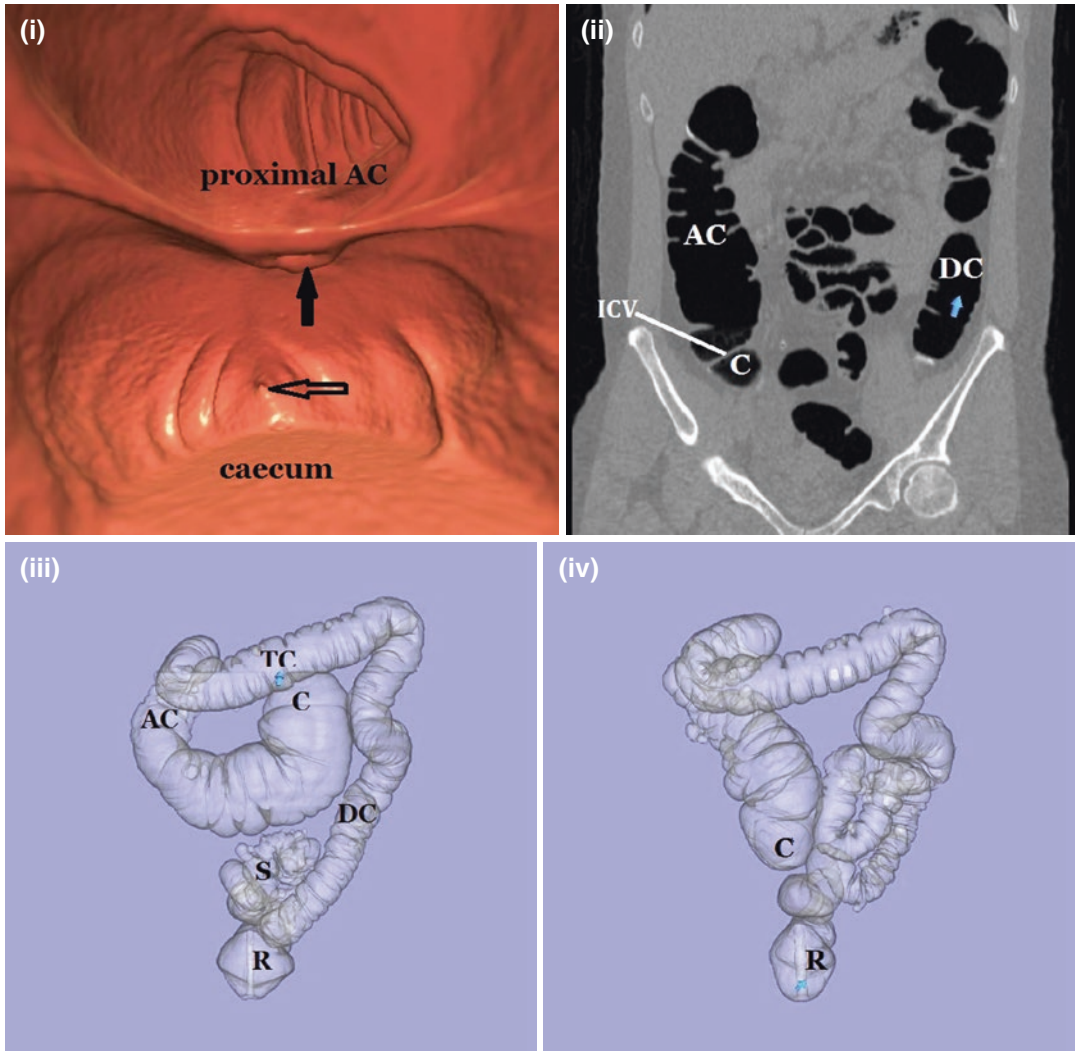

Fig. 11.10 Caecum (**i**) 3D view of ICV (closed black arrow), caecum, proximal ascending colon (AC), and appendiceal orifice (open black arrow); (**ii**) 2D coronal view: ascending colon (AC); ileocaecal valve (ICV); caecum (C); descending colon (DC); (**iii**) Supine colon-map showing abnormal position of caecum (C) below the TC. Rectum (R); sigmoid colon (S); descending colon (DC); transverse colon (TC); ascending colon (AC); (**iv**) Prone colon-map shows normal position of caecum (C) indicating mobility with postural change. Rectum (R)

11.3.10 Appendix

The vermiform appendix is part of the caecum. Its length varies from 2.5 to 33 cm [11]. Its average length is between 5 and 10 cm: its base is usually situated 2 cm below the ICV. Its intra-abdominal position may vary widely depending on the peritoneal fold which represents the mesentery of the appendix [11, 12]. The convergence of the three taeniae coli in the caecum form two prominent folds called the crow's feet that flank the appendiceal orifice and is shown on the 3D endoluminal view (Fig. 11.11a (i)) [3]. Figure 11.11a (ii) and (iii) demonstrate the orifice of the appendix and appendiceal lumen. Figure 11.11b (i)–d (iv) are a range of 2D and 3D images of the appendix in various locations in the abdomen. Figure 11.11e (i) and (ii) show the appendix in the inguinal canal.

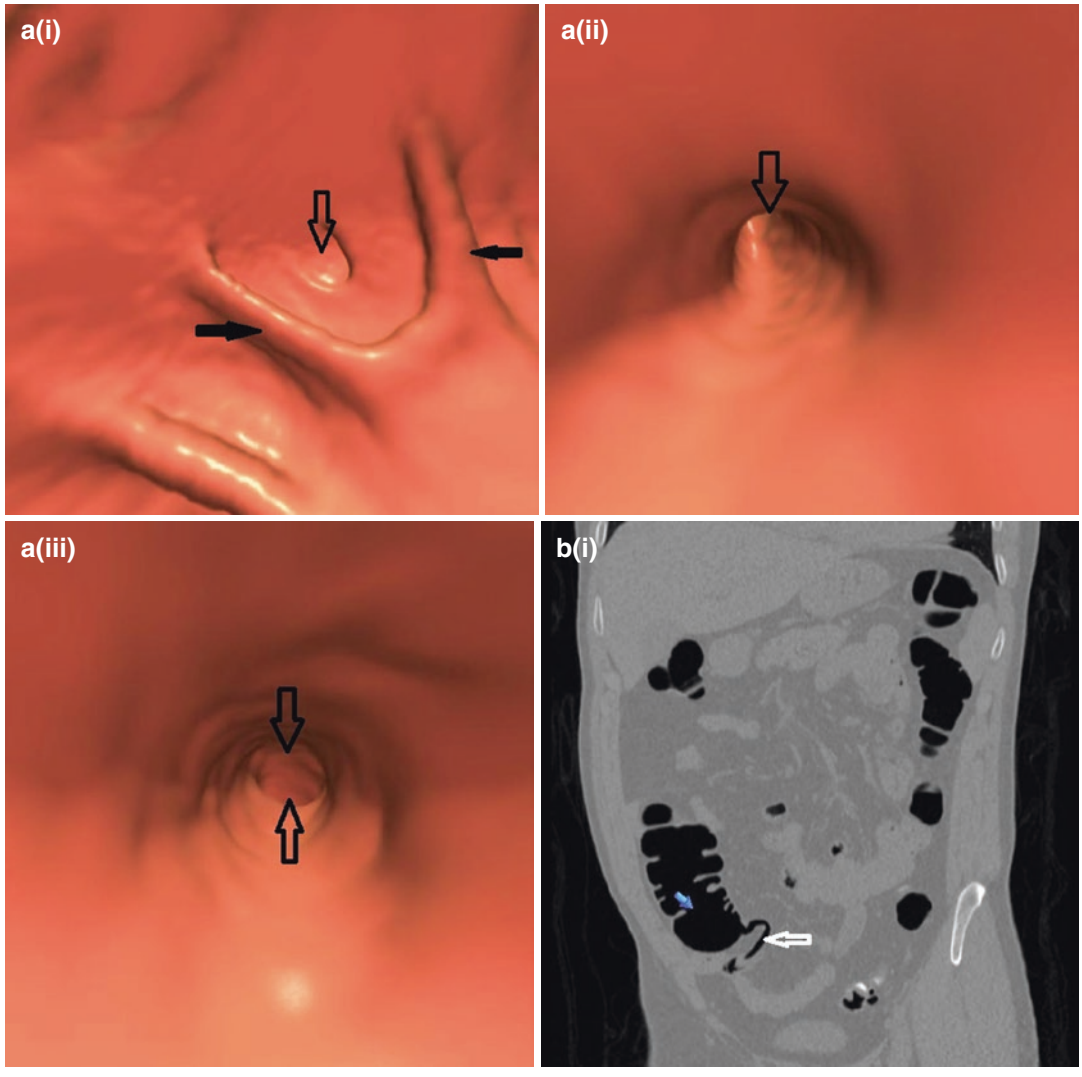

Fig. 11.11 Appendix. (**a**) (**i**) 3D view of appendiceal orifice (open black arrow) and crow's feet (closed black arrows); (**ii**) 3D view of orifice of appendix (open black arrow); (**iii**) 3D view of appendiceal lumen (open black arrows). (**b**) (**i**) Air in appendix (open white arrow) on 2D coronal view;

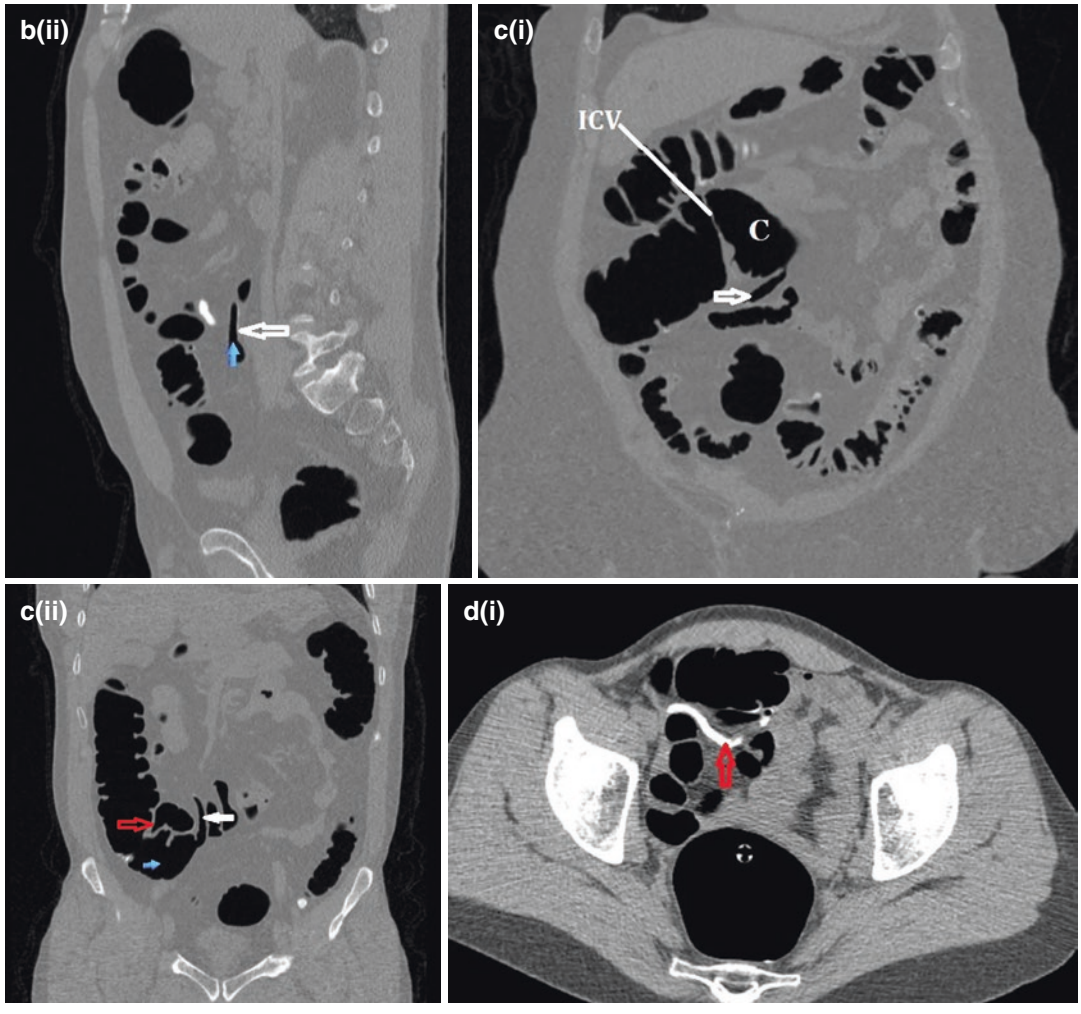

Fig. 11.11 (**ii**) 2D sagittal view showing air in the appendix (open white arrow). (**c**) (**i**) 2D coronal view showing malrotated caecum (C), air-filled appendix (open white arrow), and ileocaecal valve (ICV); (**ii**) 2D coronal view showing air in terminal ileum (open red arrow) and air in appendix (closed white arrow). (**d**) (**i**) 2D axial showing barium filled appendix (open red arrow);

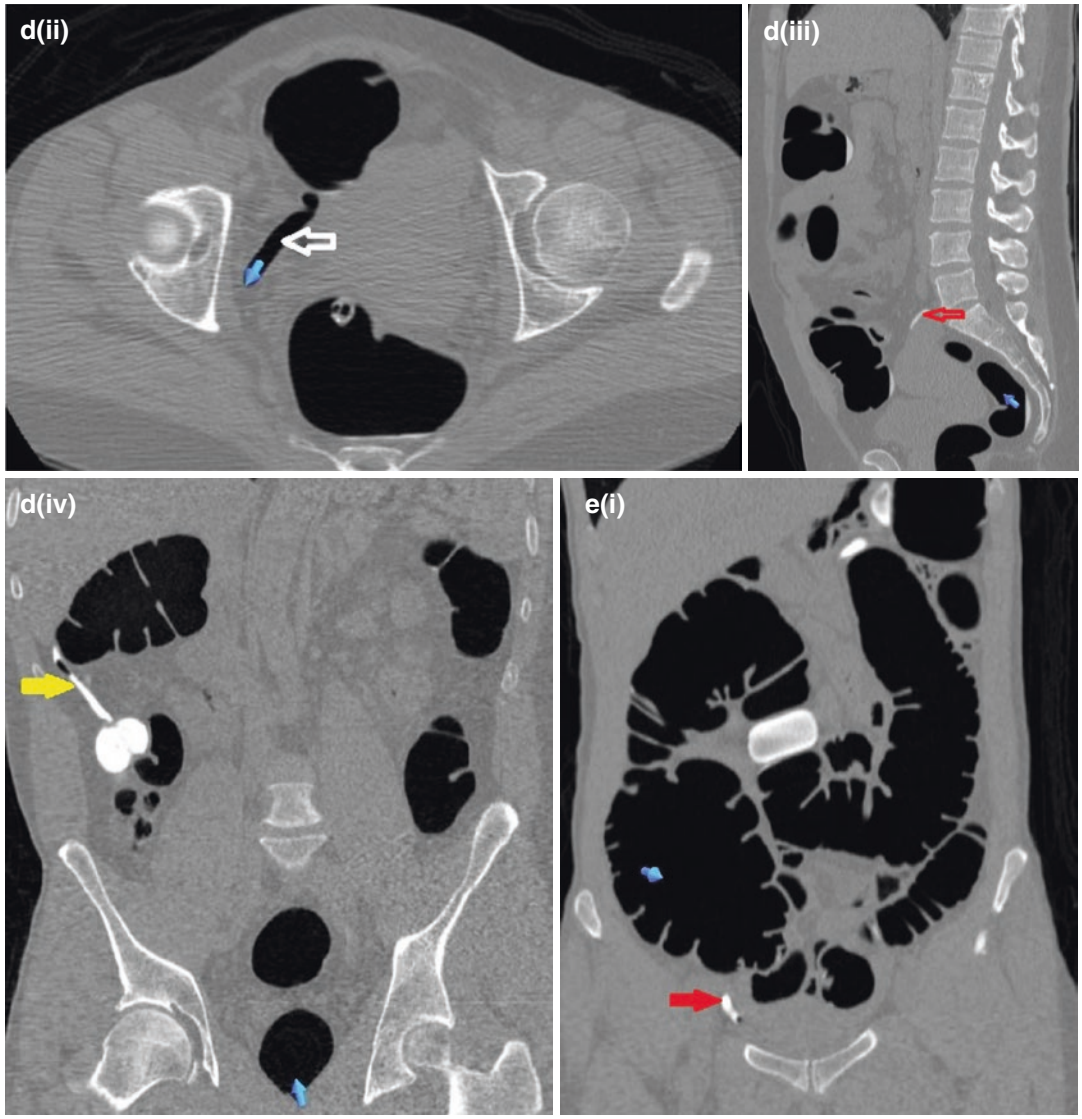

Fig. 11.11 (**ii**) 2D axial showing retrocaecal appendix filled with air (open white arrow); (**iii**) 2D sagittal view showing appendix (open red arrow) adjacent to spine; (**iv**) 2D coronal view showing sub-hepatic appendix (yellow arrow). (**e**) (**i**) 2D coronal view showing appendix (closed red arrow) in inguinal canal;

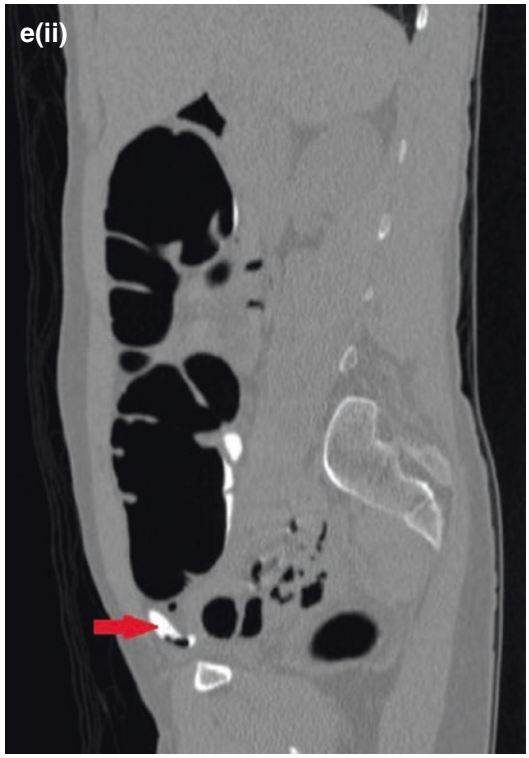

Fig. 11.11 (**e**) (**ii**) 2D sagittal view showing appendix (closed red arrow) in inguinal canal

11.4 Malrotation of the Bowel

Malrotation is a failure during the development of normal rotation of any part of the intestinal tract. Congenital malrotation of the midgut often presents clinically in the first month of life; more commonly in the first post-natal week where the newborn presents with bilious vomiting [13]. This would be a medical emergency as the cause may be due to malrotation of the midgut with volvulus. If an early diagnosis is not made, this could result in complications, such as ischaemia of the small bowel loops, and subsequent death. Most patients born with malrotation will be asymptomatic with a normal clinical history [14]. Malrotation in such patients is an incidental finding when they undergo a screening CTC examination after the age of 50 years. Malrotation does not occur in isolation in this abnormality. With it comes malfixation of the mesentery, which results in abnormal mobility of portions of the bowel [15]. Figure 11.12a (i)–b are examples of such a pathology.

At CTC when patients with bowel malrotation are shown the images, they are often very surprised as they were unaware and asymptomatic with a normal clinical history. They usually do not entertain the possible need for surgical intervention . Some authorities advocate surgical correction (Ladd's procedure) for all patients with malrotation, regardless of age [16]. Failure to correct the abnormality may result in an intussusception or volvulus, in the future. This would then become a surgical emergency to correct the underlying abnormality.

11.4.1 Mobility of Colon Segments

The sigmoid colon and transverse colon are intraperitoneal structures and may be mobile depending on how loosely the mesentery is attached to them [3]. In view of such mobility, it often appears as if polyps move with postural change (supine to prone) during a CTC study. A mobile lesion on CTC should not be assumed to be stool. The ascending colon, descending colon, and rectum are retroperitoneal in position and do not usually change position. As shown in Fig. 11.1 above, the caecum usually lies in the right iliac fossa. However, in approximately 10% of the population the caecum and ascending colon are incompletely fixed which allows for a wide range of mobility. Although displacement of the caecum and ascending colon does not cause symptoms, the onset of appendicitis may be difficult to diagnose clinically, especially if the displaced colon lies in the left upper quadrant of the abdomen or is sub-hepatic in position. Figure 11.13 (i) and (ii) demonstrate mobility of the caecum.

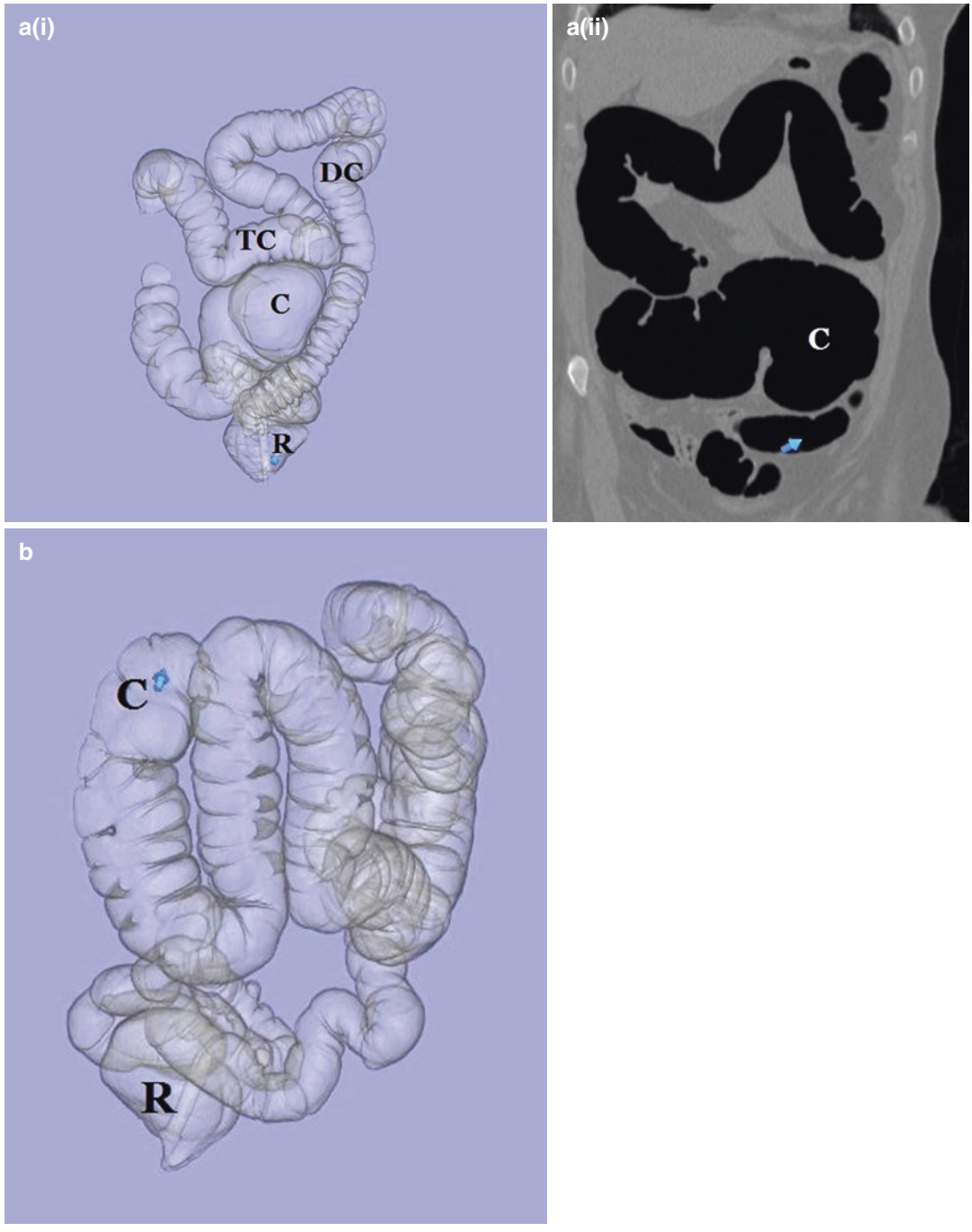

Fig. 11.12 Malrotation of the bowel. (**a**) (**i**) Supine colon-map of a malrotated caecum.(C). Rectum (R); descending colon (DC); transverse colon (TC). Note the gap in the ascending colon (technical); (**ii**) 2D coronal view of a malrotated cecum (C). (**b**) Supine colon-map showing sub-hepatic caecum (C). Rectum (R)

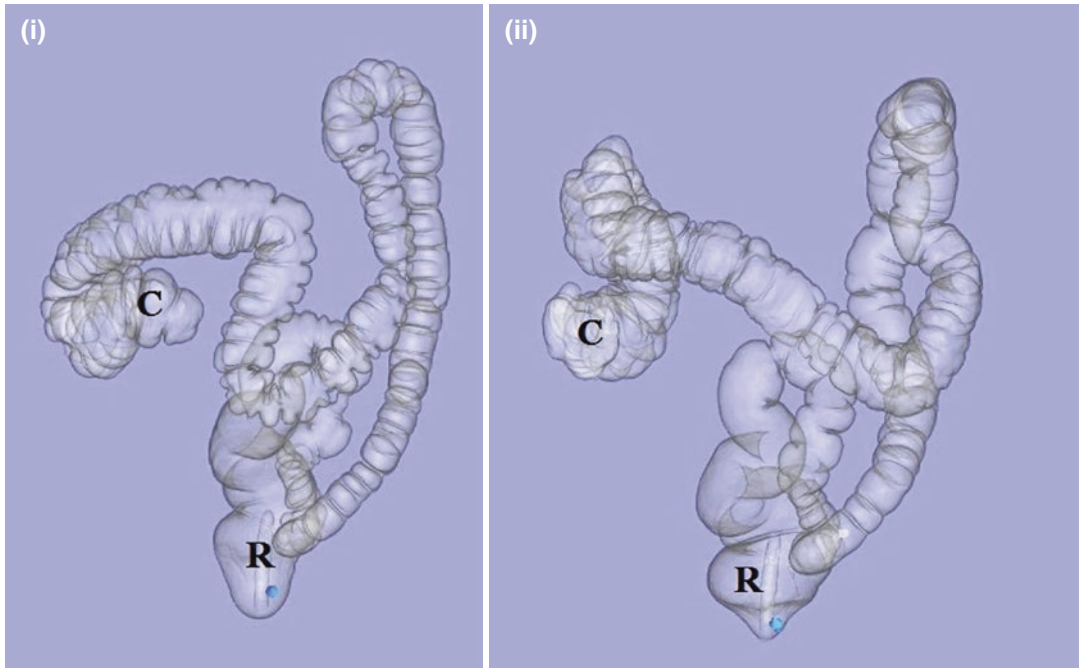

Fig. 11.13 Mobility of segments (**i**) Supine colon-map. Caecum (C) and rectum (R); (**ii**) Prone colon-map shows different positions of caecum (C). Rectum (R)

11.5 Extrinsic Impressions

Any structure that lies adjacent to the colon may cause an extrinsic impression on the colon lumen [17]. An extrinsic impression may present as a submucosal lesion and cause problems, particularly during optical colonoscopy. These impressions are easily identifiable when 2D MPR is performed. The most common sources of these impressions include the kidneys, aorta and iliac arteries, uterus and adnexa, and adjacent gastrointestinal tract (GIT), such as the small bowel. The 'continuous fold' sign occurs when a structure, which is causing the extrinsic impression, displaces but does not efface the overlying colonic fold. Figure 11.14a (i)–g (ii) are examples of extrinsic impressions on 3D and 2D images.

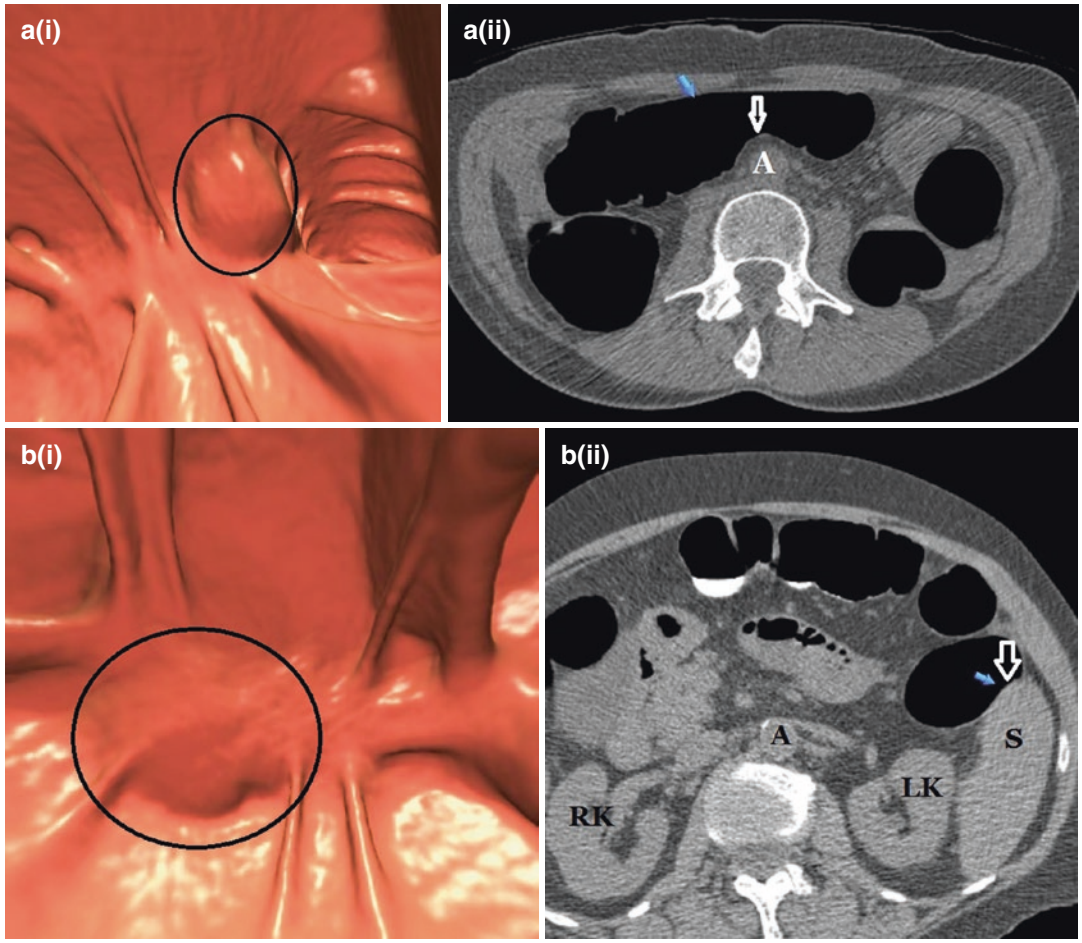

Fig. 11.14 Extrinsic impressions. (**a**) (**i**) 3D view of an extrinsic impression (circle) on bowel caused by the aorta; (**a**) (**ii**) 2D axial view shows aorta causing external impression on colon (open white arrow). (**b**) (**i**) 3D view of spleen (circle) causing an extrinsic impression on colon; (**b**) (**ii**) 2D axial view shows an extrinsic impression (open white arrow) on colon caused by the spleen (S). Aorta (A); right and left kidneys (RK and LK).

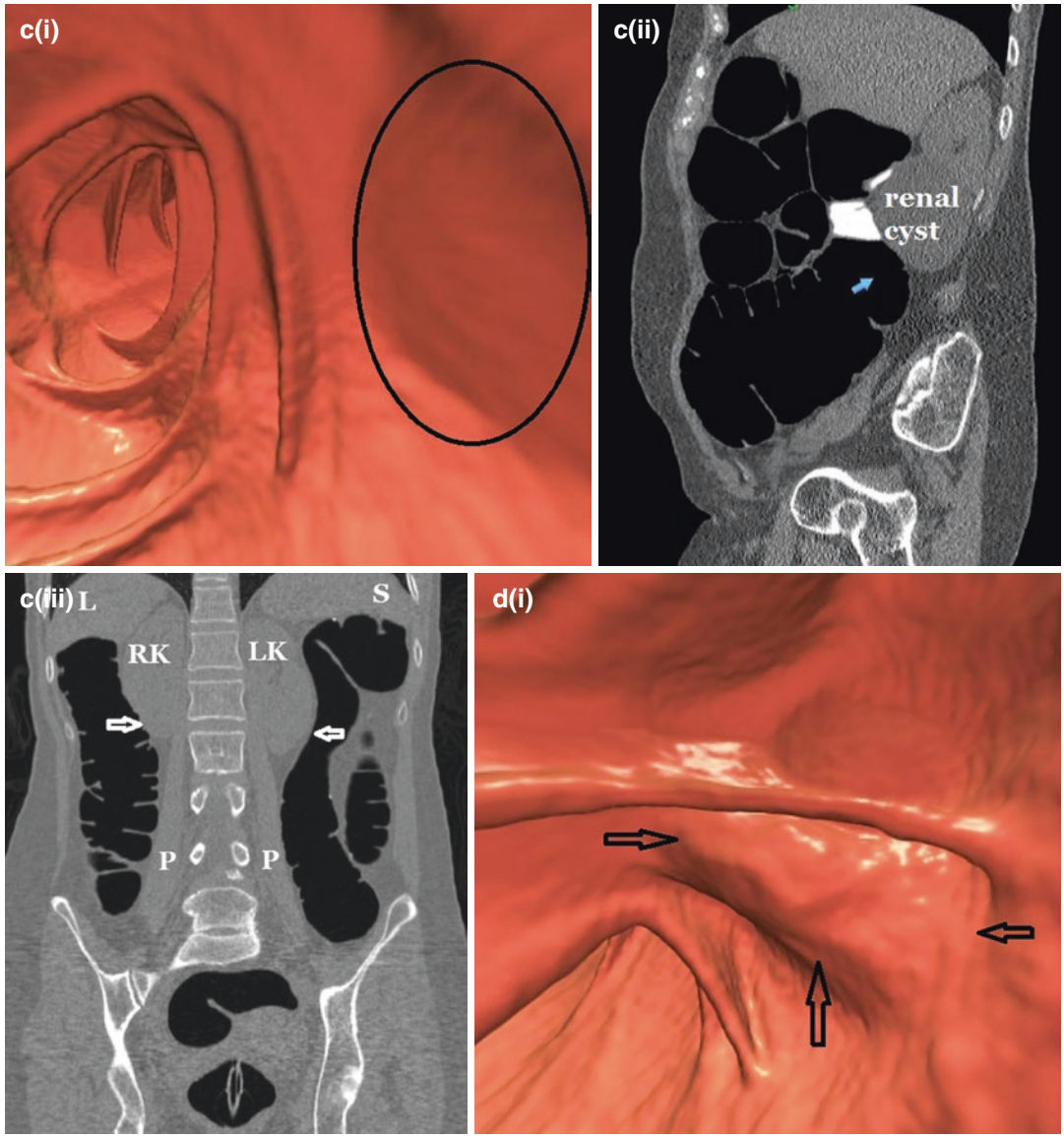

Fig. 11.14 (**c**) (**i**) 3D view showing extrinsic impression on colon due to a renal cyst (circle); (**c**) (**ii**) 2D sagittal view shows renal cyst in lower pole of right kidney impinging on the caecum (C); (**c**) (**iii**) 2D coronal view shows extrinsic impression of lower pole of kidneys (open white arrows) on colon. *RK* right kidney, *LK* left kidney, *L* liver, *S* stomach. (**d**) (**i**) 3D view shows psoas muscle extrinsic impression (open black arrows) on colon;

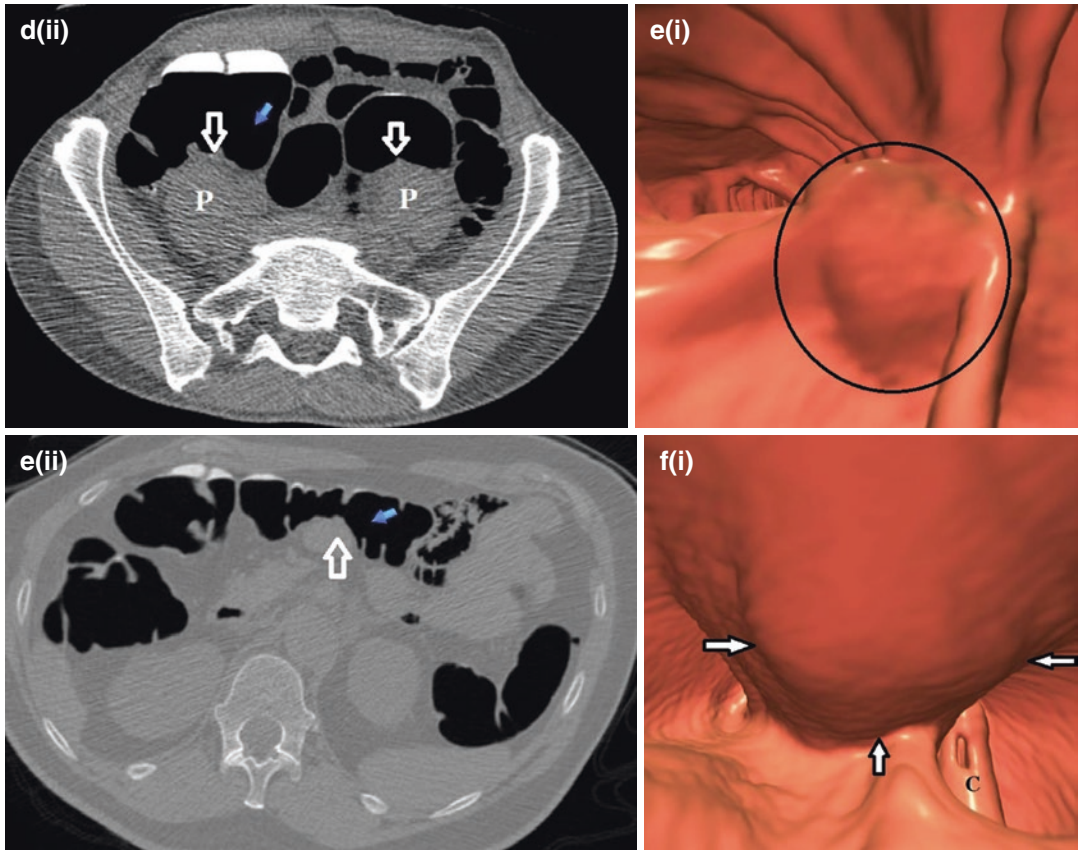

Fig. 11.14 (**d**) (**ii**) Prone 2D axial view showing psoas muscles (P) indenting bowel (open white arrows). (**e**) (**i**) 3D view showing extrinsic impression by small bowel (circle); (**e**) (**ii**) 2D axial view shows extrinsic impression of small bowel (open white arrow) on colon. (**f**) (**i**) 3D view shows extrinsic impression of uterine fibroid (arrows). Rectal catheter (C);

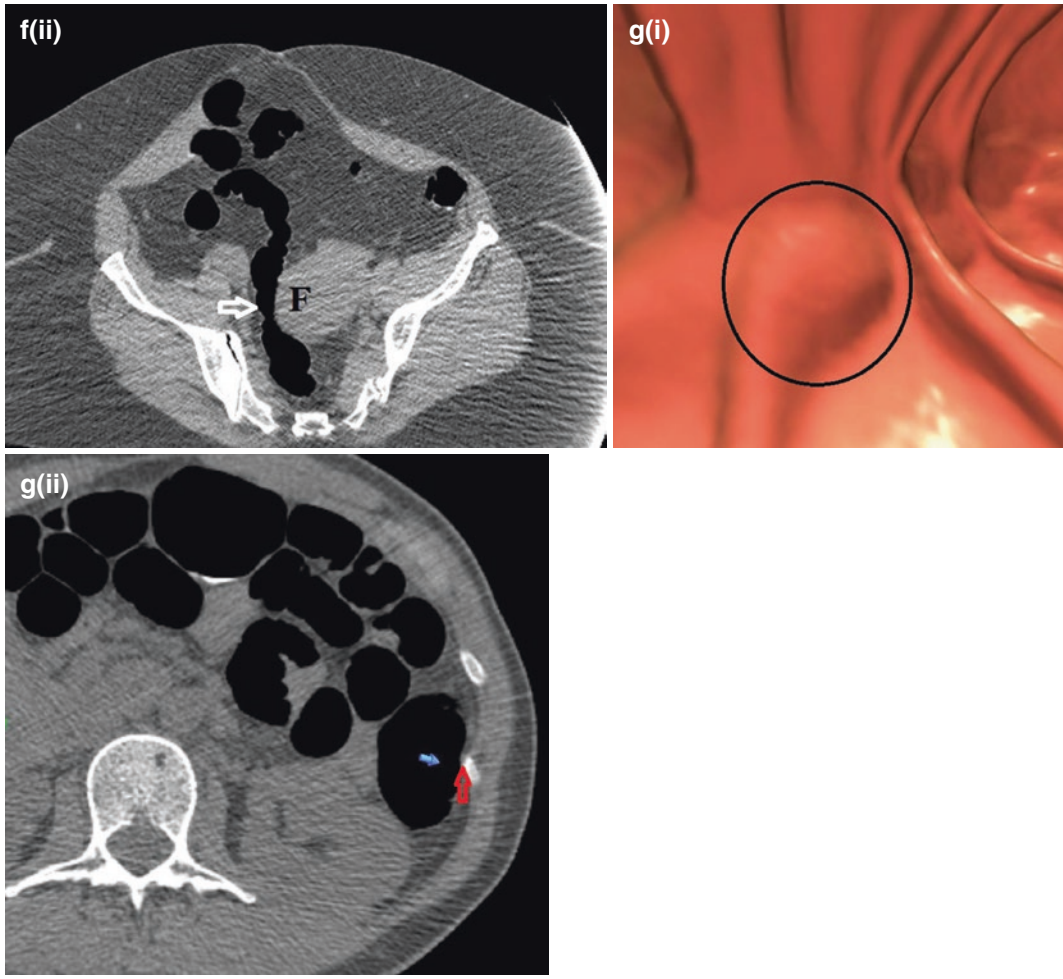

Fig. 11.14 (**f**) (**ii**) 2D axial view of a pedunculated uterine fibroid (F) causing narrowing of rectum (open white arrow). (**g**) (**i**) 3D view shows a rib causing extrinsic impression (circle); (**g**) (**ii**) 2D axial view of a rib causing extrinsic impression (open red arrow)

11.6 Salient Points of CTC Anatomy

The following needs to be considered when interpreting CTC images.

- The position of the rectum and valves of Houston and normal variants.
- The rectosigmoid junction has a loosely attached mesentery which allows for mobility; it may be redundant in some people.
- The descending colon is relatively fixed; its folds are circular in appearance.
- The transverse colon's folds are triangular in appearance; it has a loose mesenteric attachment and it often changes in position with postural change during a 2-view CTC study.
- The ascending colon has triangular folds.
- The ileocaecal valve (ICV) is constant relative to the terminal ileum and caecum; its appearance varies from a labial type to a more bulbous polypoidal/papillary type; it may be open or closed during a CTC study; it has a central depression or 'pit' orifice where the terminal ileum empties into the right colon.
- The caecum is proximal to the ICV; it may be mobile and displaced.
- The vermiform appendix is part of the caecum; its intra-abdominal position may vary widely due to mobility of the caecum.

- Extrinsic impressions (caused by structures adjacent to the bowel) may be present on the colon lumen.

11.7 Summary

Knowledge of normal anatomy of the colon, its variants, and extrinsic impressions on it, is essential for correct interpretation of 2D and 3D CTC images. Malrotation and mobility of some segments of the colon may be evident in CTC studies. Mobile segments may change position during a standard 2-view CTC study: supine and prone scans.

References

1. Muto T, Bussey HJR, Morson BC. The evolution of cancer of the colon and rectum. Cancer. 1975;36(6):2251–70. https://doi.org/10.1002/cncr.2820360944.
2. Pickhardt PJ. Screening CT colonography: how I do it. AJR. 2007;189(2):290–8. https://doi.org/10.2214/ajr.07.2136.
3. Yee J. Virtual colonoscopy. Philadelphia: Lippincott, Williams & Wilkins; 2008. p. 123–4.
4. De Haan MC, Pickhardt PJ, Stoker J. CT colonography: accuracy, safety and position in organised population screening. Gut. 2015;64(2):342–50. https://doi.org/10.1136/gutjnl-2014-308696.
5. Bortz JH. CT colonography: an approach for a successful examination. S Afr J Rad. 2014;18(1):607, 11 pages. https://doi.org/10.4102/sajr.v18i1.607.
6. Regge D, Monica PD, Galatola G, et al. Efficacy of computer-aided detection as a second reader for 6–9 mm lesions at CT colonography: multicenter prospective trial. Radiology 2013; 266 (1): 168–176.
7. Halligan S, Mallett S, Altman DG, et al. Incremental benefit of computer-aided detection when used as a second and concurrent reader of CT colonographic data: multiobserver study. Radiology. 2011;258(2):469–76. https://doi.org/10.1148/radiol.10100354.
8. Netter F. The Ciba collection of medical illustrations, vol 3. Digestive system. Part 2. Lower digestive tract. New York: Colour Press. 1962. pp. 54–63.
9. Hamilton SR. Structure of the colon. Scand J Gastroentrol Suppl. 1984;93:13–23.
10. Abramson DJ. The valves of Houston in adults. Am J Surg. 1978;c136:334–6.
11. Ahmed I, Asgeirson K, Beckingham I, Lobo D. The position of the vermiform appendix at laparoscopy. Surg Radiol Anat. 2007;29:165–8. https://doi.org/10.1007/s00276-007-0182-8.
12. Varsamis N, Pouggouras K, Salveridis N, et al. Appendiceal intussusception. In: Lulu G, editor. Current concepts in colonic disorders, 2012. pp. 47–64. [cited 2022 October 30]. http://www.intechopen.com/books/current-concepts-in-colonic-disorders/appendicealintussusception.
13. Strouse PJ. Disorders of intestinal rotation and fixation ("malrotation"). Pediatr Radiol. 2004;34:837–51. https://doi.org/10.1007/s00247-004-1279-4.
14. Torres AM, Ziegler MM. Malrotation of the intestine. World J Surg. 1993;17:326–31.
15. Pickhardt PJ, Bhalla S. Intestinal malrotation in adolescents and adults: spectrum of clinical and imaging features. AJR. 2002;179(6):1429–35.
16. Maxson RT, Franklin PA, Wagner CW. Malrotation in the older child: surgical management, treatment, and outcome. Am Surg. 1995;61(2):135–8.
17. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009.

CTC Traps and Artefacts

12

Joel H. Bortz

12.1 Introduction

It is important when interpreting both intracolonic and extracolonic images to be familiar with the normal appearance of all structures. We need to be familiar with normal CTC images in order to recognise potential traps (pitfalls) that could impact on image interpretation [1, 2]; at times one can be misled by artefacts [3] that could be mistaken for pathology. In this chapter, the importance of being aware of potential traps and artefacts at CTC interpretation is underscored with examples.

12.2 General Principles

Prominent folds and shifting of pedunculated polyps present more of a problem on 2D than 3D interpretation. Figure 12.1 (i–iv) is an example of complex folds. Submucosal lesions and stool filled diverticula become more of an issue on 3D. However, the complementary nature of 2D (two-dimensional) and 3D (three-dimensional) evaluation usually resolves these issues. The below 12 broad groups of potential traps, including artefacts, are the focus of this chapter.

- cathartic preparation and tagging solutions
- sigmoid diverticular disease
- polyp morphology
- anatomical locations and structures
- external impressions of organs and bony structures on the colon
- position of the catheter
- movement artefacts
- beam hardening artefacts
- ingested artefacts
- electronic cleansing
- mucus strand
- tampon and vaginal pessary

Artefacts are unwanted features on a CTC image that may obscure or simulate pathology [3]. The above groups are discussed with examples. The following abbreviations are used in this chapter.

- 2D: two-dimensional
- 3D: three-dimensional
- ICV: ileocaecal valve
- MDCT: multidetector CT
- OC: optical colonoscopy
- RLD: right lateral decubitus

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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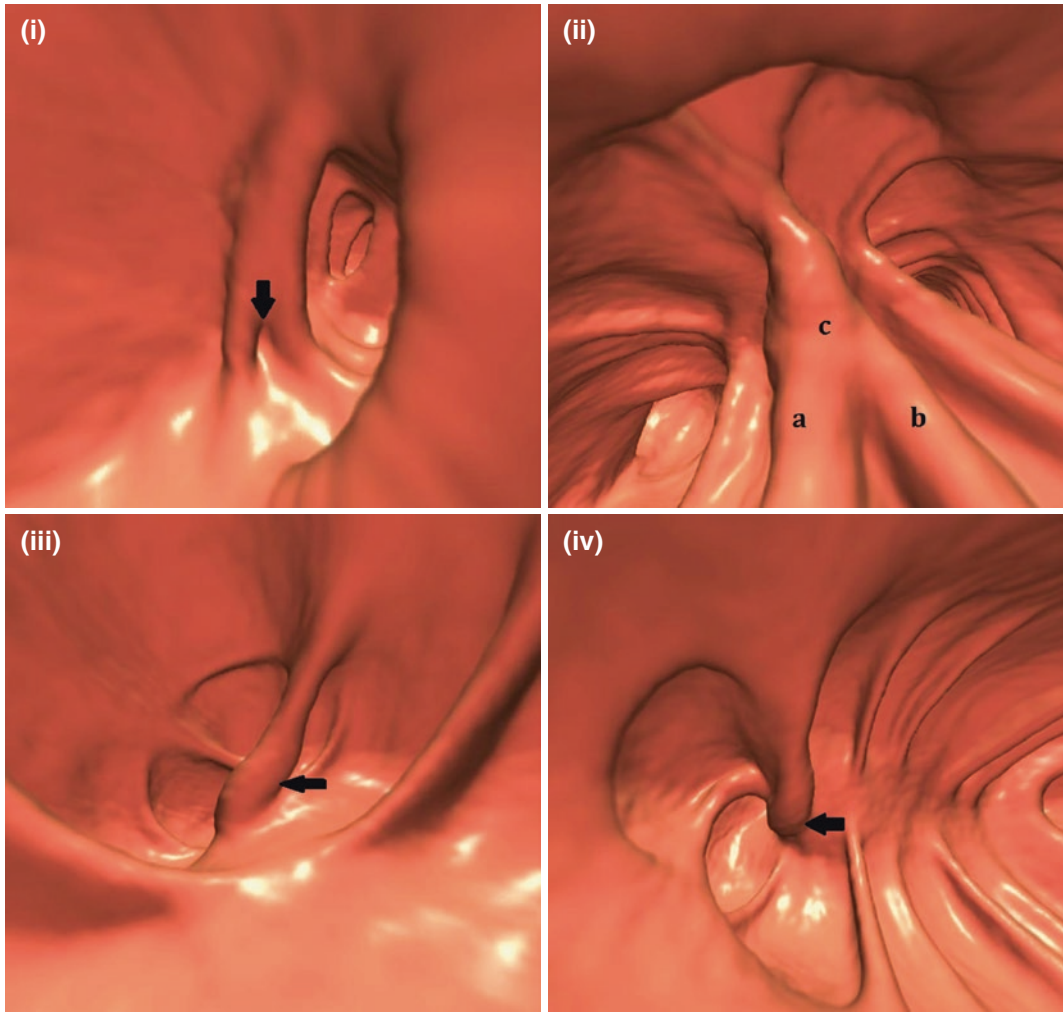

Fig. 12.1 (**i**) Bifid fold (arrow). (**ii**) Two folds (a and b) joining to form a single fold (c). (**iii**) Mild twisting of haustral fold (arrows). (**iv**) Shortened and thickened fold (arrow)

12.2.1 Cathartic Preparation and the Use of Tagging Solutions

Bowel preparation and the use of tagging solutions are discussed in Chap. 9. We need to be aware of potential traps that may be caused by poor bowel preparation in terms of

1. retained stool
2. different appearances of stool and its characteristics
3. movement of stool during postural change, for example, supine to RLD or prone positions [4]

In order to differentiate a polypoidal lesion from stool there are clues available: 2D and 3D viewing are complementary [4]. The former is the most useful method to make the distinction. Stool may be covered by barium and frequently contains small bubbles of air giving it a heterogeneous appearance (Fig. 12.2a). Air within stool is not identified on 3D viewing. Most typically

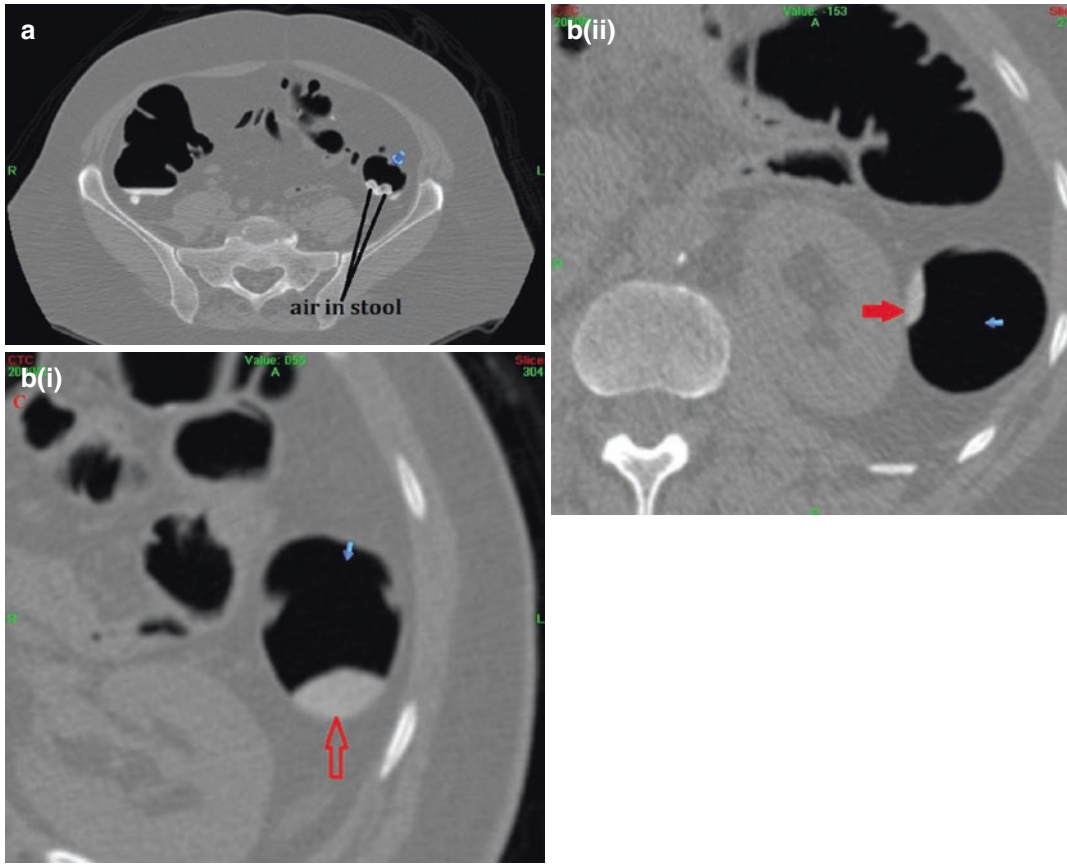

Fig. 12.2 (**a**) 2D axial view showing air in stool. (**b**) (**i**) 2D axial supine showing stool (open red arrow). (**ii**). 2D RLD view showing movement of stool (red arrow)

stool will move to the opposing wall when the patient is turned from the supine to the prone, or RLD position. Figure 12.2b (i) and (ii) shows movement of stool between supine and RLD position.

12.2.1.1 Retained Faecal Matter

In order to visualise colon anatomy, it is necessary for the bowel to be clean [4, 5]. This entails the use of a cleansing regimen that patients must follow prior to the study to eliminate bulky stool from the colon (see Chap. 9). Most cathartic agents enable bowel cleansing to occur. However, small particles of adherent stools may remain on the colon wall and may mimic a sessile polyp. It is easier to identify large bulky stool that sometimes remain. The shape may be polypoidal, squared, or faceted in appearance; it may occasionally be confused with a large villous lesion. Bulky stools are usually mobile and on translucent display (TD) may reveal mottled low-density lesions. Figure 12.3a (i)–d (ii) shows a range of examples of stool being a potential interpretation trap.

Tagging is an integral part of colonic preparation [4]. Barium tags any remaining stool adherent to the bowel lumen which usually allows for easy distinction between stool and polyps [6]. Software systems that include a TD function (such as Viatronix) display barium as white [4].

Tagging agents Gastrografin and Omnipaque (see Chap. 9) have a dual action. They stain the residual fluid white thus aiding in 2D evaluation

of submerged polyps as well as emulsifying the stool adherent to the bowel wall thus causing a secondary catharsis [6]. They provide further internal tagging of solid debris. In a small percentage of cases, the mucosa, particularly in the caecum and ascending colon, may have adherent stool on the surface. We use 2D to evaluate adherent stool seen in this area of the colon: it is quicker and more accurate than 3D. Figure 12.3e shows adherent stool.

12.2.2 Electronic Cleansing

During a CTC examination, faecal matter may obscure lesions. Electronic cleansing marks the stool that has been tagged. The stool is then removed electronically [7]. This method does produce cleansing artefacts. Figure 12.4a (i) and (ii) illustrates before and after electronic cleansing of the colon. As described in Chap. 9, bowel preparation includes the use of tagging.

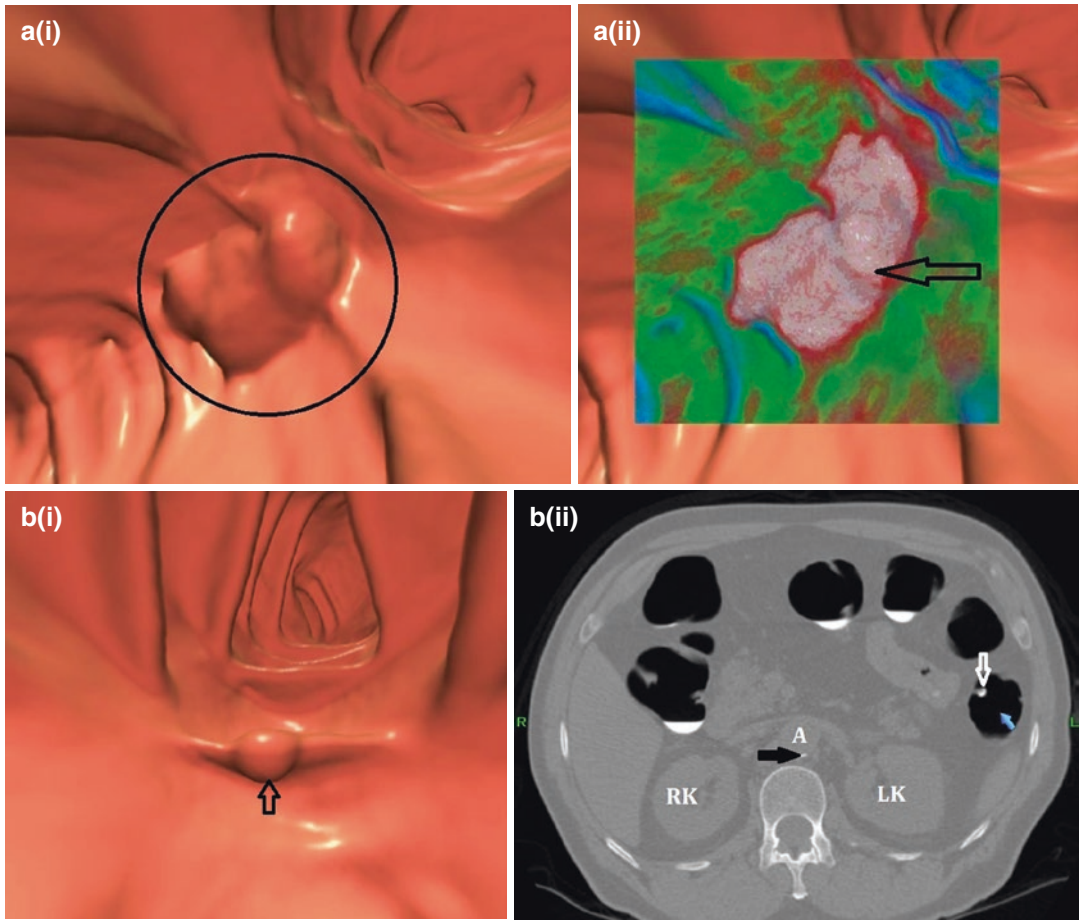

Fig. 12.3 (**a**) (**i**) 3D endoluminal view showing lobulated polypoidal lesion (circle). (**ii**) TD confirming stool (open black arrow) and not a polyp. (**b**) (**i**) 3D view showing polypoidal lesion on haustral fold (open black arrow). (**ii**) 2D axial showing stool (open white arrow). *RK* right kidney, *LK* left kidney, *A* aorta. Small amount of atherosclerotic calcification on posterior wall of aorta (black arrow).

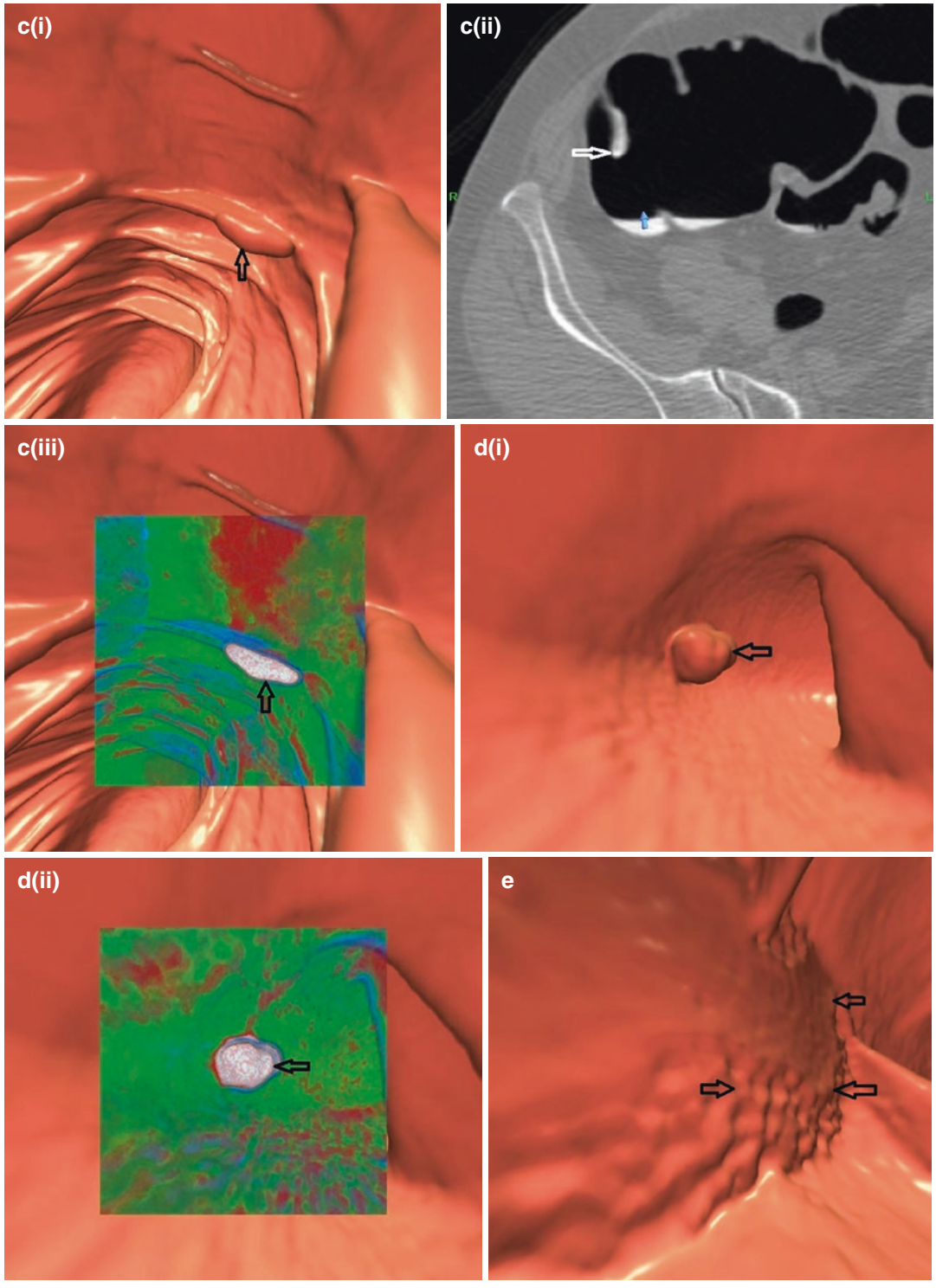

Fig. 12.3 (**c**) (**i**) 3D view showing thickened haustral fold (arrow). (**ii**) Axial 2D showing barium surrounding haustral fold (white arrow). (**iii**) TD confirming barium (black arrow) and not a polyp. (**d**) (**i**) 3D endoluminal view showing a sessile lobulated polypoidal lesion (arrow). (**ii**) TD showing stool (arrow) and not polyp. (**e**) Adherent non-opacified stool having indentations similar to the appearance of the surface of a golf ball (arrows)

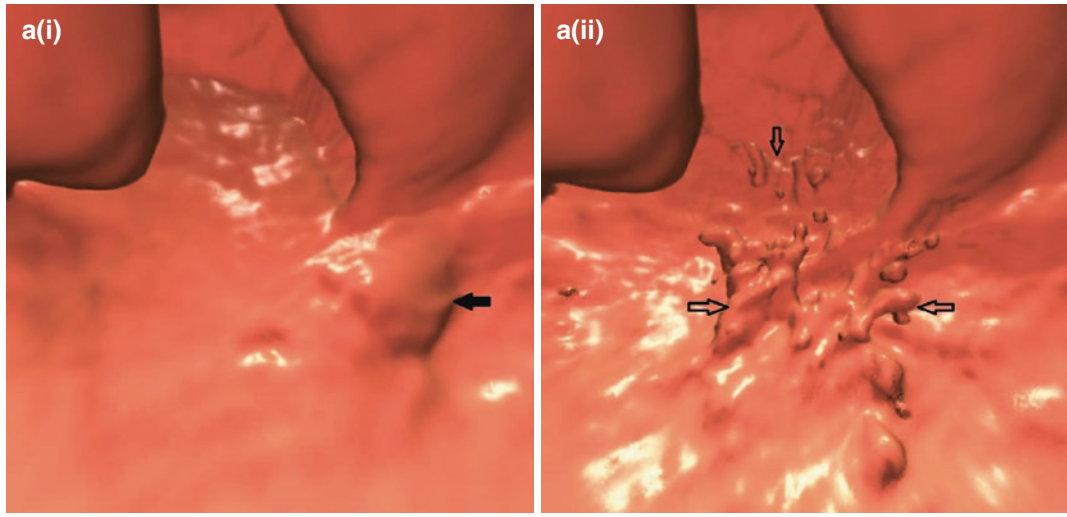

Fig. 12.4 (**a**) (**i**) 3D view showing stool (arrow) that may be obscuring lesions. (Courtesy of Viatronix, Stony Brook, NY). (**ii**) 3D view showing artefacts (arrows) caused by electronic cleansing. (Courtesy of Viatronix, Stony Brook, NY)

Same-day CTC examinations, after an incomplete or failed optical colonoscopy (OC), tend to be sub-optimal as tagging has not been performed (see Chaps. 10 and 20) [4]. Untagged stool is a huge problem. Electronic cleansing is available on most software systems, which allows for visualisation of mucosa covered by fluid and/or stool. On the other hand, electronic cleansing creates subtraction artefacts that present interpretation problems. This is counterproductive as the produced artefacts are unwanted and impact on image evaluation. Electronic cleansing is not routinely performed because it may cause a large number of artefacts which may make interpretation difficult. In addition, part of the surface mucosa may be electronically removed and this could result in missed lesions [4]. The author does not use electronic cleansing because it causes artefacts. Pickhardt and Kim (personal communication) advise against using electronic cleansing in CTC studies.

12.2.3 Sigmoid Diverticular Disease

This disease is covered in more detail in Chap. 16. For the purpose of discussion, the following potential traps are presented. Poor or incomplete luminal distension and thickened folds (Fig. 12.5a), underpin potential pitfalls in this group. How can this potential pitfall be overcome? The use of spasmolytics enables improved bowel distension [4]. In Europe, and South Africa, Buscopan is often used to relax the bowel for good distension (see Chap. 8).

Another potential trap is that of stool-filled diverticula. On 3D, it may produce an appearance of a polyp. The complementary role of 2D identifies stool-filled diverticula as discussed in Chap. 16. Figure 12.5b is an example of 2D showing an impacted diverticulum.

12.2.4 Morphology of Polyps

The shape and form of flat lesions and carpet lesions are potential pitfalls. Polyp measurements can be a potential interpretation trap. It is important to ensure measurements are accurate as discussed in Chap. 14. Shifting pedunculated polyps can be potential interpretation traps. It is important to use a 2-view scan for 3D and 2D evaluation as evident in Fig. 12.6 (i) and (ii).

12.2.5 Anatomical Locations and Structures

Both the location and structure of the appendix, and the ileocaecal valve (ICV) are potential inter-

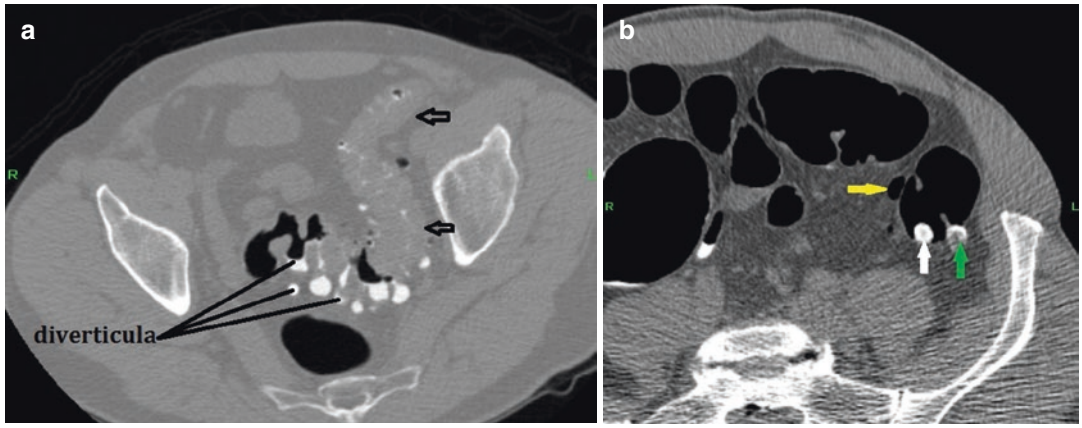

Fig. 12.5 (**a**) Axial 2D showing very poor distension of the colon (open black arrows) and multiple diverticula. (**b**) 2D axial view shows stool (white arrow) and impacted diverticulum (green arrow). Yellow arrow shows diverticulum filled with air

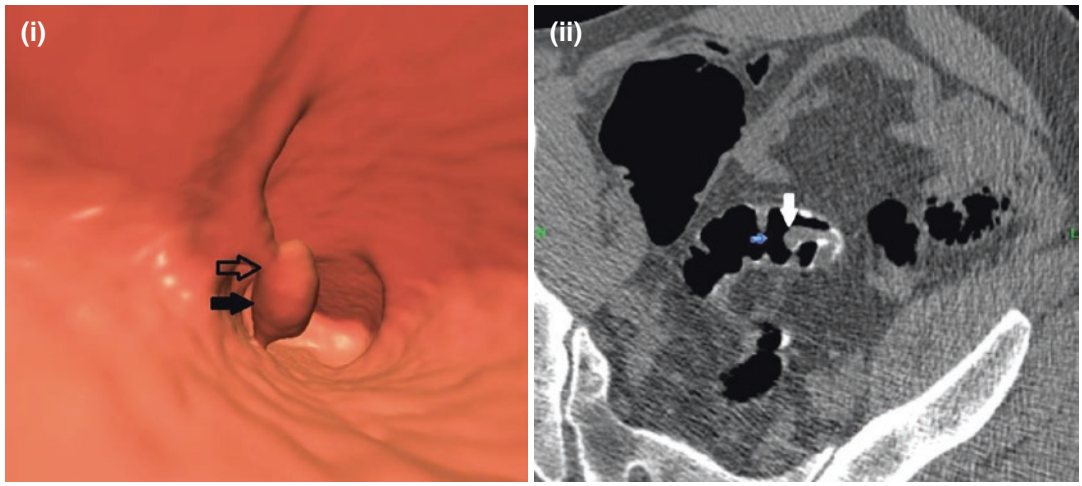

Fig. 12.6 (**i**) 3D endoluminal view showing pedunculated polyp (black arrow) on a short stalk (open black arrow). (**ii**) Axial 2D view shows pedunculated polyp (white arrow)

pretation traps when evaluating CTC images. The vermiform appendix is part of the caecum. Its length varies from 2.5 to 33 cm [8]. Its average length is between 5 and 10 cm and its base is usually situated 2 cm below the ICV. Its intra-abdominal position may vary widely depending on the peritoneal fold which represents the mesentery of the appendix [8]. Figure 12.7a and b shows varying abdominal positions of an appendix. Examples of different anatomical locations of both the appendix and ICV are presented in Chap. 11.

12.2.6 External Impressions of Organs and Bony Structures on the Colon

As discussed in Chap. 11, we need to be aware of extrinsic impressions on the colon lumen due to structures that lie adjacent to the colon. Figure 12.8 (i) and (ii) shows an extrinsic impression on the colon lumen caused by spondylolisthesis. A range of extrinsic impressions on the colon are presented in Chap. 11.

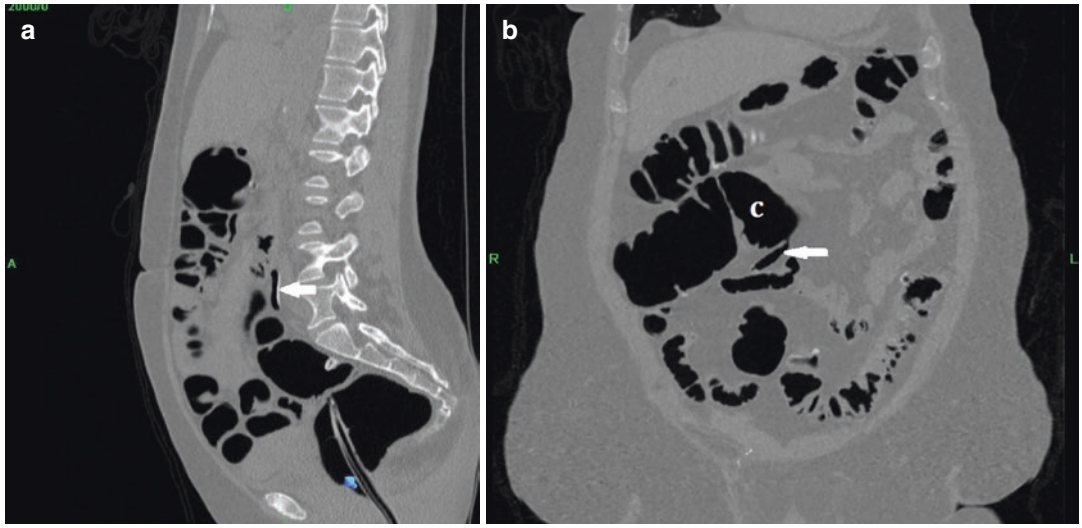

Fig. 12.7 (**a**) Sagittal 2D view showing pre-vertebral appendix (white arrow). (**b**) Coronal 2D showing malrotated caecum (C) with appendix (white arrow)

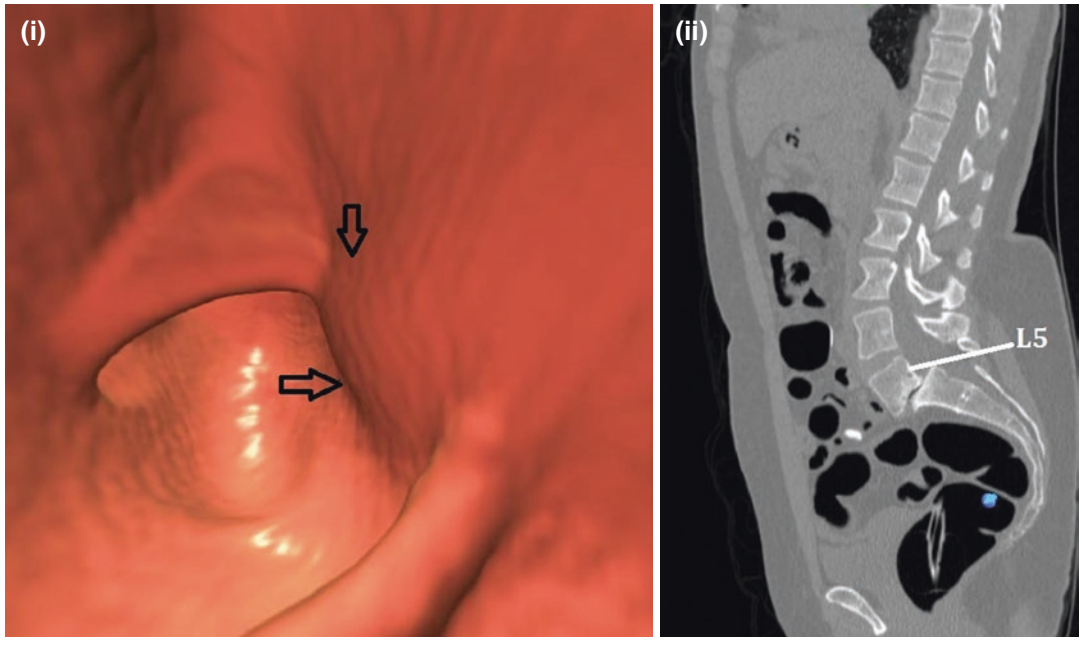

Fig. 12.8 (**i**) 3D view of sigmoid colon showing extrinsic soft tissue bulge (arrows) due to spinal spondylolisthesis. (**ii**). Sagittal 2D grade 2 spondylolisthesis of L5 on S1. This is associated with disc degenerative disease between L5 and S1

12.2.7 Position of the Catheter

The position of the rectal catheter can impact on evaluating the anorectal region [9]. Occasionally, the rectal catheter may be inserted too far into the rectum with the result the tip then projects beyond the superior valve of Houston. Although this is easily identified, sometimes when flying from the caecum to the rectum the catheter's tip may assume the shape of a polyp as shown in Fig. 12.9a (i) and (ii). Another example of this pitfall is when the tip of the catheter comes into

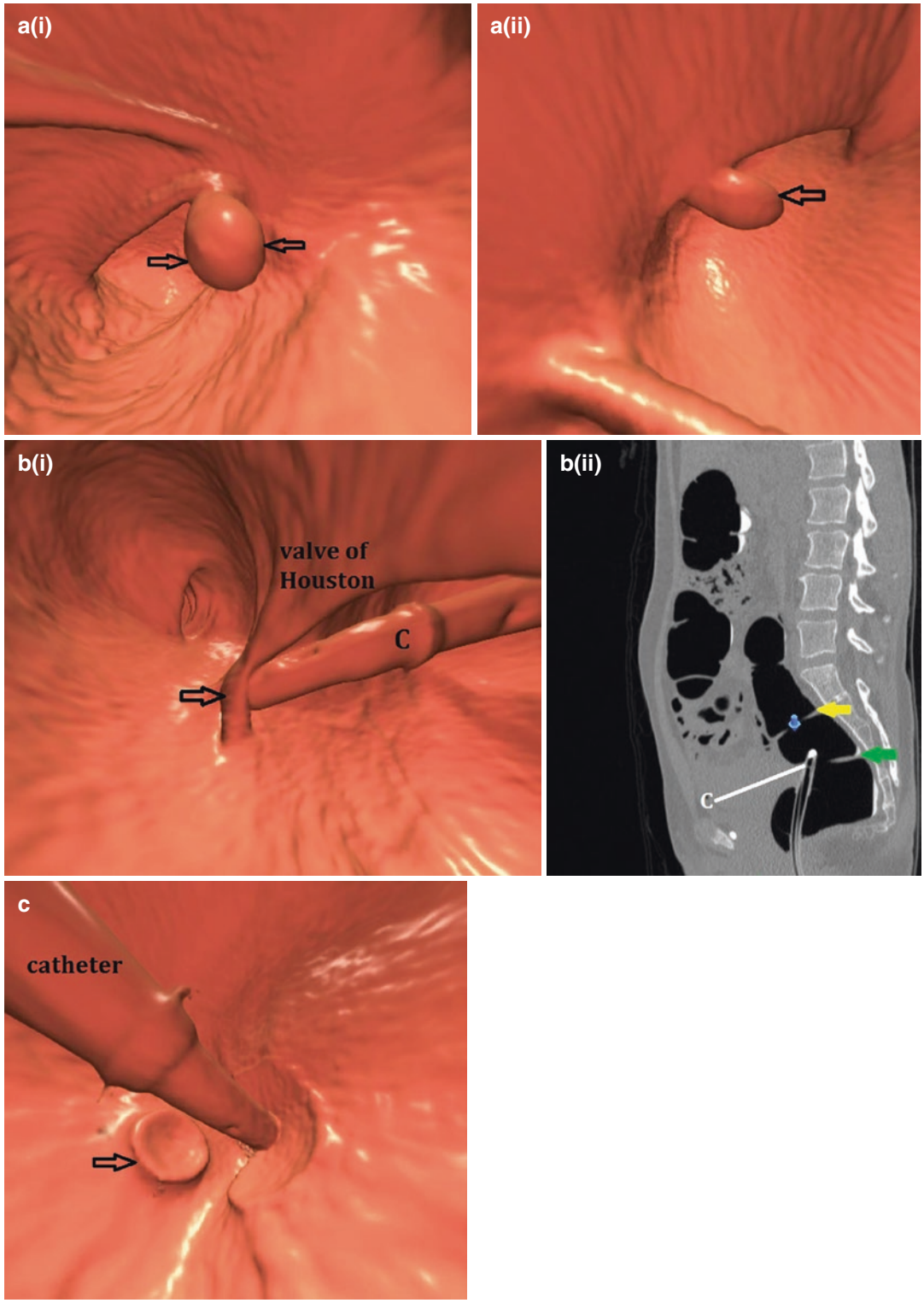

Fig. 12.9 (**a**) (**i**) 3D view showing catheter tip simulating a polyp (arrows). (**ii**) 3D view showing catheter tip simulating a polyp (arrow). (**b**) (**i**) 3D view showing catheter tip distorting fold (open black arrow). Rectal catheter = C. (**ii**) Sagittal 2D view showing tip of catheter (C) extending beyond the middle valve of Houston (green arrow). Superior valve of Houston (yellow arrow). (**c**) Meniscus sign (arrow)

contact with the superior valve of Houston and causes an extrinsic impression on the mucosa as evident in Fig. 12.9b (i) and (ii).

The author's standard technique is to perform a 360° fly around the rectal catheter to ensure adequate visualisation of all surrounding features. This technique also reduces the chances of a polyp being missed due to it being obscured by the rectal catheter as discussed in Chap. 13.

To keep the catheter in position in the rectum, it is essential to inflate the balloon, but as discussed in Chap. 13 pathologies, such as internal haemorrhoids, may be obscured. To visualise compressed haemorrhoids, it is essential that the balloon is deflated when the patient is in the prone position (see Chap. 13). Furthermore, an inflated balloon may cause a defect called the meniscus sign [1]. Figure 12.9c demonstrates this defect. The meniscus sign is also discussed in Chap. 13.

12.2.8 Movement Artefacts

It is essential that patients co-operate during CTC examinations (see Chap. 2). Adequate breath holding during scanning is essential [4]. For all scans, instruct the patient to inhale, then exhale, and suspend breathing during scanning. Breathing during scanning causes artefacts as evident in Fig. 12.10(i)–(iii). Technological advances in CT imaging have resulted in very short scanning times which also reduce risk of movement artefacts. Patients should not move during scanning to prevent movement artefacts.

12.2.8.1 'Dense Waterfall' Sign

The 'dense waterfall' sign is an artefact that is not related to voluntary patient movement or breathing. It was first described by Boyce et al. [10] in 2012. It is a luminal artefact, which occurs when opacified luminal fluid flows from a higher to a lower level relative to the patient position on the scanner table. It is caused by the CT scanner catching the movement of the opacified fluid at a moment in time. A distinctive arciform artefact, which is not due to patient breathing, patient movement, spasm, or beam hardening, is created. It is best seen on 2D views where the artefact is most prominent [11]. It may occur in the sigmoid colon, descending colon, transverse colon, ascending colon, and caecum (Fig. 12.11a–g (ii)). This artefact may also be seen on abdominal multidetector CT (MDCT) studies [10]. It occurs in approximately 25% of studies but does not usually obscure pathology. It may however potentially obscure pertinent CTC findings [10].

12.2.9 Beam Hardening Artefacts

Dark streaks are produced by beam hardening as well as scatter. Both produce dark streaks. These streaks are between two high attenuation objects, for example, metal or bone, with surrounding bright streaks [3]. Examples include unilateral or bilateral hip replacements, and surgical clip artefacts. Examples of beam hardening artefacts are presented in Fig. 12.12a (i)–e.

12.2.10 Ingested Artefacts

It is important for patients to follow instructions as discussed in Chap. 2. Bowel preparation commences the day before the scheduled examination and a 24 h liquid diet is required (see Chap. 9). An ingested vitamin tablet may resemble a polyp (Fig. 12.13a). Oil capsules (e.g., omega 3) do not always dissolve; they may remain intact in the gastrointestinal tract for a period of time. The same applies to softgel long-acting cold and flu capsules. Both types of capsules may resemble a polyp particularly on a 3D display. Figure 12.13b(i)–(iii) presents examples of an ingested fish oil capsule. These foreign objects do not adhere to the bowel mucosa and move with postural change. Furthermore, the internal attenuation of these ingested artefacts is very different from a polyp. According to Yee [2], we must also be aware of ingested vegetable matter, such as corn and seeds, as they too can be confused with polyps.

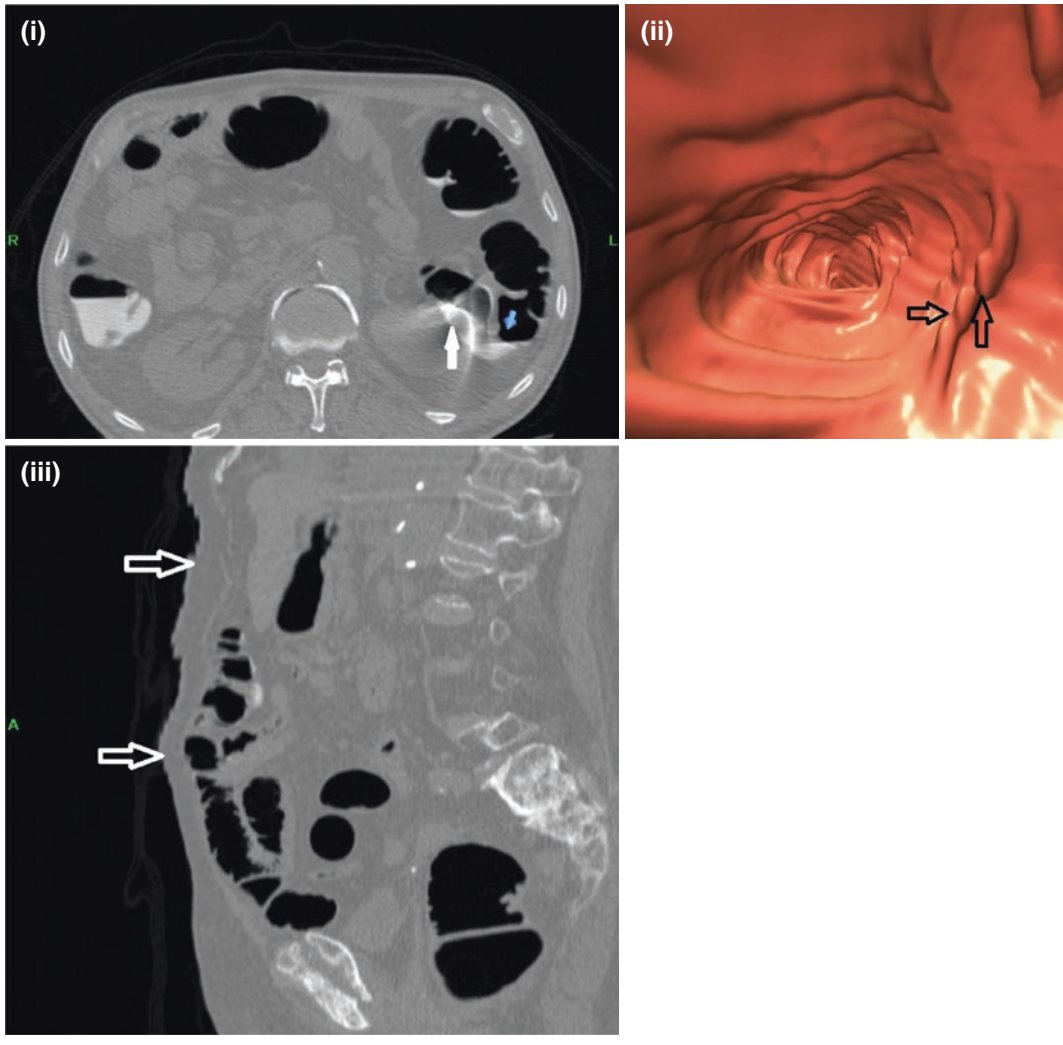

Fig. 12.10 (**i**) 2D axial view showing focal motion artefact in the descending colon (arrow). Rest of colon is normal. (**ii**) Example of a breathing stepped artefact (arrows). (**iii**) Sagittal 2D showing breathing artefact on skin surface (arrows)

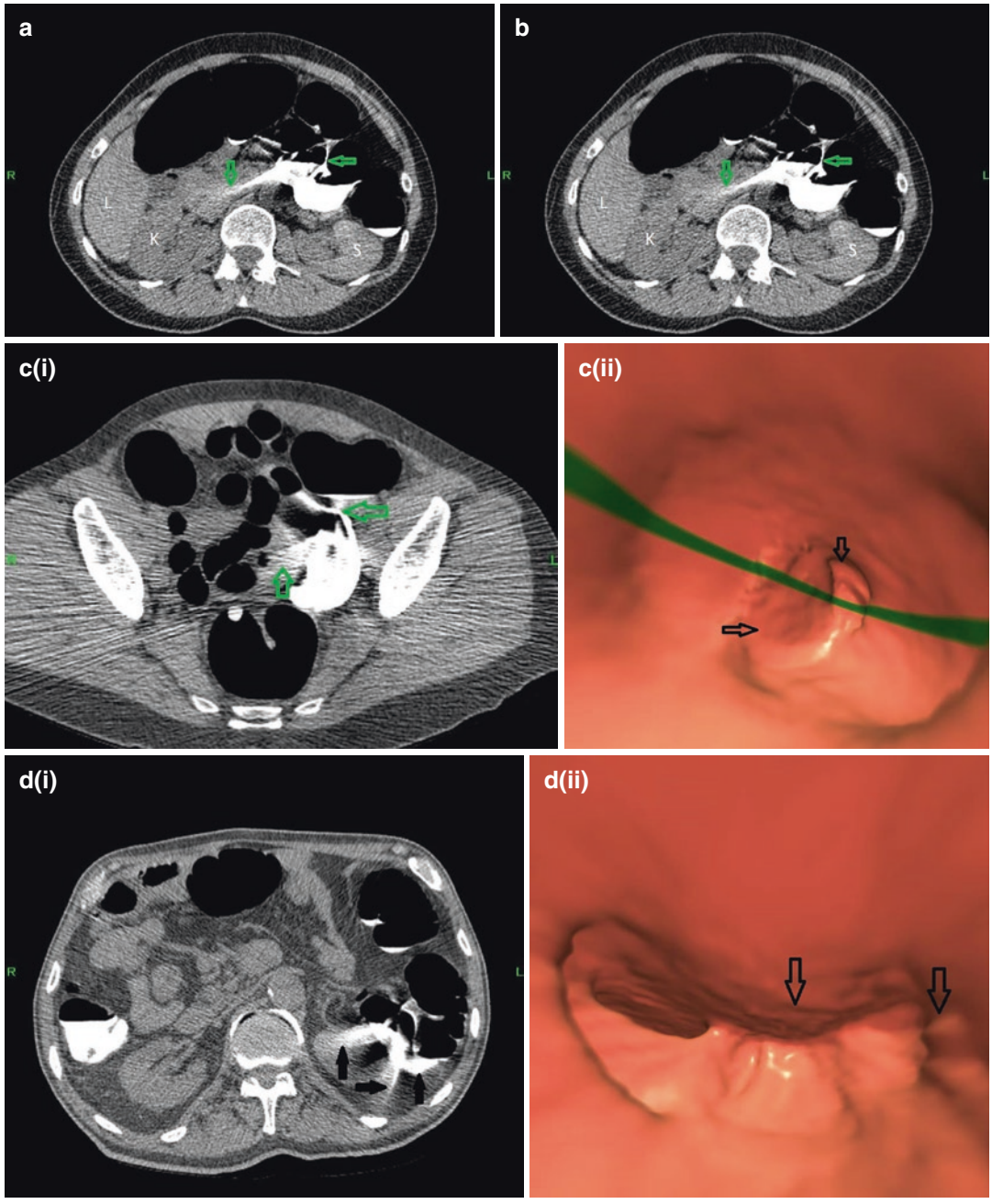

Fig. 12.11 (**a**) 2D axial view showing the arciform artefact of the 'dense waterfall' sign (DWS) in the sigmoid colon (open green arrows). (**b**) 2D axial view showing the arciform artefact from the DWS in the sigmoid colon. (**c**) (**i**) 2D axial showing the DWS in the sigmoid colon (open black arrows). (**ii**) 3D endoluminal view showing the artefact caused by the DWS (open black arrows). (**d**) (**i**) 2D axial view showing the DWS (black arrows). (**ii**) 3D endoluminal view showing the artefact caused by the DWS (open black arrows).

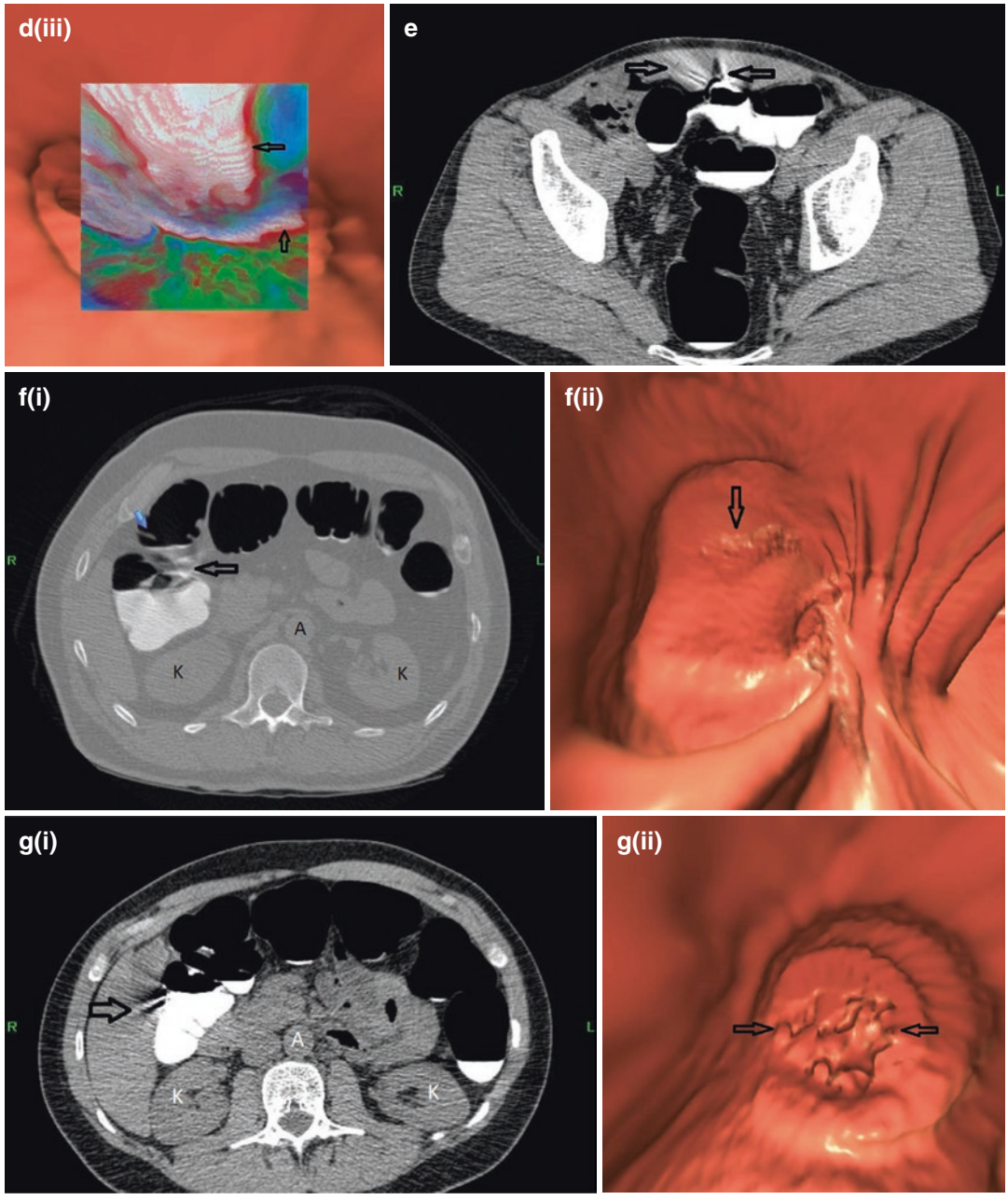

Fig. 12.11 (**iii**) Translucent display showing contrast fluid artefact (white and open black arrows). (**e**) 2D axial view showing the alternating dark and light appearance of the DWS artefact in the transverse colon (open black arrows). (**f**) (**i**) 2D axial showing DWS (open black arrows) in the ascending colon. *K* kidneys, *A* aorta. (**ii**) 3D endoluminal view showing the artefact caused by the DWS (open black arrow). (**g**) (**i**) 2D axial showing the DWS artefact in the ascending colon (open black arrow). *K* kidneys, *A* aorta. (**ii**) 3D endoluminal view showing the artefact caused by the DWS (open black arrow)

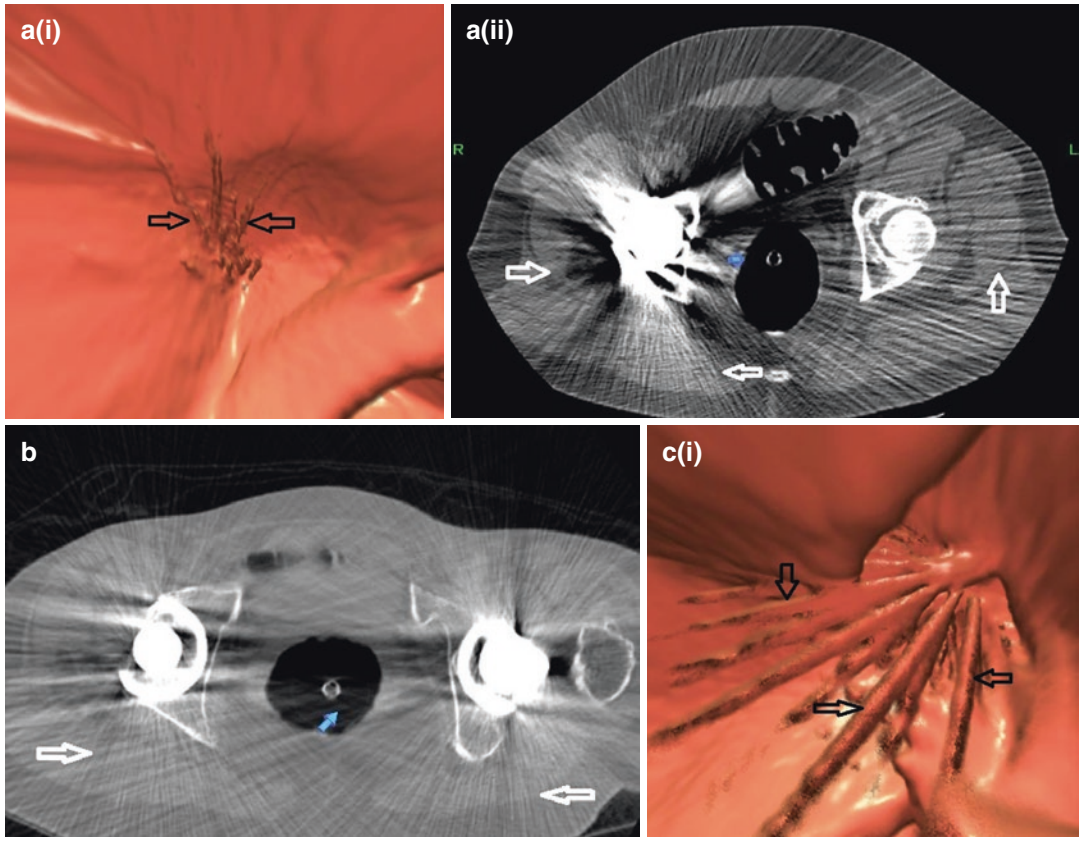

Fig. 12.12 (**a**) (**i**) Beam hardening artefact (arrows) due to right hip prosthesis. (**ii**) Axial 2D showing streak artefact (arrows) due to right hip prosthesis. (**b**) Axial 2D showing streak artefact (arrows) due to bilateral hip prostheses. (**c**) (**i**) Streaks due to beam hardening artefact (arrows).

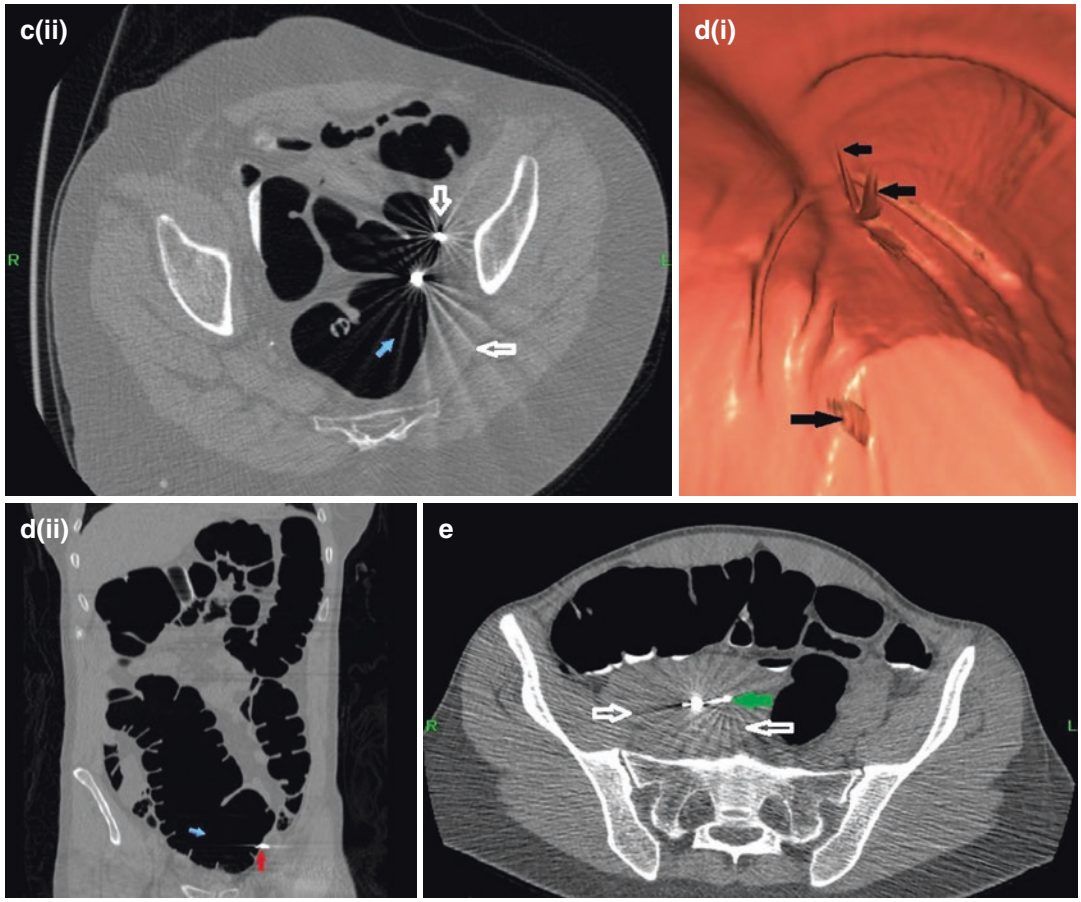

Fig. 12.12 (**ii**) 2D view streaks from surgical clip (white arrows). (**d**) (**i**) Streaks due to beam hardening artefact from surgical clips (arrows). (**ii**) 2D coronal view shows surgical clip (red arrow) in appendiceal region. (**e**) 2D axial view showing streak artefact (open white arrows) from an intrauterine device (green arrow)

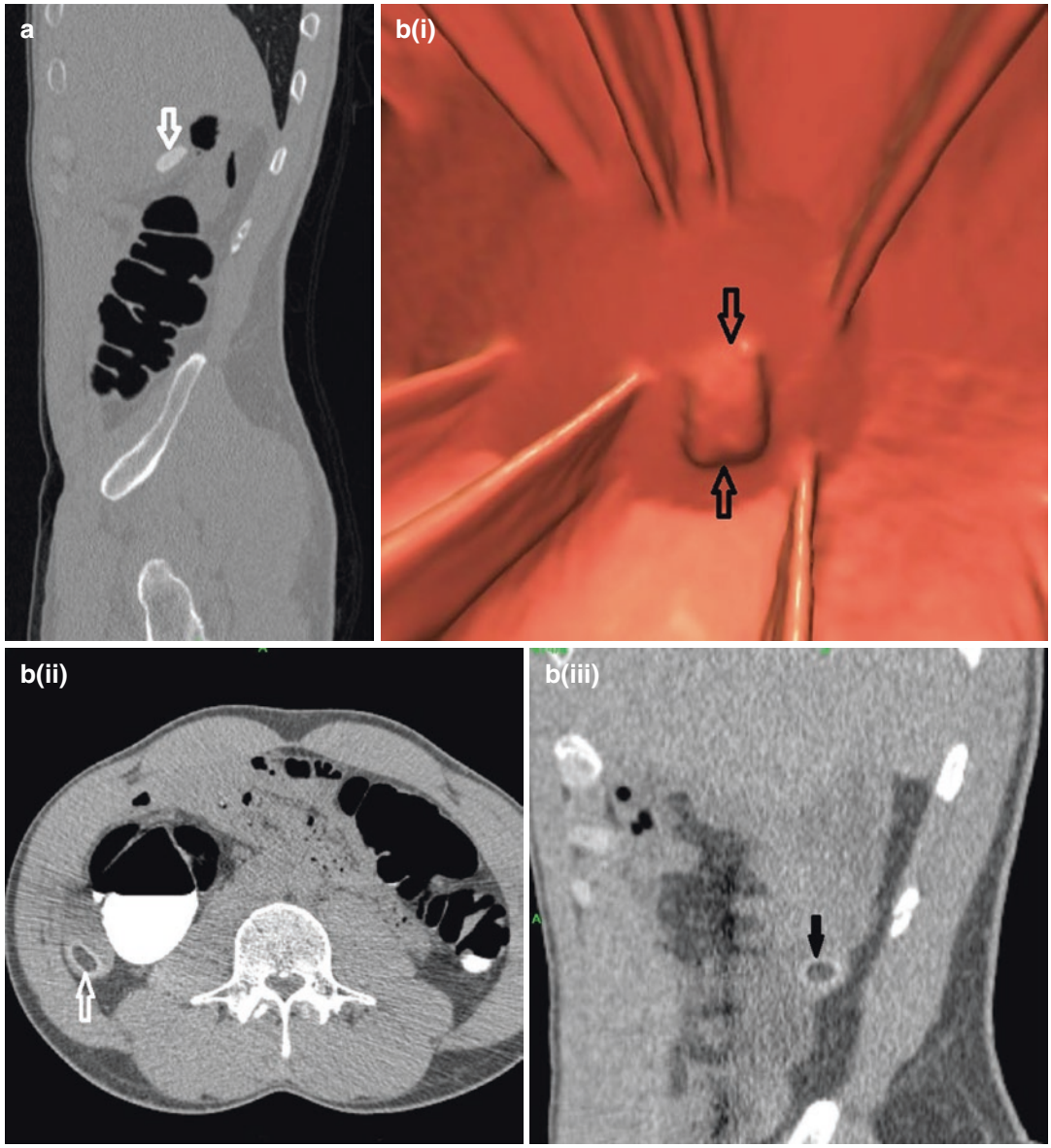

Fig. 12.13 (**a**) 2D sagittal view shows multivitamin capsule (arrow). (**b**) (**i**) 3D view shows density due to fish oil capsule (arrows). (**ii**) 2D axial view shows oil capsule (arrow). (**iii**) 2D sagittal view shows oil 'fat' centrally (arrow)

12.2.11 Mucus Strand

A mucus strand may sometimes be confused with a pedunculated polyp. It has a thin linear strand which extends across normal haustral folds as shown in Fig. 12.14 (i) and (ii). Occasionally, the tagging agent (barium) may be incorporated into the strand and will show as a high density of TD.

12.2.12 Tampon and Vaginal Pessary

Figure 12.15a (i) and (ii) is an example of a tampon visualised on 2D. Figure 12.15b shows a vaginal pessary. A vaginal pessary is a removable device that is used to support pelvic organ prolapse, such as the bladder, uterus, and/or rectum.

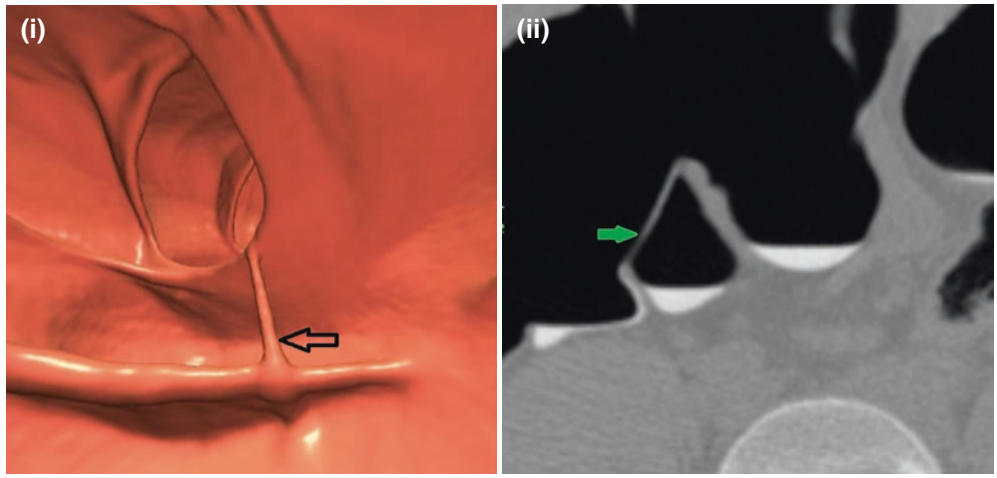

Fig. 12.14 (**i**) Arrow points to mucus strand between two haustral folds. (**ii**) 2D axial view shows mucus strand between folds (green arrow)

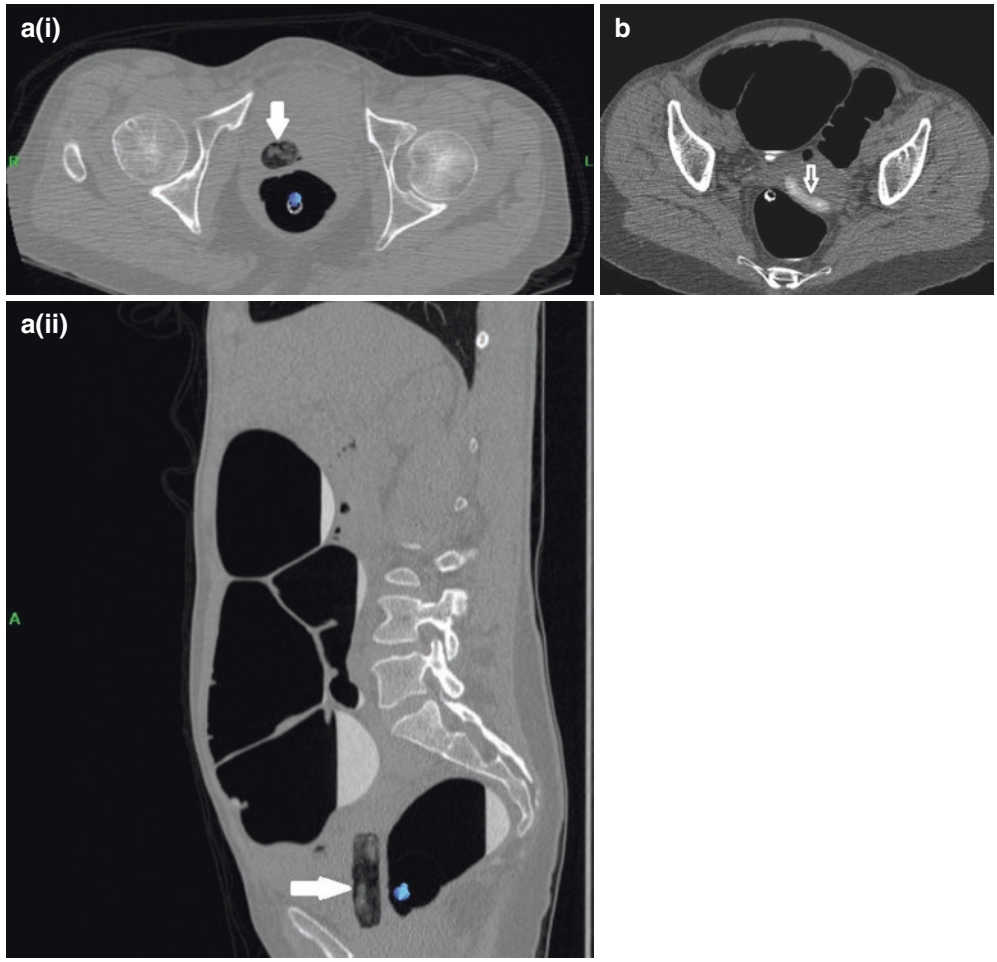

Fig. 12.15 (**a**) (**i**) Axial 2D showing vaginal tampon (white arrow). (**ii**) Sagittal 2D showing vaginal tampon (white arrow). (**b**) Axial 2D showing curvilinear density (arrow) in keeping with vaginal pessary supporting uterus

Key Messages

- Poor bowel preparation could be a potential pitfall as adherent stool may obscure polyps.
- Poor bowel distension could result in non-visualisation of lesions.
- Extrinsic impressions on the colon lumen could result in misdiagnosis.
- Lack of knowledge of colon anatomy, and normal variants, could be a potential pitfall in terms of anatomical location of structures.
- Incorrect positioning of the rectal catheter could be a potential pitfall.
- Movement and breathing artefacts could present confusing images.
- The 'dense waterfall' sign is a luminal artefact.
- Ingested artefacts could be misinterpreted as polyps.
- Beam hardening artefacts could obscure lesions.
- Electronic cleansing could introduce artefacts.
- 2D and 3D views are complementary for interpreting CTC images.

12.3 Summary

There are many potential traps that may cause an unwary person performing and reading CTC studies to 'trip up'. An adequately cleansed bowel and good distension of the colon with CO_2 minimises most potential pitfalls. For example, a well-prepared colon minimises the potential pitfall of the presence of stool in the colon; good bowel distension using a CO_2 insufflator enables good visualisation of all segments of the colon. Beam hardening artefacts, caused by metal hip prosthesis, for example, may be present on both 2D and 3D images. Movement and breathing artefacts should not be evident if there is good patient co-operation. By using combined 2D-3D interpretation methods, a vast majority of these potential pitfalls should be recognised and handled in the appropriate manner. Electronic cleansing of the colon is not recommended at this stage as it produces artefacts.

Acknowledgements Viatronix Stony Brook, New York is thanked for providing the electronic cleansing images of the colon.

References

1. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009. p. 239–313.
2. Yee J. Virtual colonoscopy. Philadelphia: Lippincott, Williams & Wilkins; 2008. p. 94–154.
3. Boas FE, Fleischmann D. CT artefacts: causes and reduction techniques. Imaging Med. 2012;4(2):229–40.
4. Bortz JH. CT colonography: an approach for a successful examination. S Afr J Rad. 2014;18(1):607, 11 pages. https://doi.org/10.4102/sajr.v18i1.607.
5. Pickhardt PJ. Screening CT colonography: how I do it. AJR. 2007;189(2):290–8. https://doi.org/10.2214/ajr.07.2136.
6. Kim DH, Hinshaw L, Lubner MG, et al. Contrast coating for the surface of flat polyps at CT colonography: a marker for detection. Eur Radiol. 2014;24(4):940–6. https://doi.org/10.1007/s00330-014-3095-z.
7. Cai W, Zalis ME, Näppi J, Harris GJ, Yoshida H. Structure-analysis method for electronic cleansing in cathartic and noncathartic CT colonography. Med Phys. 2008;35(7):3259–77.
8. Ahmed I, Asgeirsson K, Beckingham I, Lobo D. The position of the vermiform appendix at laparoscopy. Surg Radiol Anat. 2007;29:165–8. https://doi.org/10.1007/s00276-007-0182-8.
9. Pickhardt PJ. Differential diagnosis of polypoidal lesions seen at CT colonography (virtual colonoscopy). Radiographics. 2004;24(6):1535–56.
10. Boyce CJ, Vetter JR, Pickhardt PJ. MDCT artefact related to the intra-scan gravitational flow of opacified luminal fluid (the "Dense Waterfall" sign). Abdom Imaging. 2012;37(2):292–6.
11. Pickhardt PJ, Kim DH. CT colonography: pitfalls in interpretation. Radiol Clin North Am. 2013;51(1):69–88.

13 Internal Haemorrhoids, Anal Papilla, and Other Anorectal Lesions

Joel H. Bortz

13.1 Introduction

During a CTC study, haemorrhoids are the most frequently seen and diagnosed condition affecting the anorectal region [1]. Most anorectal conditions are benign; they may often be diagnosed clinically by a rectal examination or anosocopy without the need for a full endoscopic examination. During a CTC study, it is important to check structures around the catheter. The structures could be internal haemorrhoids, anal papillae, polyps, or tumours.

As discussed in Chap. 10 when a patient is in the prone position, the sterile disposable catheter's balloon is deflated in order to visualise internal haemorrhoids, if present [2]. The correct placement of the catheter is important in CTC. This chapter focuses on internal haemorrhoids. It is therefore important to describe their causes and anatomical location [3]. In addition, we need to consider anal papillae and tumours [4].

The following abbreviations are used in this chapter.

- 2D: two-dimensional
- 3D: three-dimensional
- CO_2: carbon dioxide

13.2 Rectal Tube Position

According to Pickhardt [4], we need to bear the position of the rectal catheter in mind when evaluating the anorectal region. The catheter tip may cause extrinsic impression of an adjacent rectal fold, for example, or the tip itself may appear polypoidal at three-dimensional (3D) images. When the author examines this region, his standard technique is to fly 360° around the catheter to check that there are no polyps being obscured by the balloon. This technique is also described in Chap. 14.

There are several catheters available. For example, the Vimap catheter, which is available in Europe can withstand 100 cc air inflation. A 3-way connection has a separate drainage connection for any residual fluid in the rectum. By having this drainage connection there is no contamination of incoming CO_2 because the latter has its own connection. The 3-way connection catheter is no longer available in the United States. The author now uses a 2-way connection (see Fig. 10.2c in Chap. 10); maximum air inflation is 50 cc.

Distension of the balloon catheter may produce a 'pseudolesion' or 'filling defect' on the 3D study. Figure 13.1a (i, ii) depicts a meniscal defect, which is visualised on the supine studies, and presents as a pseudolesion caused by the inflated balloon abutting on the rectal mucosa. Occasionally, a meniscal defect will be to the side of the catheter. Deflating the balloon when the

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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patient is in the prone position usually eliminates such interpretation problems. Figure 13.1a (iii) shows a 3-way connection catheter and inflated balloon. Figure 13.1a (iv) shows an inflated balloon defect and residual rectal stained fluid. To minimise visualisation of the latter, the patient should be sent to the restroom/lavatory as the rectum must be emptied of any residual fluid before commencing the CTC study (see Chap. 10).

Occasionally, the catheter may be inserted too far into the rectum as shown in Fig. 13.1b (i). This may then cause the tip of catheter to protrude beyond the valve of Houston; this may simulate a polyp in appearance. It may also push against the valve of Houston causing an extrinsic impression as shown in Fig. 13.1b (ii). Correct placement of the catheter is essential to avoid interpretation problems.

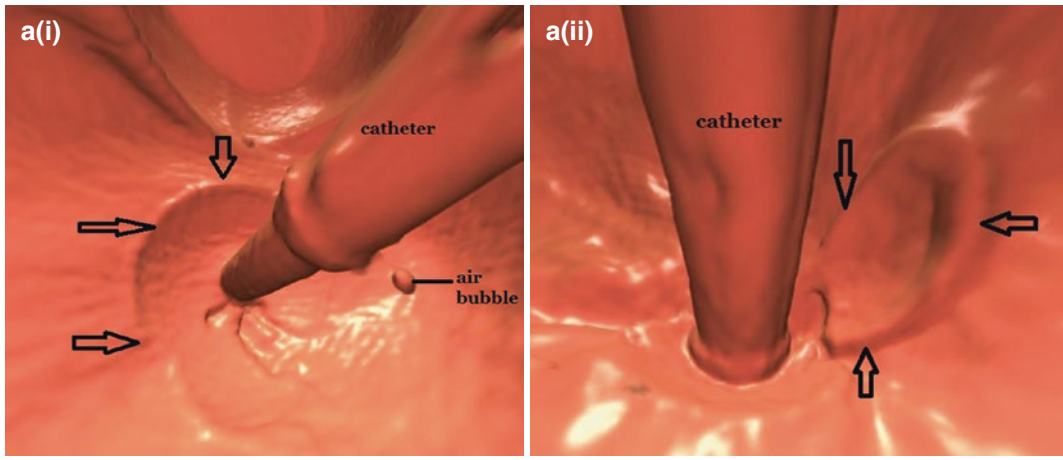


Fig. 13.1 (**a**) (**i**) 3D supine view shows meniscal defect (open black arrows) due to inflated balloon. (**ii**) 3D supine image shows inflated balloon to the side of the catheter causing a meniscal defect (open black arrows).

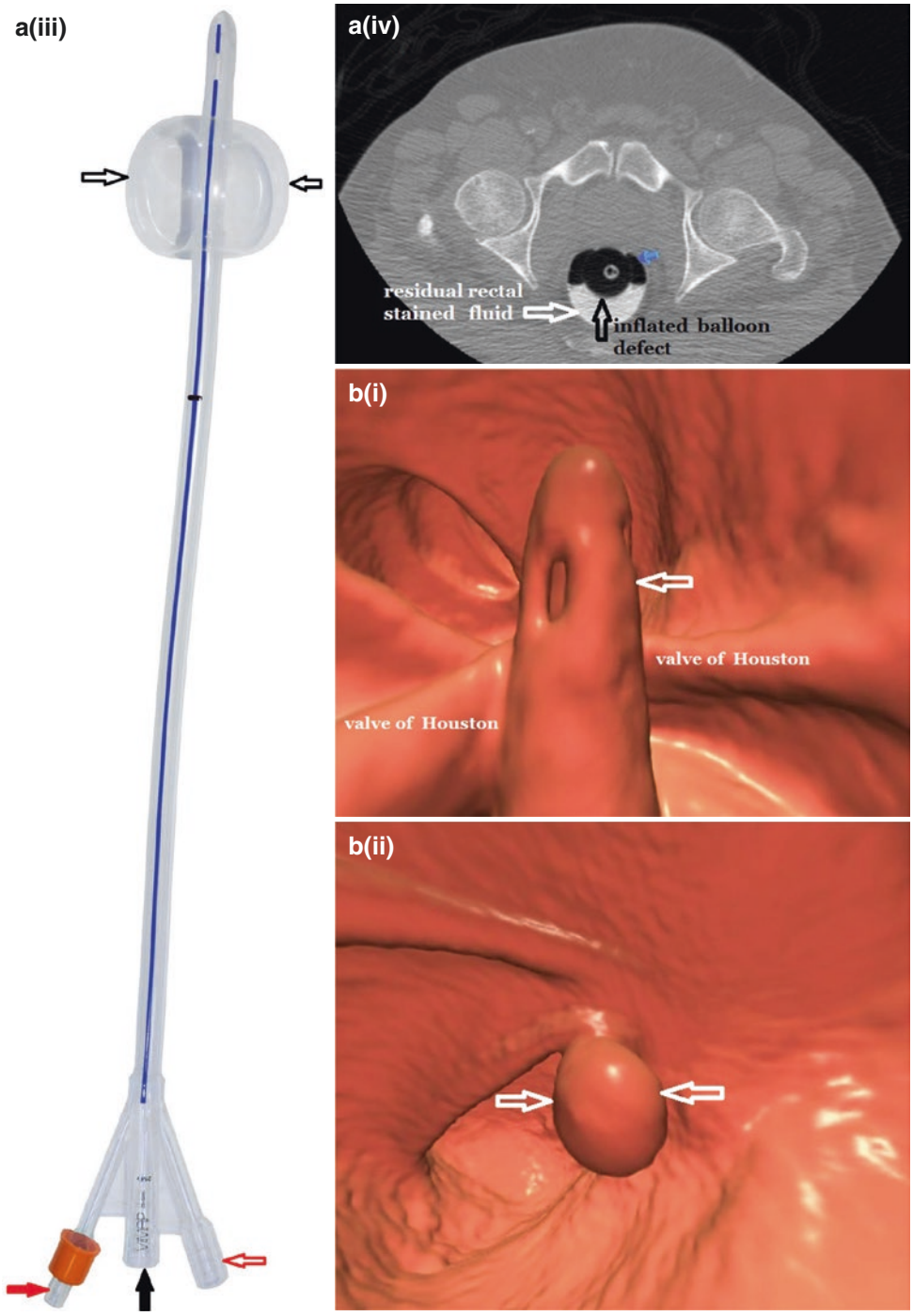


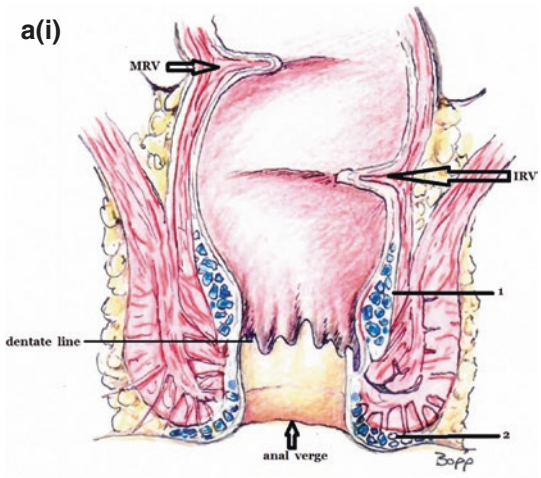
Fig. 13.1 (**iii**) Vimap 3-way connection catheter. Connection to inflate balloon with 35 cc air (red open arrow). Insufflator connection (closed black arrow). Connection for drainage bag (closed red arrow/orange ring on tube). Inflated balloon = open black arrows. (**iv**) 2D axial image shows inflated balloon (open black arrow) and residual rectal stained fluid (open white arrow). (**b**) (**i**) 3D image shows the catheter incorrectly placed. Its tip (open white arrow) extends beyond the valve of Houston. (**ii**) 3D image shows tip of catheter projecting beyond the valve of Houston simulating a polyp (open white arrows)

13.3 Definition and Causes of Haemorrhoids

Haemorrhoids are vascular structures in the anal canal. They are the result of varicose dilatations of the rectal veins [4]. They are very common in both males and females, and most patients are asymptomatic. Haemorrhoid frequency increases with age. Causes of haemorrhoids include vigorous straining, chronic constipation, and pregnancy. They are often complicated by inflammation, thrombosis, and bleeding. There are four types of haemorrhoids: internal, external [5], prolapsed, and thrombosed.

13.4 Anatomical Location of Internal and External Haemorrhoids

There are two types of haemorrhoids based on their location: internal and external haemorrhoids [5]. An external haemorrhoid is one that is in a vein of the inferior haemorrhoidal plexus. It is below the dentate line which divides the squamous epithelium of the anus from the columnar epithelium of the rectum [1, 3]. An internal haemorrhoid is above this line. Figure 13.2 (i, ii) demonstrates the anatomy of rectum as well as location of internal and external haemorrhoids. Haemorrhoids are vascular structures



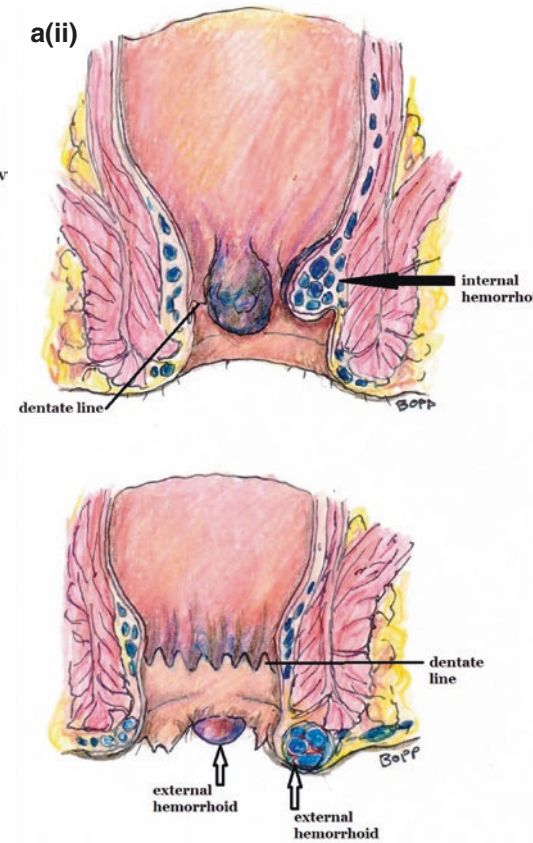


Fig. 13.2 (**i**) Anatomy of rectum. Middle rectal fold of valve of Houston (MRV). Internal rectal fold of valve of Houston (IRV). 1 = submucosal space and internal hemorrhoidal plexus. 2 = external hemorrhoidal plexus in perianal space$^{\phi}$. ($^{\phi}$Adapted from [5]). (**ii**) Internal haemorrhoid above the dentate line (top). External haemorrhoids (bottom)$^{\phi}$. ($^{\phi}$Adapted from [5])

in the anal canal. They may become pathological when swollen and/or inflamed, and in such a situation there may be bleeding associated with pain. Internal haemorrhoids may grow in size and become large. This may occasionally result in large haemorrhoids prolapsing externally; most times they retract spontaneously. However, some may not retract; when this happens they are referred to as 'prolapsed piles'. Care has to be taken when inserting the rectal catheter in a patient with 'prolapsed piles'.

13.4.1 2D and 3D Architecture of Internal Haemorrhoids

On CTC scans, internal haemorrhoids appear as small protrusions in the rectal vault at the dentate line [3]. They have a smooth contour and are located in a concentric manner around the rectal tube. An inflated balloon can obscure the presence of internal haemorrhoids; the prone position with the balloon deflated shows the internal haemorrhoid as evident in Fig. 13.3a (i, ii). Both two-dimensional (2D) and 3D views may visualise internal haemorrhoids: on 2D they present as small protrusions, whereas on 3D they may be raised linear defects or polypoidal in shape. Figure 13.3b (i)–f (ii) illustrates 2D and 3D views of internal haemorrhoids.

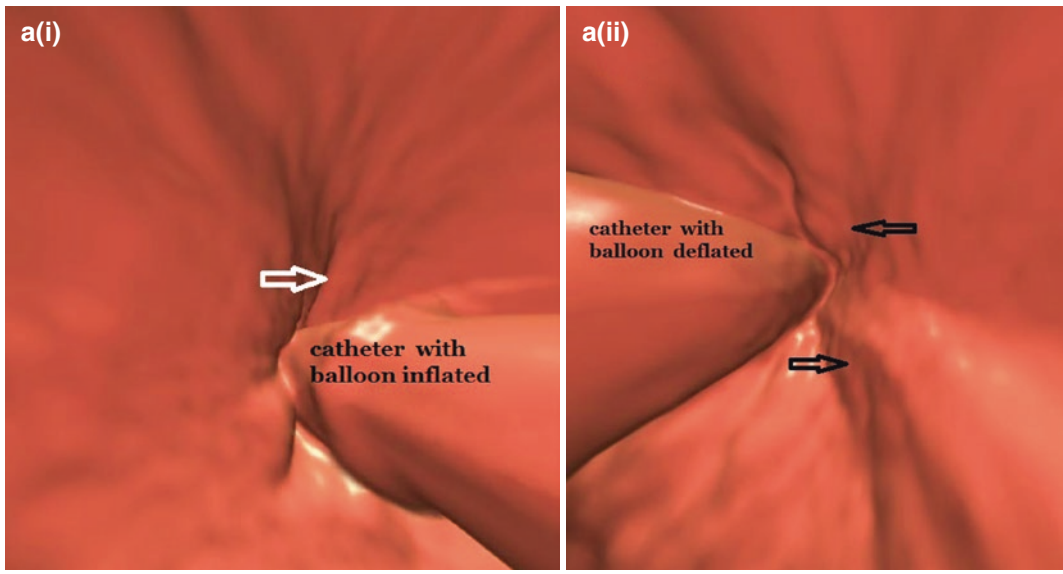


Fig. 13.3 (**a**) (**i**) 3D view of inflated balloon. Internal haemorrhoid (open white arrow). (**ii**) 3D prone view with deflated balloon shows internal haemorrhoids more prominently (open black arrows).

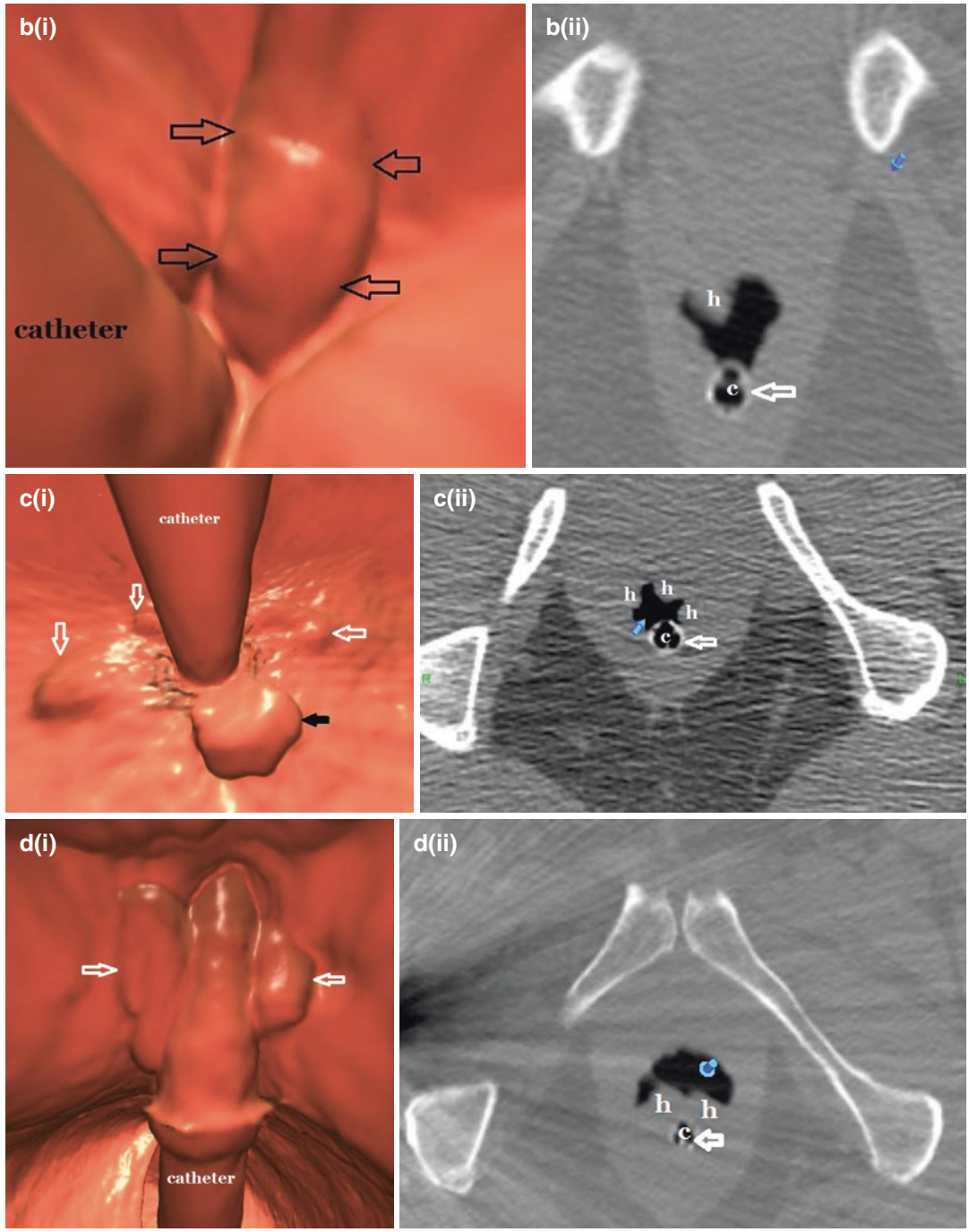


Fig. 13.3 (**b**) (**i**) 3D image shows polypoidal internal haemorrhoid (open black arrows). (**ii**) 2D axial view shows internal haemorrhoid (h). C = rectal catheter (open white arrow). (**c**) (**i**) 3D image of four internal haemorrhoids. Closed black arrow = polypoidal form defect. Open white arrows = linear internal haemorrhoids. (**ii**) 2D axial of polypoidal internal haemorrhoids (h). C = rectal catheter (open white arrow). (**d**) (**i**) 3D supine image of large polypoidal internal haemorrhoids (open white arrows). (**ii**) 2D axial image showing internal haemorrhoids (h). C = rectal catheter (open white arrow).

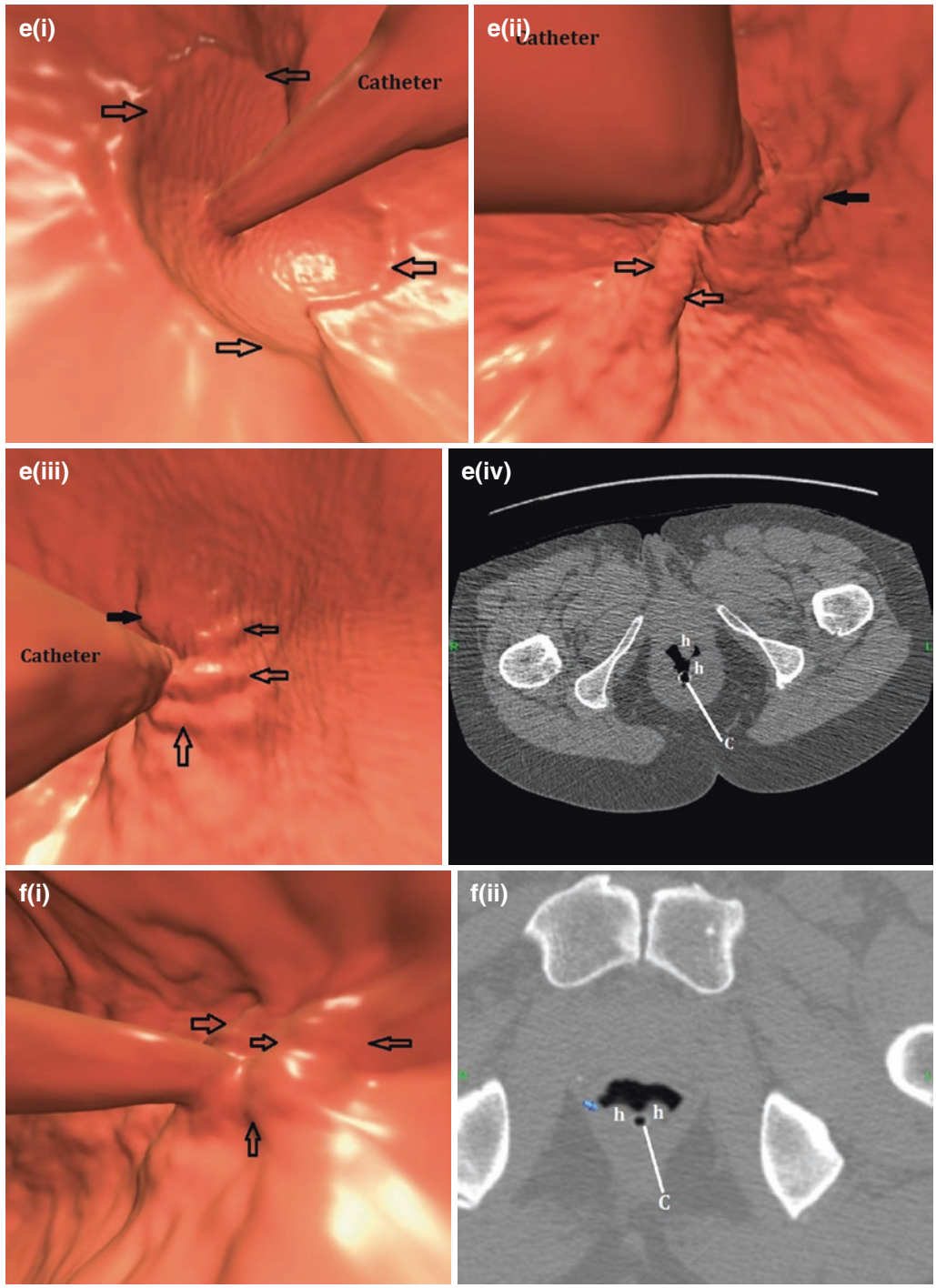


Fig. 13.3 (**e**) (**i**) 3D endoluminal supine view showing artefact (arrows) caused by inflated balloon of rectal catheter. No pathology noted. (**ii**) Prone view with balloon deflated. Open black arrows depict a large linear haemorrhoid. Closed black arrow depicts polypoidal haemorrhoid. These haemorrhoids were not visualised on the supine view with inflated balloon. (**iii**) Prone view with balloon deflated. A different angle of the same patient showing three linear haemorrhoids (open black arrows) as well as the polypoidal haemorrhoid (closed black arrow). (**iv**) 2D axial view showing haemorrhoids (h). C = rectal catheter. (**f**) (**i**) 3D endoluminal view showing large internal haemorrhoids (arrows). (**ii**) 2D axial view showing internal haemorrhoids (h). C = rectal catheter

13.5 Other Anorectal Pathology

13.5.1 Anal Papilla

Internal haemorrhoids may be confused with an hypertrophied anal papilla, which is a benign condition. An anal papilla represents focal fibrous prominence of tissue at the dentate line. An anal papilla is essentially internal skin tags. These tags are in response to chronic irritation or anal fissuring [4]. Anal papillae are small, usually <6 mm in size. The diagnosis of an anal papilla is made by its consistent anatomic position at the anorectal junction. In the vast majority of cases, the papilla is in contact with the rectal tube at its lowest visualised point (Fig. 13.4).

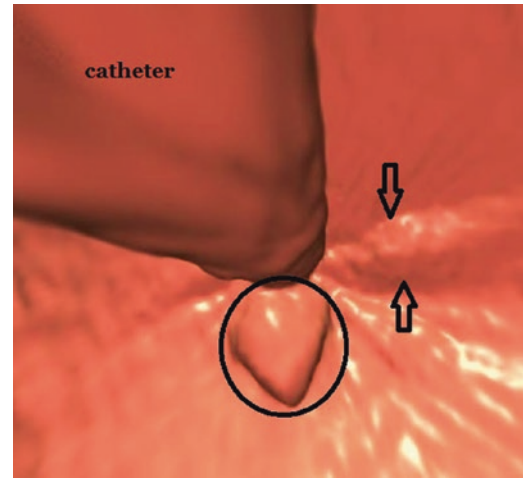


Fig. 13.4 3D image showing linear internal haemorrhoids (open black arrows) and anal papilla (circle)

13.5.2 Difference Between an Anal Papilla and a Rectal Polyp

Can we distinguish an anal papilla from a rectal polyp? We can because a polyp would be a short distance from the catheter (Fig. 13.5). Compared with previously used large catheters, the small ones that are now used should not obscure visualisation of rectal polyps [2].

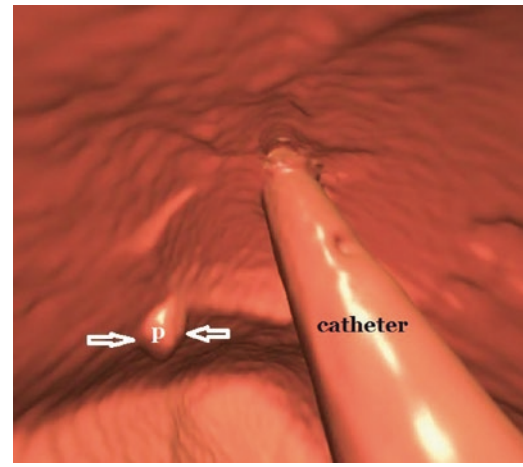


Fig. 13.5 3D image shows polyp (p and open white arrows) away from the catheter

13.5.3 Rectal Tumours

When evaluating anorectal CTC images, we need to consider the possibility of a malignant lesion. A lesion with irregular polypoidal defects is a cancer. Figure 13.6 a (i)–(iii) shows rectal

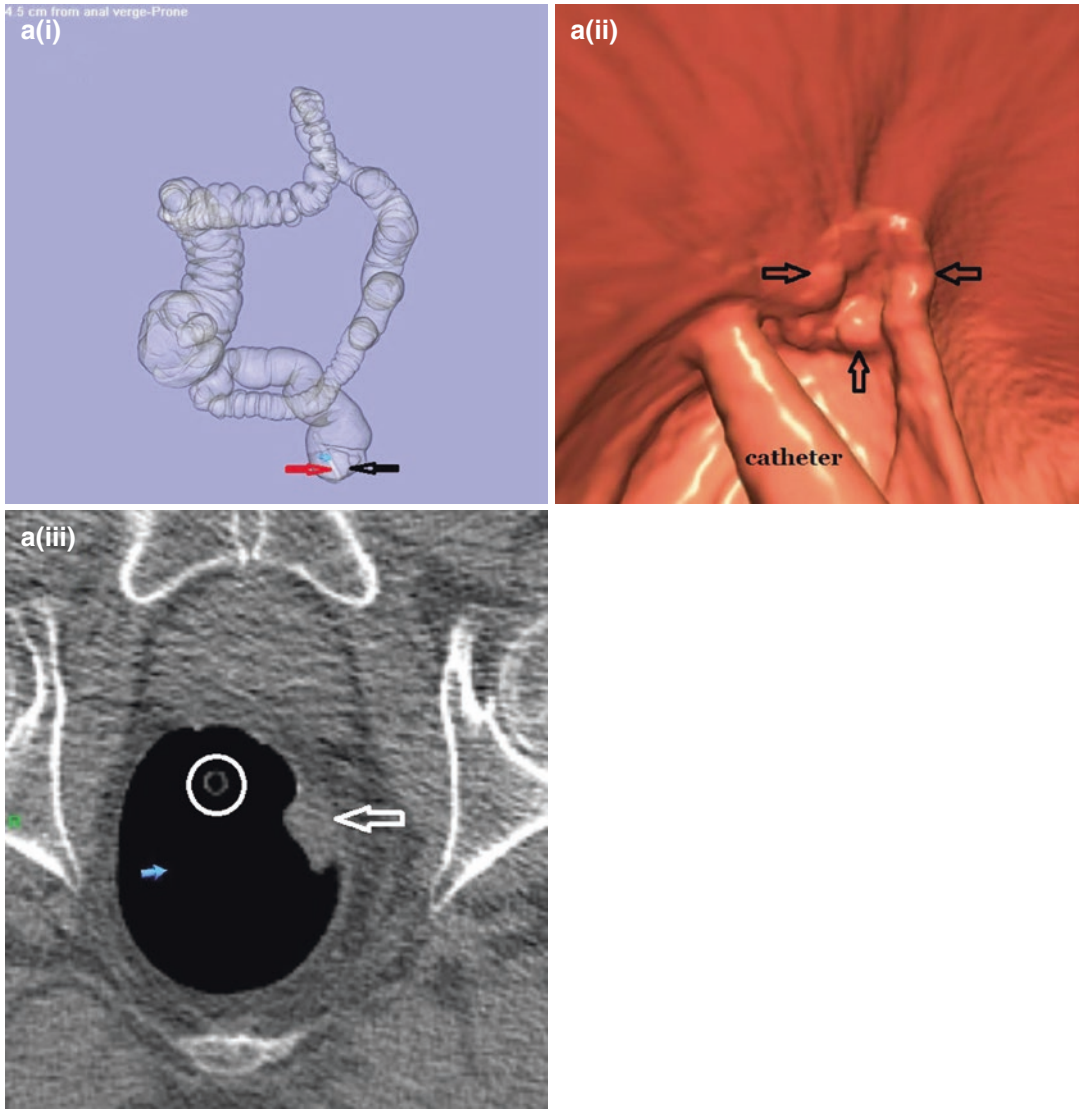


Fig. 13.6 (**a**) (**i**) Prone colon-map showing left rectal wall lesion (open black arrow). Rectal catheter (open red arrow). (**ii**) 3D view of an irregular polypoidal lesion in rectum in keeping with cancer (open black arrows). (**iii**) 2D axial image shows catheter (white circle) and lesion left rectal wall in keeping with cancer (open white arrow)

cancer. The majority of tumours (80%) are squamous cancer; the rest are adenocarcinomas [4]. Rectal tumours may be aggressive in immunocompromised patients, particularly those who have the acquired immunodeficiency syndrome (AIDS) [4].

13.6 Valves of Houston

As discussed in Chap. 11, the three valves of Houston are located in the rectum. They are transverse folds [6]. During a CTC study, it is important that they are carefully assessed in a fly-

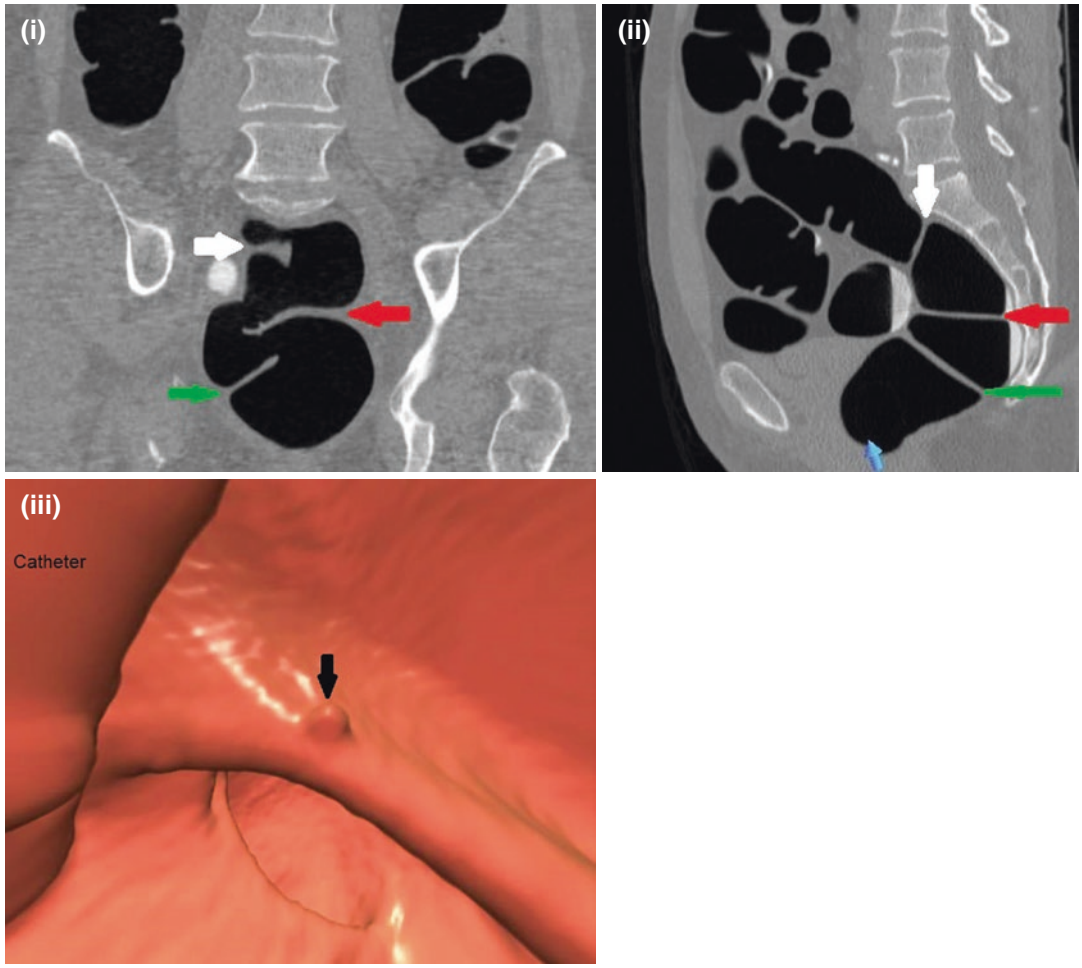


Fig. 13.7 (**i**) 2D coronal view showing the valves of Houston. Green arrow = inferior valve. Red arrow = middle valve. White arrow = superior valve. (**ii**) 2D sagittal view showing the valves of Houston. Green arrow = inferior valve. Red arrow = middle valve. White arrow = superior valve. (**iii**) 3D view showing a 3 mm polyp on valve of Houston

through by looking behind them to check for hidden lesions [7]. Figure 13.7 (i, ii) shows the three valves of Houston. Figure 13.7 (iii) shows a polyp on a valve.

13.7 Rectal Varices

Rectal varices are collateral vessels between the portal circulation and systemic circulation as a result of portal hypertension from underlying cirrhosis of the liver [8, 9]. See Chap. 19 for causes of the latter. Literature reports that rectal varices in the submucosa become large and tortuous [10, 11]. Although uncommon bleeding may occur in patients with rectal varices [12]. Rectal varices extend proximal to the dentate line into the rectum [9]; usually 4 cm above the anal verge [13]. In view of their location, it is important to not confuse them with internal haemorrhoids at CTC (see dentate line in Fig. 13.2 (i, ii)). Their tortuous impression on the submucosa flattens when a patient is in the prone position in a CTC study [7, 11]. Figure 13.8 (i–iii) is an example of rectal varices courtesy of Prof D Kim Wisconsin University.

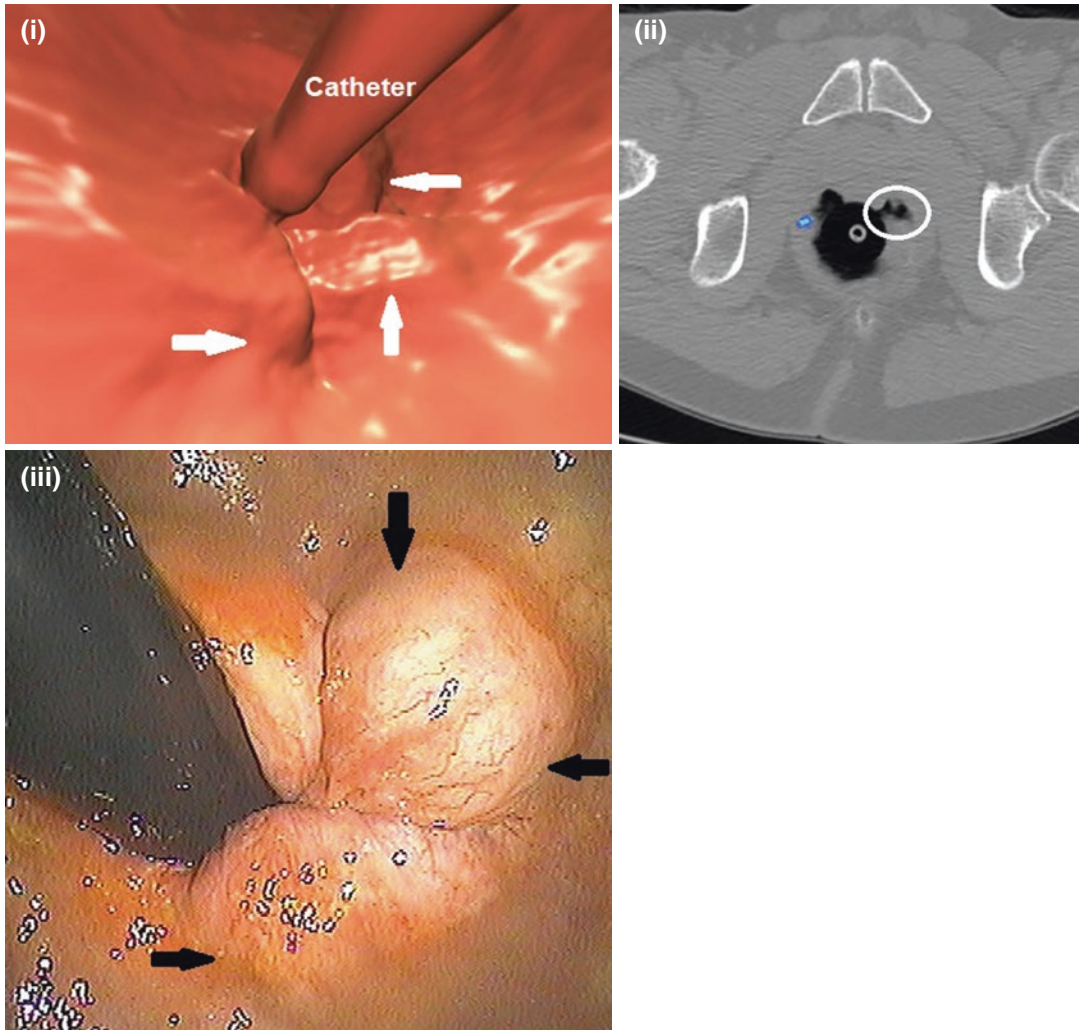


Fig. 13.8 (**i**) Supine 3D image showing elevated polypoidal mass (arrows) in the rectum in keeping with rectal varices. (**ii**) 2D supine axial view showing soft tissue prominence (green circle). (**iii**) Polypoidal mass (arrows) confirmed as rectal varices at optical colonoscopy

Key Messages

There are several points to consider when interpreting CTC images in the anorectal region.

- It is important to check structures around the rectal catheter.
- Haemorrhoids are the most frequently seen and diagnosed condition affecting the anorectal region.
- To best visualise internal haemorrhoids, the balloon must be deflated when the patient is in the prone position.
- Internal haemorrhoids appear as small protrusions in the rectal vault at the dentate line; they have a smooth contour and are located in a concentric manner around the rectal tube.
- Both 2D and 3D views may visualise internal haemorrhoids: on 2D they present as small

protrusions, whereas on 3D they may be raised linear defects or polypoidal in shape.

- In the majority of cases, an anal papilla is in contact with the rectal tube at its lowest visualised point.
- A rectal polyp would be a short distance from the catheter.
- Important to assess the valves of Houston on fly-through.
- Important to not misdiagnose rectal varices as internal haemorrhoids.

13.8 Summary

Haemorrhoids are easily recognised on both 2D and 3D images. On 2D they present as small protrusions, whereas on 3D they may be raised linear defects or polypoidal in shape and lie in close proximity to the rectal catheter. Both anal papilla and rectal tumours need to also be considered when evaluating structures in close proximity to the rectal catheter. Malpositioning of the tube may cause confusion as well. It is important to carefully check the valves of Houston to exclude pathology. Rectal varices should not be misdiagnosed as internal haemorrhoids.

Acknowledgements Clinton Bopp is thanked for drawing the diagrams illustrating internal and external haemorrhoids. Professor David Kim at Wisconsin University is thanked for images of rectal varices.

References

1. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009. p. 213–4.
2. Bortz JH. CT colonography: an approach for a successful examination. S Afr J Rad. 2014;18(1):607, 11 pages. https://doi.org/10.4102/sajr.v18i1.607.
3. Yee J. Virtual colonoscopy. Philadelphia: Lippincott, Williams & Wilkins; 2008. p. 114, 123–124.
4. Pickhardt PJ. Differential diagnosis of polypoidal lesions seen at CT colonography (virtual colonoscopy). Radiographics. 2004;24(6):1535–56.
5. Netter F. The Ciba collection of medical illustrations, vol 3. Digestive system. Part 2. Lower digestive tract. New York: Colour Press. 1962. p. 58.
6. Kenig J, Richter P. Definition of the rectum and level of the peritoneal reflection—still a matter of debate? Wideochir Inne Tech Maloinwazyjne. 2013;8(3):183–6. https://doi.org/10.5114/wiitm.2011.34205.
7. Lefere P, Gryspeerdt S. CT colonography: avoiding traps and pitfalls. Insights Imaging. 2011;2:57–68. https://doi.org/10.1007/s13244-010-0054-3.
8. Al Khalloufi K, Laiyemo AO. Management of rectal varices in portal hypertension. World J Hepatol. 2015;7(30):2992–8. https://doi.org/10.4254/wjh.v7.i30.2992.
9. Maslekar S, Toh E-W, Adair R, Bate JP, Botterill I. Systematic review of anorectal varices. Color Dis. 2013;15(12):e702–10.
10. Mankowski-Gettle L, Kim DH, Pickhardt PJ. Anorectal pitfalls in computed tomography colonography. Abdom Radiol (NY). 2019;44(11):3606–24. https://doi.org/10.1007/s00261-019-02186-x.
11. Trilisky I, Wroblewski K, Vannier MW, Horne JM, Dachman AH. CT colonography with computer-aided detection: recognizing the causes of false-positive reader results. Radiographics. 2014;34(7):1885–905. https://doi.org/10.1148/rg.347130053.
12. Robertson M, Thompson AI, Hayes PC. The management of bleeding from anorectal varices. Curr Hepatol Rep. 2017;16:406–15. https://doi.org/10.1007/s11901-017-0382-6.
13. Ganguly S, Sarin SK, Bhatia V, Lahoti D. The prevalence and spectrum of colonic lesions in patients with cirrhotic and noncirrhotic portal hypertension. Hepatology. 1995;21(5):1226–31. https://doi.org/10.1016/0270-9139(95)90041-1.

Polyps: Types and Sizes

14

Joel H. Bortz

14.1 Introduction

The primary aim of a screening CT colonography (CTC) study is to detect and identify lesions in the colon. Readers of CTC images need to have a working knowledge of polyp morphology and how to measure polyps, [1] as well as what recommendations to make when polyps are present. It is advisable to include the following disclaimer in all CTC reports: CTC is not intended for detection of diminutive polyps (≤5 mm), the presence or absence of which will not change the clinical management of the patient [2] (see Table 21.2). The head of a pedunculated polyp only is measured; the length of its stalk is not measured. There are three sizes of polyps: diminutive ≤5 mm; small 6–9 mm; and advanced adenoma ≥10 mm (large polyp).

When a lesion ≥6 mm is detected, this indicates that a study is positive. Polyps ≥10 mm are routinely removed. The chance of malignancy is <1% in an asymptomatic low-risk individual [3]. Polyps may be sessile, pedunculated, or flat. A variation of the flat polyp is a laterally spreading lesion known as a carpet lesion. Fifty percent (50%) of adults older than 50 years will harbour at least one colorectal polyp [4]. Fourteen percent (14%) of asymptomatic individuals will have polyps >6 mm. The prevalence rate of large polyps (>10 mm, advanced adenoma) and small polyps (6 mm–9 mm) is 6% and 8%, respectively [1]. Prevalence rate is defined as the number of people in a population who have a specific disease at a given time [5]. It should not be confused with incidence, which measures the number of new cases of the disease in a population, during a specified period, such as months or years [6]. Incidence indicates how many people within a specified time newly acquire this disease.

CTC came of age in 2003 with the groundbreaking article by Pickhardt et al. [7]: the findings of their study of 1233 asymptomatic adults showed that CTC was as effective as optical colonoscopy (OC) in the diagnosis of small and large polyps. They were the first to use barium sulphate to tag stool and Gastrografin to tag residual fluid.

Colorectal cancer (CRC) is the second leading cause of death worldwide. According to the World Health Organisation [8], in 2020 the third most common site of cancer was CRC. It is the third most common cancer diagnosed in both women and men in the United States [9]. Therefore, the value of screening lies in the ability of CTC to detect and prevent CRC rather than CRC detection alone; in 2008, the American Cancer Society endorsed CTC as a recommended screening test [9].

CTC is not a replacement for OC; it is an alternative and complementary screening option.

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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What are its main advantages compared with OC? There are several.

- It is safer: It is a minimally invasive study with an extremely low risk of perforation.
- No risk of introduction of infection as the sterile rectal catheter is discarded after each study.
- It is cheaper and more cost-effective.
- It is a quicker screening test with an average room time of 20 min.
- No anaesthesia required, thus no related risks.
- More sensitive than OC in cancer detection.
- Extracolonic organs are visualised (see Chaps. 18 and 20).

There are four main disadvantages of CTC.

- It is a non-therapeutic test as it is a non-invasive study.
- Significant polyps cannot be removed or biopsied.
- Cannot be used in patients with ulcerative colitis or Crohn's disease.
- Patients are exposed to ionising radiation.

There is consensus in the literature that all large polyps (≥10 mm) detected at CTC should be referred for polypectomy [10, 11]. Diminutive polyps (≤5 mm) generally do not warrant polypectomy. There is however a difference of opinion for management of small polyps (6–9 mm) [12]. It is uncertain whether the benefits of polypectomy outweigh the risks and cost associated with the OC procedure. In 1997, the reported miss rates of small lesions at OC was 13% [13], whereas later studies report higher miss rates, namely 22–28% for polyps, and 20–24% for adenomas [14]. The miss rate of polyps at CTC, compared to those missed with OC despite previous detection and localisation, is reported as 21.5% [15]. Put differently, 21.5% of discordant polyps 6 mm or greater were detected at CTC, but not confirmed at subsequent OC [15]. This indicated a false-negative finding at OC.

The following abbreviations are used in this chapter.

- 2D: two-dimensional
- 3D: three-dimensional
- AI: artificial intelligence
- CAD: computer-assisted diagnosis
- CRC: colorectal cancer
- DECT: dual-energy computed tomography
- DL: deep learning
- GIST: gastrointestinal stromal tumour
- HP: hyperplastic polyp
- ML: machine learning
- OC: optical colonoscopy
- SSP: sessile serrated polyp
- TD: translucent display
- TSA: traditional serrated adenoma

14.2 Definition of Colon Polyps, Adenoma, and Lesion

A polyp is a growth of tissue that extends from the colonic mucosa (inner lining of the colon) into the colonic lumen (hollow centre). It is a structure that arises from the colonic mucosa; it has homogenous soft-tissue attenuation and demonstrates a fixed point of attachment to the bowel wall, and projects into the colonic lumen [16]. An adenoma is a benign epithelial tumour of glandular tissue. A lesion is a pathological abnormality of a structure [17].

Polyps vary in size from 1 to 30 mm or more. They are classified according to their morphology: sessile, pedunculated or flat; size (diminutive ≤5 mm; small 6–9 mm; large ≥10 mm); and histology.

14.3 Polyp Morphology, Prevalence Range, and Need for Accurate Measurements

Polyps ≥30 mm are generally termed masses or tumours. Those that are ≤30 mm are usually divided into three morphologic categories: sessile; pedunculated; and flat. Sessile polyps have a broad base of attachment as shown in Fig. 14.1a whereas pedunculated polyps have a well-defined head and stalk as shown in Fig. 14.1b. Polypoid structures refer to both of these polyp types, and they account for the majority of polyps visualised at CTC.

A flat polyp is a subset of sessile structures that has plaque-like morphology and is not pol-

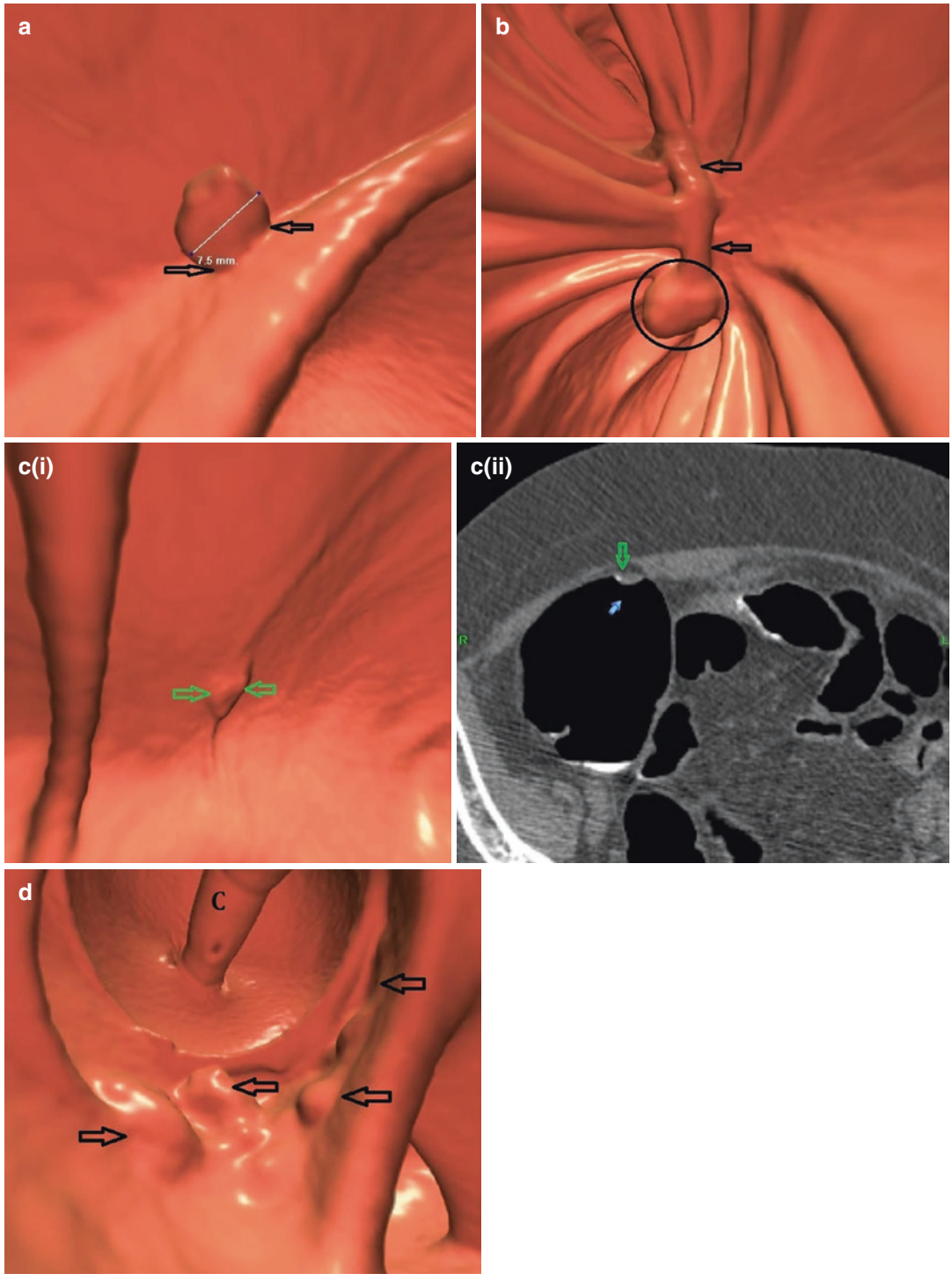

Fig. 14.1 (**a**) 3D endoluminal view showing small (7.5 mm) sessile polyp on posterior aspect of haustral fold. Broad base of attachment (arrows). (**b**) 3D endoluminal view showing pedunculated polyp. Head = circle. Stalk = arrows. (**c**) (**i**) 3D view shows a flat, mildly lobulated interhaustral lesion (open green arrows). (**ii**) 2D axial view shows a minimally raised soft-tissue density with a small amount of barium on surface (open green arrow). Histology tubulovillous adenoma. (**d**) 3D endoluminal view of rectum showing rectal catheter (C) and carpet lesion extending for 40 mm (open black arrows). Histology confirmed tubulovillous adenoma (Courtesy of Prof Kim, Wisconsin University)

ypoid in appearance as shown in Fig. 14.1c (i, ii). Usually, the polyp height is less than half its width. A better description is polyp elevation above the surrounding mucosal surface, which is typically 3 mm or less if the polyp is less than 30 mm [18]. Flat polyps tend to be large in cross-sectional imaging (≥30 mm), but they are not bulky [19]. A carpet lesion is a subset of flat lesions; it is a laterally spreading, or superficially spreading tumour, which occurs mainly in the caecum and rectum (Fig. 14.1d). Carpet lesions are discussed in more detail in Sect. 14.11.

Flat adenomas have been shown to be less likely to harbour high-grade dysplasia compared with sessile or pedunculated adenomas [20]. Patients with flat adenomas were not found to be at greater risk for advanced adenomas at subsequent colonoscopy. In fact, flat lesions <30 mm are not a major concern compared with polypoid lesions of similar size.

Management of CTC patients with polyps is dependent on polyp size: measurements of colon polyps therefore must be as accurate and exact as possible. For example, a deviation of 1 mm in a small polyp's measurement (6–9 mm) could result in a change of diagnosis. To underscore this if a small 6 mm polyp is under-measured by 1 mm, it would then fall within the diminutive polyp range of ≤5 mm, whereas an over measurement of a 9 mm polyp by 1 mm would mean a patient could be diagnosed as having an advanced adenoma (≥10 mm, large polyp). Why is this critical? Small polyps differ from diminutive ones; the histology changes to adenomatous in 66% of cases and non-adenomatous for the rest. An advanced adenoma is at a higher risk for cancer progression; thus, polyps ≥10 mm are routinely removed. An over measurement would cause a patient to undergo an unnecessary polypectomy. To obtain the closest exact size of polyps means that two-dimensional (2D) and three-dimensional (3D) measurements of multiplanar images are essential to avoid under/over measurements.

14.4 Polyp Measurement

The purpose of screening CTC is to detect polyps and to measure their size accurately because linear measurements are used in patient management decisions. Both 2D and 3D images are required to accurately measure polyps. As a general rule, 3D measurement may overestimate size whilst 2D usually underestimates size. An average of both measurements is therefore needed to obtain the most accurate size measurement of a polyp. Software that can do the measurements quickly and accurately should be used; failure to do this task will hamper 3D endoluminal measurements.

Literature shows a strong relationship between the size of a polyp and the likelihood of a malignancy [21]. A CTC study is considered to be abnormal when a polyp that is 6 mm or greater is detected. Diminutive polyps (≤5 mm) are usually ignored, particularly when diagnosed by CTC (Fig. 14.2a (i–iii)). When diagnosed by OC, they are usually removed in most patients.

Polyps 6–9 mm are termed small polyps. A range of examples of small polyps is presented in Fig. 14.2b (i)–e (iii). There is considerable debate as to whether all small polyps should be removed on the same day or left in situ for a surveillance period of 3 years before a repeat CTC is performed [1]. The polyp size is re-assessed for any volume or linear growth [22]. This alternative was accepted by the Working Group on Virtual Colonoscopy as a non-invasive and acceptable strategy [16].

There is consensus that large lesions >10 mm should be removed by OC. The features of large lesions at CTC are demonstrated in Fig. 14.2f (i)–h(iii) The incidence of cancer in a lesion 10 mm in size in an asymptomatic screening patient is only 1%. It is therefore clear that polyps in a patient who is under a 3-year surveillance programme must have measurements as accurate as possible on a base-line study. This is because a

1 mm or more increase in a polyp's size will indicate growth and may tip the patient into the 10 mm range where an OC then becomes necessary.

Linear polyp size is defined by the longest dimension among the three orthogonal 2D multiplanar reconstruction views: axial, sagittal, and coronal. Electronic calipers are used for linear measurements of polyps. Volume measurement is a newer and more promising technique; a small change in polyp diameter corresponds to a much larger proportional change in polyp volume. Figure 14.2i (i–iii) illustrates volume measurement. Volume measurement's margin of error is more relaxed than that of linear measurement [23].

The Viatronix V3D System, which the author uses, is able to provide automated measurements, but there tends to be some 'overflow' of the correct borders of a polyp as shown in Fig. 14.2i (i–ii). This software does however allow for a semi-automated method of volume determination using 2D images; currently, it is more accurate than the automated method.

For accurate measurement of polyps in 2D, the following window settings are used: W 2000 HU, L 0 HU. In the 3D setting, accurate measurement is dependent on positioning the polyp in a head-on (en face) position, and not looking down the colon lumen to measure. When in the correct 3D endoluminal position, the electronic callipers are placed at the edge of the polyp. Care must be taken to not include the penumbra or polyp shadow.

The real importance of accurate measurement occurs at a critical threshold. This is between a diminutive polyp at 5 mm and a small polyp at 6 mm, as well as between a small polyp at 9 mm and an advanced adenoma at 10 mm. The significance of the latter is discussed in Chap. 15. Should a polyp be covered by barium then an oversizing would occur if only 3D measurements were to be taken. This is because on 3D viewing barium is not observed unless translucent display (TD) is used; this allows visualisation of the internal architecture of the polyp. By switching to 2D measurement, 'downsizing' of the polyp would occur with the barium coating being excluded from the measurement.

When measuring in 2D, the orthogonal plane that most closely aligns to the long axis of the polyp is selected. In the 3D endoluminal view, the line (red = 2D axial view; green = 2D sagittal view; blue = 2D coronal view) must pass through the long axis of the polyp as shown in Fig. 14.2j (i–iii). In these figures, the red line corresponds to the 2D axial view, and the line runs through the short axis (middle) of the polyp. If we use this measurement, the polyp will be incorrectly measured, and the polyp will be undersized. If we use the green line on the 3D endoluminal view, it also passes through the short axis of the polyp. It would not be the correct one to choose as it also under-measures true polyp size. If we look at the 3D endoluminal view with the blue line, corresponding to the 2D coronal view (Fig. 14.2j (iv)), it passes through the long axis of the polyp and will be the most correct measurement.

Clinical audits of polyp measurements in CTC studies should be performed regularly as part of the quality improvement process that focuses on patient care, management, treatment, and outcomes. The principles of clinical audit are discussed in Chap. 27.

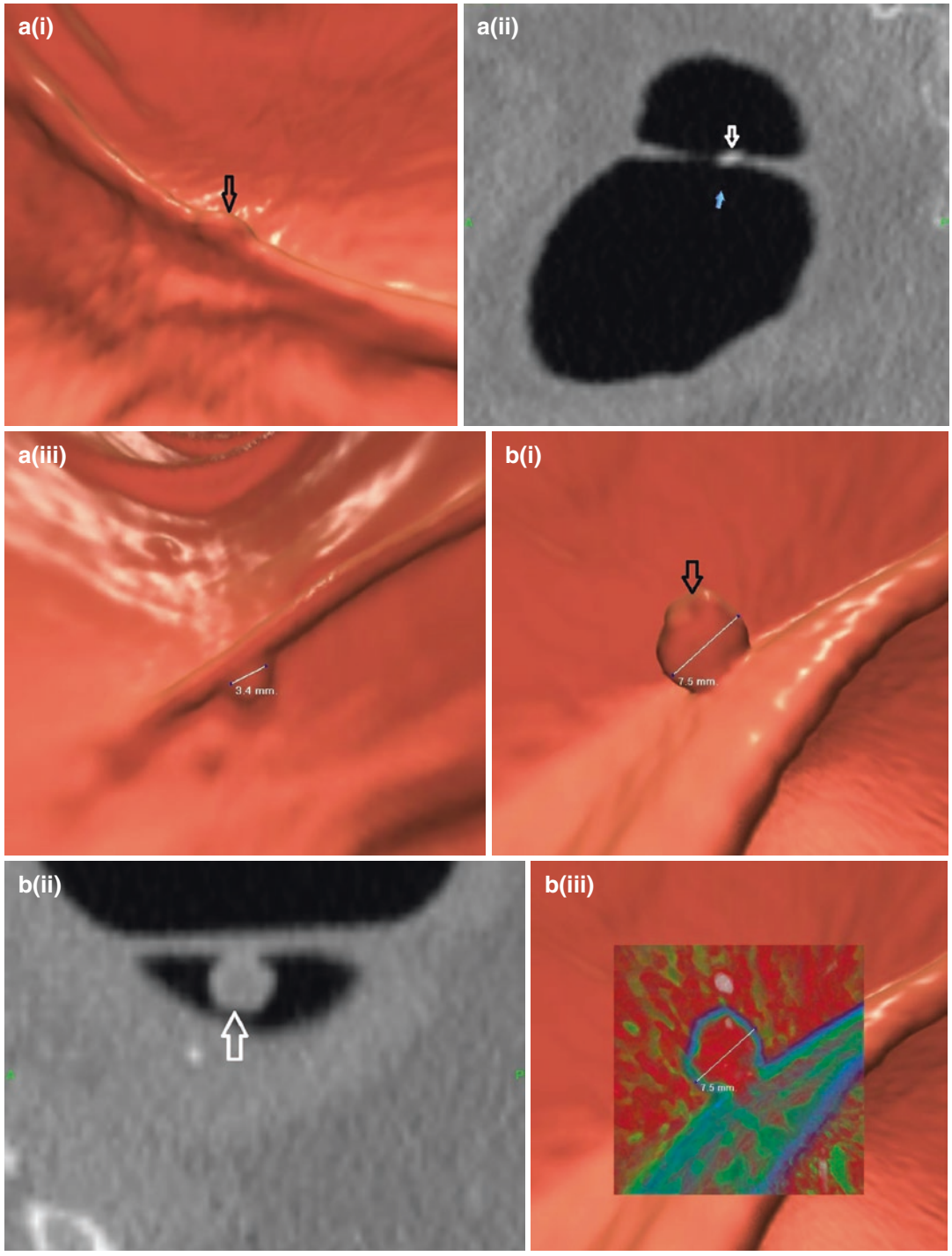

Fig. 14.2 (**a**) (**i**) 3D endoluminal view showing 4 mm haustral fold polyp (arrow). (**ii**) 2D view showing density on haustral fold (arrow = polyp). (**iii**) 3D view showing a 3.4 mm sessile polyp on posterior haustral fold (green arrow). Anterior fold (open white arrow) and direction of flight = open black arrow. (**b**) (**i**) 3D view showing small (7.5 mm) sessile polyp on posterior aspect of h. (**ii**) 2D coronal view showing sessile polyp arising from posterior fold (arrow). (**iii**) TD showing typical features of a polyp: high intensity centrally (red) surrounded by light green and blue.

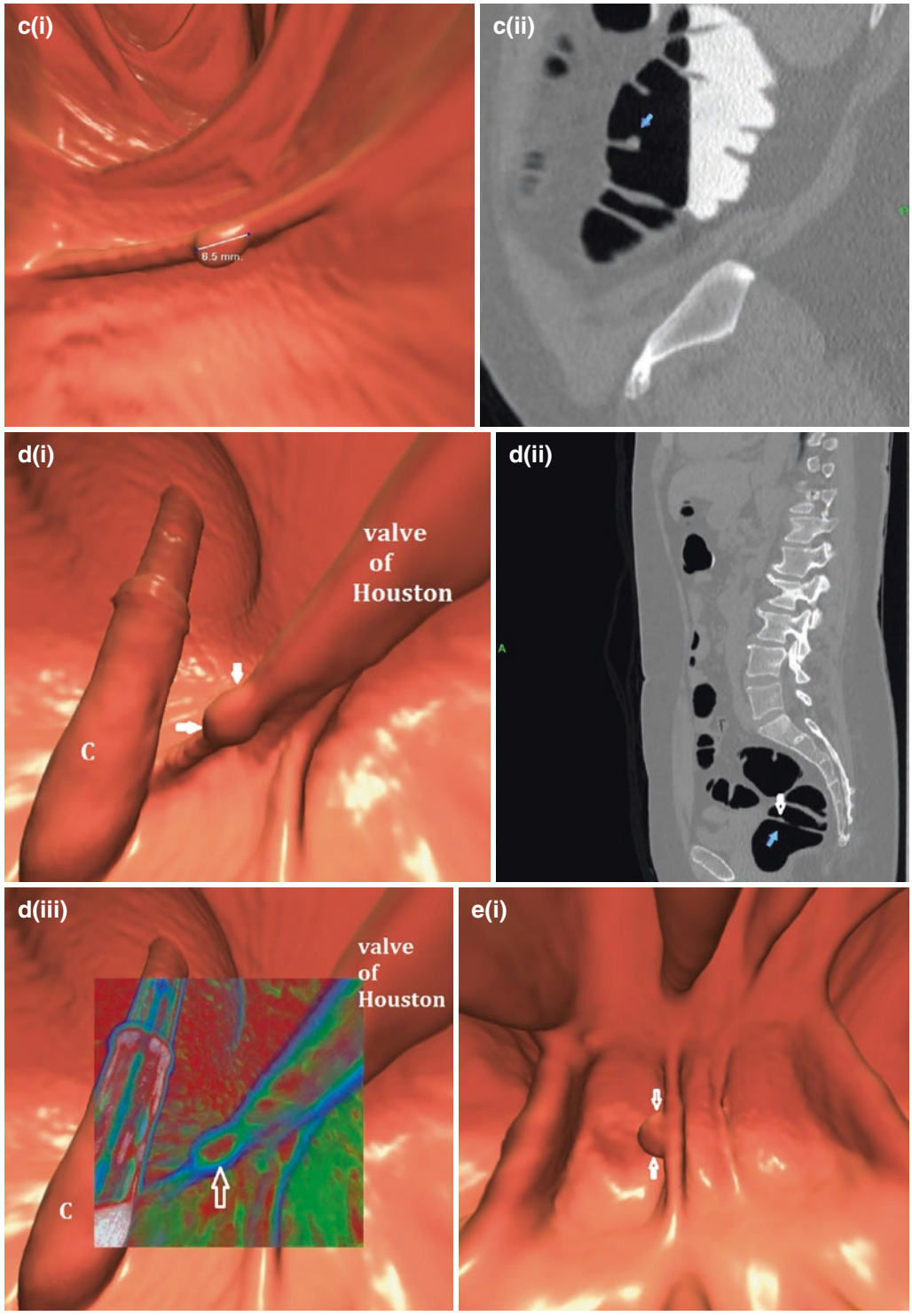

Fig. 14.2 (**c**) (**i**) 3D view showing small polyp (6.5 mm) on haustral fold. (**ii**) Sagittal 2D view showing polypoidal density on end of fold (blue arrow). (**d**) (**i**) Rectal catheter (C). Small sessile polyp on valve of Houston (white arrows). (**ii**) 2D sagittal view showing small density on inferior haustral fold (white arrow). (**iii**) Typical features of a polyp on a TD view. High intensity centrally (red) surrounded by light green and blue (open white arrow). Rectal catheter (C). (**e**) (**i**) 3D view of a 9 mm sessile polyp (open white arrows) on posterior haustral fold. Polyps on posterior folds are frequently missed on optical colonoscopy.

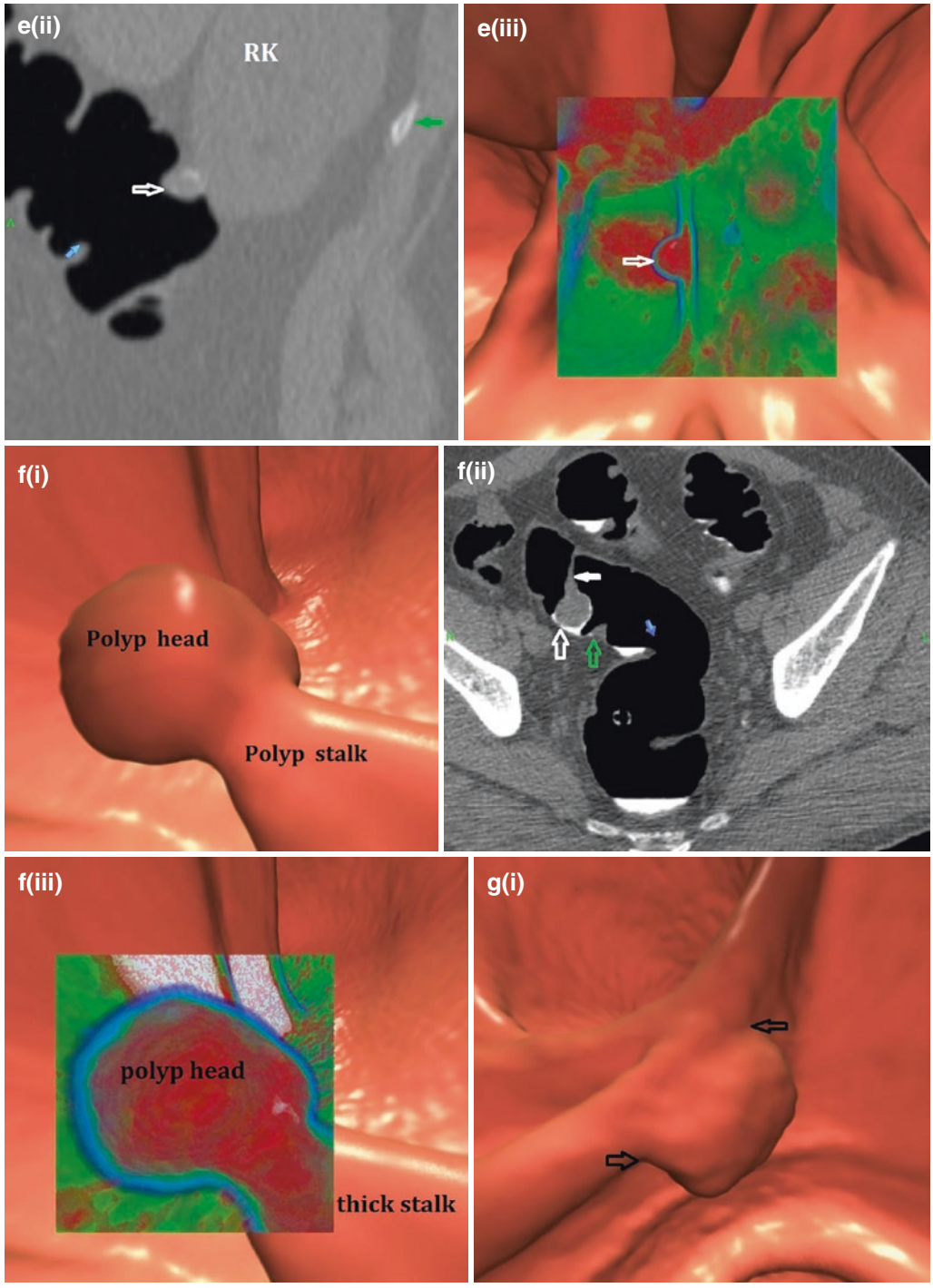

Fig. 14.2 (**ii**) 2D sagittal view showing soft- tissue polyp on posterior wall of caecum (open white arrow). RK = right kidney. Right rib (green arrow). (**iii**) Typical features of a polyp (open white arrow) on a TD view. High intensity centrally (red). (**f**) (**i**) Large pedunculated polyp on a thick stalk. (**ii**). 2D axial view showing pedunculated polyp on stalk (white arrow) with barium surrounding the polyp head (open white arrow). Note adjacent soft-tissue sessile polyp (open green arrow). (**iii**) TD showing high intensity (red) of polyp head. (**g**) (**i**) 3D endoluminal view showing 12 mm advanced adenoma. Note the broad-base sessile polyp attachment (open black arrows) on haustral fold with lobulated outline.

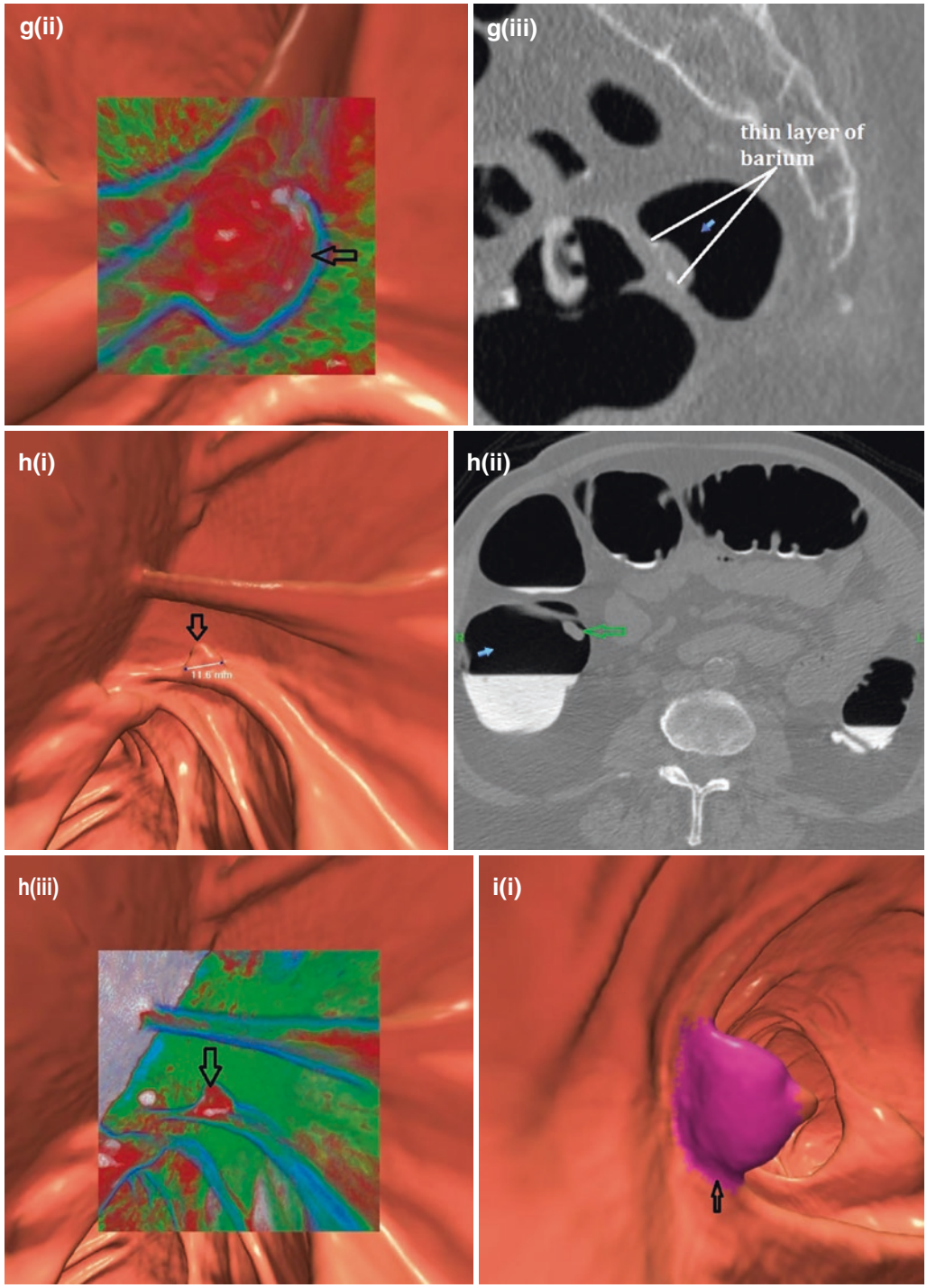

Fig. 14.2 (**ii**) 2D sagittal view showing 12 mm sessile polyp on anterior sigmoid fold. Note the small amount of barium at the base and side. (**iii**). TD showing classical features of a polyp (open black arrow). Note large central area of high intensity (red) surrounded by light green and blue colouration. (**h**) (**i**) 3D view showing a triangular shaped 11.6 mm sessile polyp (open black arrow mm) on haustral fold. (**ii**) 2D axial view showing an elongated density in relation to haustral fold (open green arrow). (**iii**) TD showing features of a sessile polyp (open black arrow). Note high intensity centrally (red) surrounded by light green and blue. (**i**) (**i**) 3D endoluminal volume measurement of a sessile polyp. Note the slight overflow of purple at the base (open black arrow).

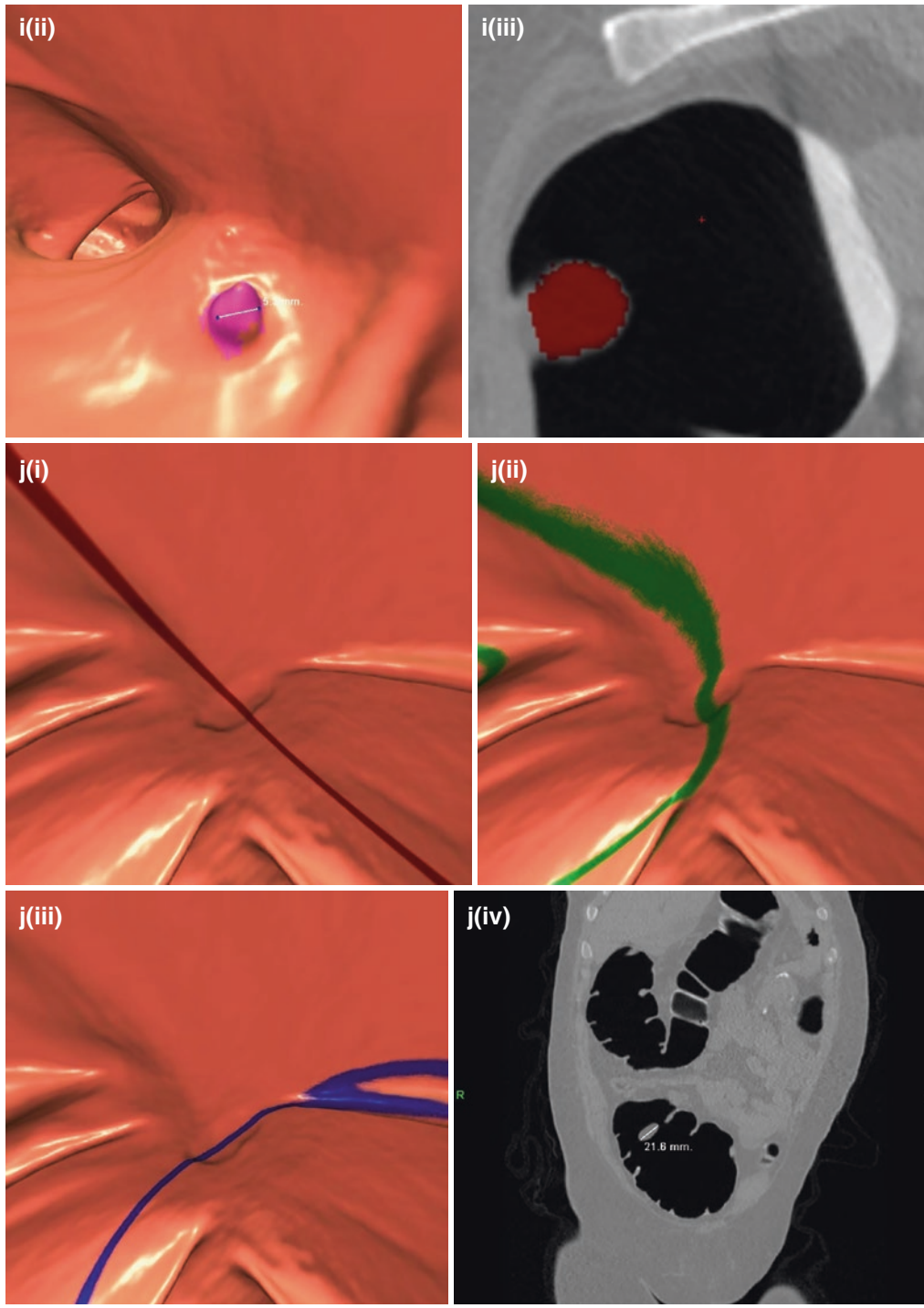

Fig. 14.2 (**ii**). 3D endoluminal head-on view of the polyp (purple). (**iii**). 2D view of the polyp that is coloured red for volume measurement. (**j**) (**i**) 3D endoluminal with a red line (corresponding to 2D axial view) passing through the short axis of the polyp. Measurement in this view will undersize the polyp. (**ii**) 3D endoluminal view with a green line (corresponding to 2D sagittal view) passing through the short axis of the polyp. Measurement in this view will undersize the polyp. (**iii**) 3D endoluminal view with a blue line (corresponding to 2D coronal view) passing through the long axis of the polyp. This indicates the correct measurement of the endoluminal view. The measurement on 2D coronal will be the correct measurement of the polyp. (**iv**) 2D coronal view shows linear measurement through the long axis of the polyp

14.5 Reporting Polyps: C Classification

A C1 to C4 classification is used when reporting CTC findings (Table 14.1). For example, normal colon or a benign lesion would be classified as C1. If a polyp or possibly advanced adenomas were noted in the study, the classification would be C3 [16].

- C0 = non-diagnostic study.
- CI = routine screening every 5 years because no visible abnormalities of the colon and no polyp ≥6 mm.
- C2 = colonoscopy or surveillance recommended if there are 2 or less 6–9 mm polyps present. If 3 or more polyps present, then only option is OC and polypectomy.
- C3 = colonoscopy and polypectomy recommended if more than 2 polyps 6–9 mm present (↑ risk of developing advanced adenoma). Any polyp ≥10 mm represents an advanced adenoma; OC and polypectomy recommended.
- C4 = A malignant appearing colonic mass is detected, which may compromise bowel lumen or demonstrate extracolonic invasion, such as lymphadenopathy or distant metastases. Surgical consultation recommended.

A revised C-Rad classification is work in progress and should be published in the near future.

Table 14.1 Colonic classifications[a]

C1	Normal colon or benign lesion
C2	Small polyps
C3	Polyp: advanced adenoma possibly
C4	A likely colonic mass

[a] Adapted from Zalis et al. [16]

14.6 Natural History of Polyps According to Lesion Size

In nearly all cases, the largest lesion will be diminutive (≤5 mm). By design, most large CTC trials have not reported diminutive lesions. Invasive cancer in this group is so rare that it can be assumed to be non-existent in terms of population screening [24]. A CTC study without polyps 6 mm or larger would be considered a negative study and would be classified C1 (normal).

According to van Dam et al. [25], a future trends report, published by the American Gastroenterological Association in 2004, noted that 'polyps ≤5 mm in size do not appear to be a compelling reason for colonoscopy and polypectomy'. Ransohoff [26] concurred by stating 'few clinicians would likely argue that colonoscopy is justified' for these lesions and added 'the overwhelming majority cannot possibly represent an important near-term health threat'.

Bond [27] is of the opinion that scientific data indicated that clinicians should shift their attention away from simply finding and harvesting all diminutive colorectal polyps. Their attention should rather focus on strategies that allow for reliable detection of the much less common, but more dangerous advanced adenoma. One third of diminutive polyps are adenomas; mainly tubular adenomas. The remainder are nonadenomas; hyperplastic polyps and mucosal tags, for example.

Lesion size is the most important factor of clinical significance. A CTC study is considered negative if no polyps are identified, or if there are polyps present that are all diminutive (≤5 mm) in size. The majority of diminutive lesions are hyperplastic or tubular adenomas and are of little or no clinical significance [27]. According to Schoenfeld [28], it is not necessary to report diminutive polyps. The chance of these lesions

being malignant or containing high-grade dysplasia at the time of detection is estimated to be far less than 1% [29]. Others maintain that it is neither clinically wise nor cost-effective for diminutive polyps to be referred for polypectomy [12].

It is only the extremely rare diminutive advanced adenoma that will likely grow over a period of 5 years and will then require removal. Invasive cancer in the diminutive size range is very rare hence can be assumed to be non-existent in terms of screening population. OC detection of diminutive lesions, and matching with CTC findings can be problematic: additional time and costs are incurred, as well as potential complications [24].

The prevalence range for polyps >6 mm in an asymptomatic screening population is 14% [1]. This means that 8% of individuals will have a polyp in the 6–9 mm range, and 6% will have a polyp ≥10 mm. For polyps larger than 6 mm, the ratio of adenomatous polyps to nonadenomatous polyps reverses; two-thirds of polyps >6 mm will have adenomatous tissue.

The screening prevalence of small polyps is about 8%, and the frequency of advanced adenoma in them is 4% [26]. The presence of high-grade dysplasia in small polyps is 0.05%, i.e. 5 in 10,000 cases. The chance of a small polyp harbouring an invasive cancer is 0.2%, i.e. 2 in 1000 cases [27, 29]. Small polyps are usually benign; two-thirds are adenomatous polyps, and the remainder are nonadenomas.

CTC studies, from the National Naval Medical Center in America, and the University of Wisconsin screening programme, have shown that for small polyps the sensitivity is in excess of 90%, and the positive predictive value (PPV) for them is more than 90% [30]. Hofstad et al. [31] are of the opinion that leaving small polyps for 3 years was a safe practice. Pickhardt and Kim [1] concur; many studies have shown that leaving small polyps in place is not a harmful practice.

A same-day OC or a 3-year surveillance period is the clinical management of visualisation of one or two small polyps at CTC (see Table 14.1 as well as Table 10.2 in Chap. 10). The working group on CTC (virtual colonoscopy) underscore that 3-year CTC surveillance for patients with one or two small polyps represents a reasonable approach [16]. If three or more polyps are seen at CTC, then OC is recommended; there is a greater likelihood that such polyps contain adenomatous tissue. Figure 14.3 shows three lesions in the right side of the colon.

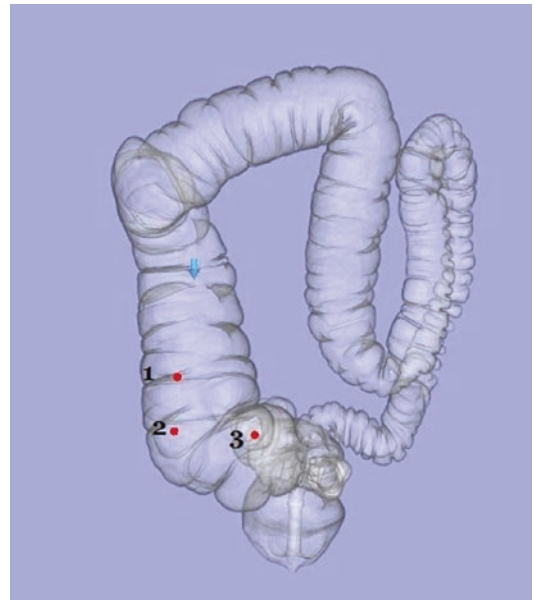

Fig. 14.3 Colon-map showing three lesions. The three red dots indicate site of pathology

14.7 Small Lesions (6–9 mm)

According to Pickhardt et al. [32], polyps that are between 6 and 9 mm are usually benign, and approximately 30% of such polyps are not adenomas. Of the small polyp group (6–9 mm), 96% lack high-grade dysplasia [33]; the probability of a 6–9 mm polyp not representing an advanced adenoma is approximately 96%. In other words, the likelihood of a lesion this size harbouring an invasive carcinoma is <1% [27]. It is reasonable to recommend interval surveillance in 3 years when one or two 6–9 mm polyps are detected in patients who do not have increased risk factors, such as no first-degree relative with a history of CRC, or no personal history of CRC or advanced adenoma. If a patient has three or more synchronous adenomatous polyps, then there is an

increased risk of developing advanced adenomas [34]. When three or more synchronous 6–9 mm polyps are detected at CTC, referral to OC and polypectomy is recommended. Note that lesions 10 mm or larger, and colonic masses ≥30 mm, are referred for OC.

14.8 Advanced Adenoma

An advanced adenoma (>10 mm, large polyp) is at higher risk for cancer progression. It represents the key target sign for CRC screening and prevention (Fig. 14.4) [35]. Between 90 and 95% of advanced adenomas are 10 mm or larger in size [10]. Only adenomas and serrated polyps have the possibility of future transformation into cancers [36]. Despite the overall preponderance of subcentimetre lesions, only a small minority of advanced adenomas are present; the vast majority of them have a villous component rather than high-grade dysplasia [10]. It is believed that if an advanced adenoma has a tubulovillous or villous component then there is a slow progression to cancer conversion [37].

There are three criteria of an advanced adenoma [10].

- Any adenoma that is large (≥10 mm) and of any histological subtype, namely tubular, tubulovillous, or villous.
- Any adenoma of any size that harbours high-grade dysplasia.
- Any adenoma of any size that contains a significant villous component (≥25% of tubulovillous or villous histology).

Advanced adenomas are located throughout the colon; proximal and distal distribution is almost equal. The cancer rate for large adenomas

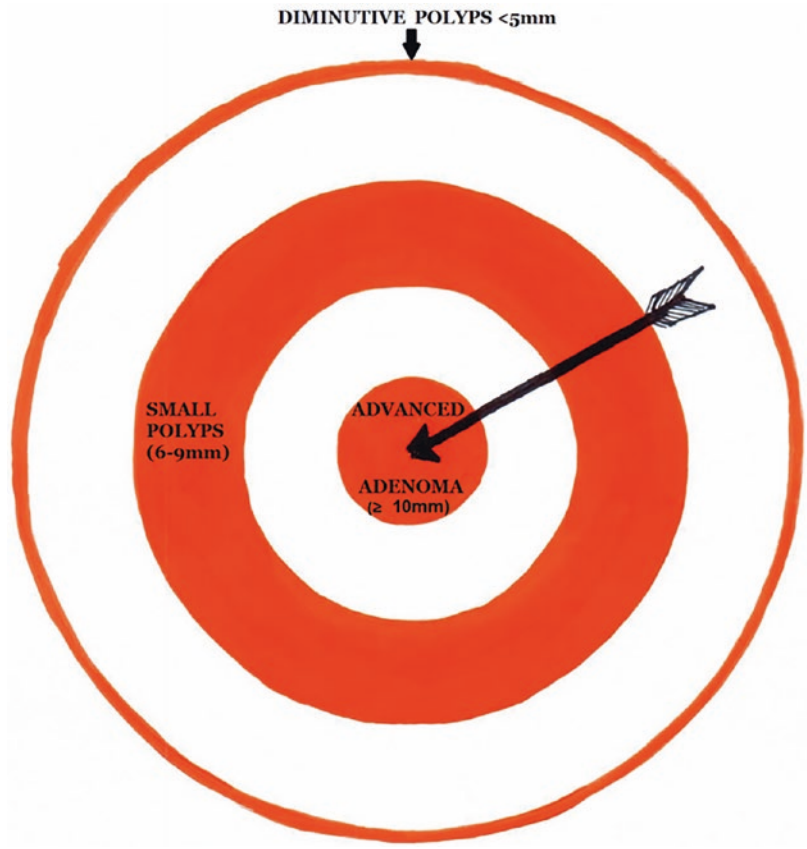

Fig. 14.4 The target is an advanced adenoma

Table 14.2 Comparison of CTC vs OC for detection of advanced adenoma [a]

Primary CTC cases (n = 3120)	Primary OC cases (n = 3163)
• Patients referred for OC (n = 246/8%) • Polyps removed at OC (n = 561)	• NA • Polyps removed (n = 2434)
Invasive cancer (n = 14)	Invasive cancer (n = 4)
Perforations (n = 0)	Perforations (n = 7/0.2%)

[a] Adapted from Kim et al. [10]

(10–20 mm) is only about 1%. Approximately 30–40% of large polyps are nonadenomatous [32]. A comparison of CTC versus OC for detection of advanced adenoma is presented in Table 14.2.

The number of advanced adenomas ≥10 mm was identical in both groups; the total number of advanced neoplasia (i.e., all advanced adenomas and carcinoids was almost identical [10]. As shown in Table 14.2, only 8% of patients who had CTC examinations were referred to OC and out of these patients 561 polyps were removed compared with 2434 removed at OC. This indicates a four-fold increase in the number of polyps removed during OC. This is indicative of the unnecessary removal of a large number of benign lesions.

Of significance there were seven perforations at OC and nil in the CTC group. The major finding in the study being that in an almost identical number of patients, 14 cancers were detected in the CTC group (n = 3120) compared with 4 cancers detected in the OC group (n = 3163).

14.9 Adenomatous Polyps

These are benign neoplastic lesions. However, over time change may occur with the gland component of a polyp: a condition known as dysplasia (abnormal growth/development of tissue, for example). The latter is graded from mild through to severe then to advanced. When this occurs, the polyp is then called an advanced adenoma. When the cancer penetrates the muscular layer of the bowel wall, it is termed an 'invasive' cancer. Based on their glandular architecture, there are three subsets of adenomatous polyps. These subsets and their prevalence percentages are listed below.

- Tubular adenoma (80–85%)
- Tubulovillous adenoma (10–15%)
- Villous adenoma (<5%)

Adenomatous polyps usually contain both glandular and villous components. The percentage of villous components in the histology indicates which subset classification is applicable and also its malignancy potential.

- Tubular adenomas usually contain less than 25% villous architecture.
- Tubulovillous adenomas contain between 25 and 75% villous component.
- Villous adenomas usually have >75% villous component.

The risk of malignant change increases with a high villous component. Although villous adenoma are uncommon, their incidence increases with advancing age. The most common sites for these polyps are the caecum and rectum. Adenomatous polyps have the potential to grow into cancer: approximately 3% will develop into cancer. On average, as a result of genetic mutations, it may take between 10 and 15 years for a benign polyp to convert to a malignant one. Such an occurrence is called the adenoma-carcinoma sequence or pathway (see Chap. 15). This sequence occurs in 85% of sporadic rectal cancers: small → large ones >10 mm → non-invasive carcinoma → invasive carcinoma [36].

An adenoma with high-grade dysplasia has the greatest risk of progressing to cancer [37]. High-grade dysplasia is now the preferred terminology and not carcinoma in situ. An invasive carcinoma refers to cancer that spreads beyond the muscularis mucosa into the submucosa. When this occurs, the cancer can potentially spread further. A malignant polyp is an adenoma with invasive carcinoma: the polyp has invaded past the muscularis mucosa into the submucosa, and metastasis may

then occur. It must be remembered that a histological diagnosis cannot be made at CTC.

14.9.1 Tubular Adenomas

This histological class is based on its glandular architecture: tubular, tubulovillous, and villous. Tubular adenomas' important points are as follows.

- They comprise 80–85% of adenomatous polyps.
- They are almost always sessile in nature.
- They contain < than 25% of villous architecture.
- They are usually <10 mm in size.
- They typically have mild dysplasia.
- They account for one third of all diminutive lesions (<5 mm) and two thirds of small polyps (6–9 mm).
- A >10 mm tubular adenoma may progress into cancer.

Figure 14.5i–iv shows a 9 mm sessile lesion. Histology confirmed tubular adenoma with no evidence of high-grade dysplasia.

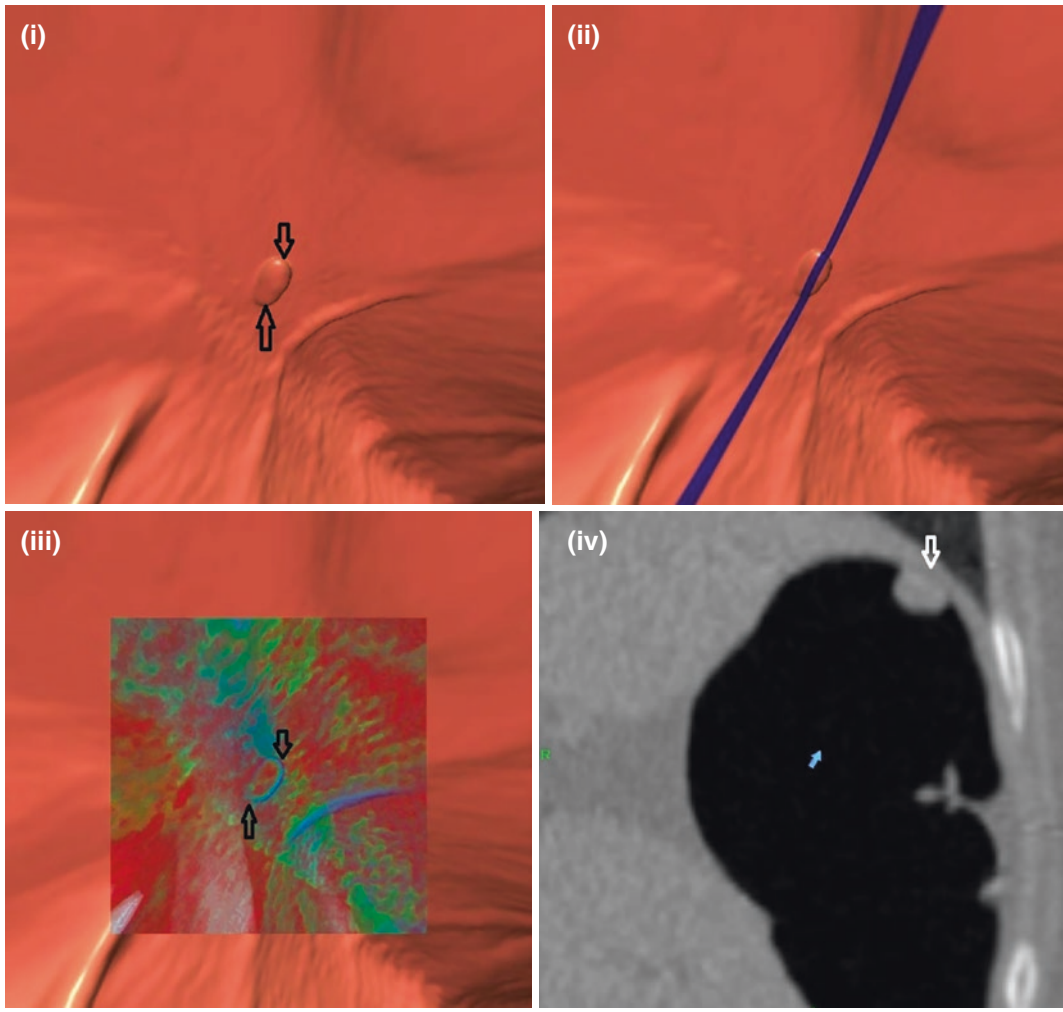

Fig. 14.5 (**i**) 3D endoluminal view of sessile lesion (black arrows). (**ii**) Blue line passes through long axis of lesion. (**iii**) Typical features of a polyp (open black arrows) on a TD view. High intensity centrally (red). (**iv**) 2D coronal view of sessile lesion (open white arrow)

14.9.2 Tubulovillous Adenomas

Their important points are presented below.

- They constitute 10–15% of all adenomatous lesions.
- They contain between 25 and 75% of villous architecture.
- They are larger than tubular adenomas, often 10 mm or greater.
- Their morphology is usually pedunculated.
- They tend to demonstrate a higher degree of dysplasia on histology.
- They are the more important target for colorectal screening and cancer prevention.

Figure 14.6i–iv shows a large lesion (26 mm) on a haustral fold. Histology confirmed a tubulovillous adenoma with no high-grade dysplasia.

14.9.3 Villous Adenomas

Their five important points are presented below.

- They comprise less than 5% of all colorectal neoplasms.

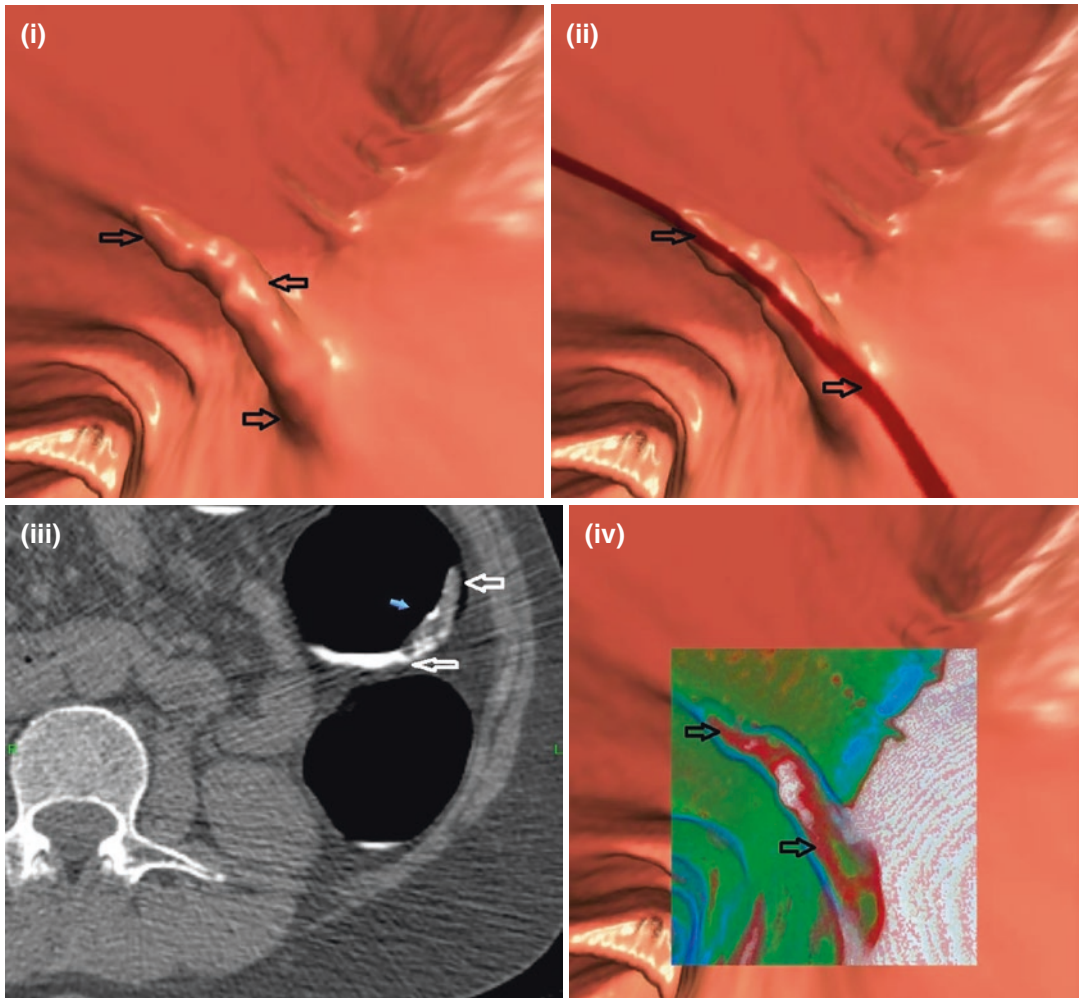

Fig. 14.6 (**i**) Thickened, lobulated haustral fold (open black arrows). (**ii**) Red line (open black arrows) passes through long axis measurement, i.e. axial on 2D. (**iii**) 2D axial view shows thickened, lobulated fold (open white arrows). (**iv**) Thickened, lobulated fold with high intensity (open black arrows) and covered in barium on TD

- They contain >75% villous architecture.
- They are larger in size (20–30 mm or more).
- They have a lobulated appearance on CTC.
- They have an increased risk for malignancy.

14.10 Hyperplastic Polyps

The main points of these polyps [38, 39] are presented below.

- Mainly benign non-neoplastic growth.
- Prevalence from 10 to 35%.
- No correlation with advancing age.
- Common and are usually diminutive.
- Sessile.
- Soft lesions that may flatten with colonic insufflation.
- Vast majority have no malignant potential.
- Hyperplastic group occurs more commonly in distal colon.
- Small minority can progress to carcinoma through serrated polyp pathway (see Chap. 15).
- Serrated polyps may progress to a carcinoma over 10–20 years and occur more commonly in proximal colon.

14.11 Carpet Lesions

Carpet lesions are uncommon. They are seen in about one in every 500 cases of CTC in an asymptomatic screening population [40]. This incidence is similar to the prevalence of unsuspected invasive cancers detected at screening colonography, which is also one in 500 studies. If tagging of stool and retained liquid has been performed, then these lesions are not difficult to diagnose. Tagging provides a thin coating of positive contrast material on a portion of the mucosal surface, which is best identified in a soft-tissue window. The coating material is usually barium. Figure 14.7i–iv is an example of a carpet lesion courtesy of Professor D Kim from Wisconsin University. The lesion is usually ≥30 mm in size. It is a flat laterally spreading colorectal mass. It will display a surface coating of contrast medium, which acts as a marker for detection. Although termed 'flat' the lesion typically has a superficially elevated mucosa which can reach a height of 4–14 mm. The edges tend to be superficially elevated from the surrounding mucosa. Untagged residual faecal material may however obscure, or even mimic a carpet lesion. To avoid misdiagnosis, it is essential to use a cathartic agent as well as tagging [41]. These lesions are not difficult to diagnose provided that both tagging of stool and residual liquid has been performed.

Carpet lesions will maintain a flat, plaque-like morphology without evidence of luminal compromise or narrowing [42]. The most common sites are in the right and left colon: the rectum, caecum, sigmoid colon, and ascending colon. The sex distribution is more equal, whereas colorectal neoplasia has a male predominance. Carpet lesions tend to occur in older patients, usually 65 years or older. Most carpet lesions are not malignant, but almost all of them require some form of surgical resection. An important point is that superficially elevated lesions are generally less aggressive than polypoidal lesions of a similar size [43].

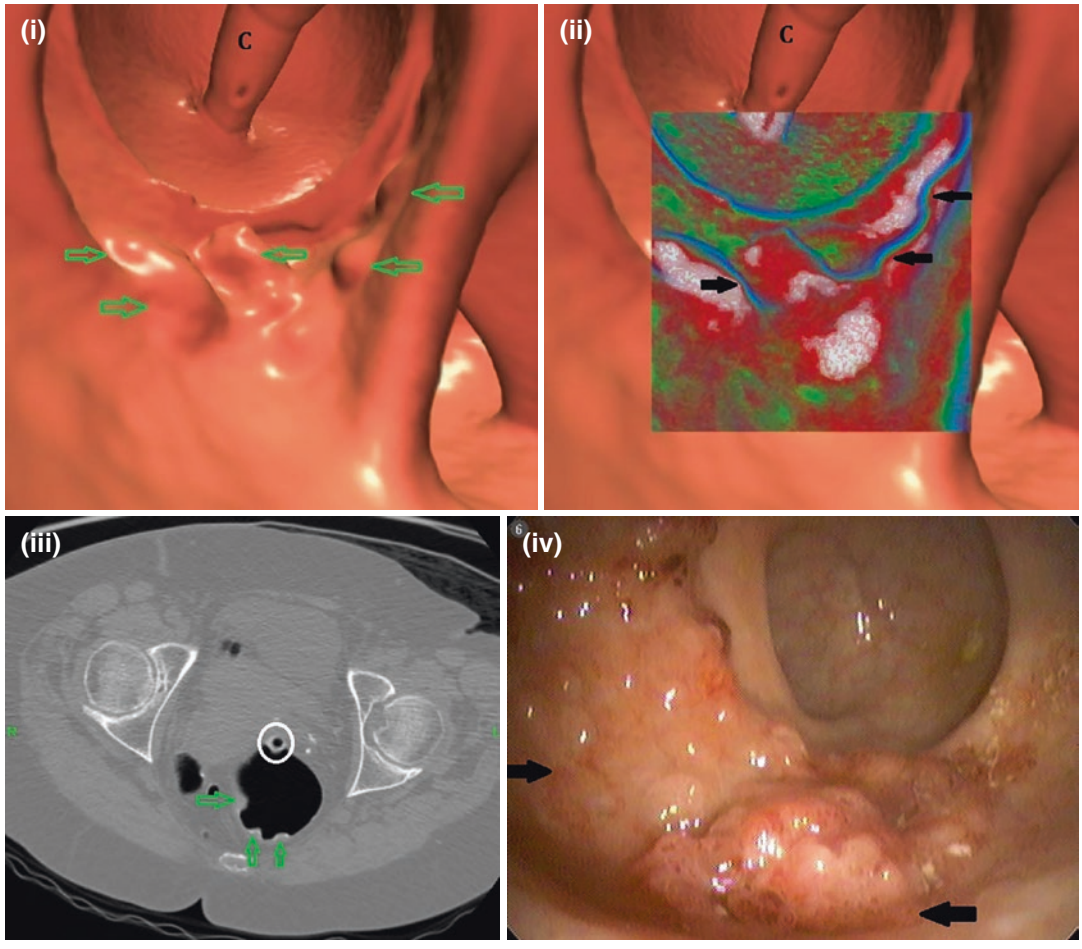

Fig. 14.7 (**i**) 3D endoluminal view of rectum showing rectal catheter (C) and carpet lesion extending for 40 mm (open green arrows). Histology confirmed tubulovillous adenoma. (**ii**) TD view showing rectal catheter (C) and lobulated high intensity regions (black arrows) covered with a thin layer of barium (white). (**iii**) 2D axial view of rectum with rectal catheter (white circle). Polyp view showing flat soft-tissue lesion (green arrows). Note the etching of positive contrast material on the surface of the lesion. (**iv**) Optical colonoscopy view confirms CTC finding of a minimally raised somewhat lobulated carpet lesion in the rectum (arrows)

14.12 Serrated Lesions of the Colon and Rectum

Serrated lesions are believed to be the precursor of about 30% of CRCs (see Sect. 15.3.2 in Chap. 15). There are two major classes of precancerous colorectal lesions [44–46].

1. Adenoma, which consists of tubular, tubulovillous, and villous histology.
2. Serrated polyps which have three subclasses [47, 48].

- Hyperplastic polyp (HP).
- Traditional serrated adenoma (TSA).
- Sessile serrated polyp (SSP). More than 90% of SSPs have no dysplastic component, whilst the rest of them do contain a dysplastic component.
  - Hyperplastic polyps (HPs) are as follows.
    Typically small and predominantly in the left colon.
    Considered to have almost no malignant potential.
  - Traditional serrated adenomas (TSA) are as follows.
    Predominantly left sided, often bulky, and easy to detect endoscopically.
    Dysplastic and precancerous.
  - Sessile serrated polyp (SSP) characteristics are as follows.
    They are the most important lesion in the serrated class.
    They are common and premalignant.
    20% of SSPs are located proximal to the sigmoid colon.
    When seen endoscopically in the proximal colon, the larger size favours SSP over HP [46, 49].

Clinicians treat a proximal colon serrated lesion ≥10 mm as an SSP even if the histological report states hyperplastic polyp. SSP detection can be extremely challenging. An SSP may have a flat or sessile shape, and its colour may be similar to the surrounding mucosa. Endoscopic features of SSP that may help in making the correct diagnosis include the following:

- pale colour
- flat or sessile shape
- mucus cap
- debris on edges or centre
- no surface vessels
- unusual ‘pits’ on surface

Histologically serrated polyps have a serrated, or saw tooth appearance from the in folding in the crypt epithelium. The clinical features of conventional adenomas and the serrated class are depicted in Table 14.3.

Table 14.3 Clinical features of conventional adenomas and the serrated class [a]

Lesion	Frequency in screening	Colonic distribution	Dysplastic	Malignant potential	Shape
Conventional adenoma	±50%	Equal distribution right and left colon	Yes	Yes	Flat and sessile 5–10% pedunculated <1% depressed
Serrated class					
Hyperplastic polyp (HP)	±30%	Rectosigmoid. Larger lesions caecum and ascending colon	No	No	Sessile or flat
Sessile serrated polyp (SSP)		Caecum and ascending colon			
SSP without cytological dysplasia	3–8%	Mostly proximal	No	Yes	
SSP with cytological dysplasia	<1%	Mostly proximal	Yes	Yes	
Traditional serrated adenoma (TSA)	Rare	Rectosigmoid	Yes	Yes	Sessile or pedunculated, often villiform

[a] Adapted from East et al. [48]

14.13 Non-neoplastic Mucosal Lesions

Eighty percent of non-neoplastic mucosal lesions are diminutive; they have no malignant potential. Non-neoplastic lesions account for 40% of polyps ≥6 mm in an asymptomatic screening population [32].

There are several lesions that fall under the non-neoplastic group:

- hyperplastic polyp (HP)
- 'mucosal' polyp
- juvenile polyp
- inflammatory polyp
- inflammatory pseudo polyp

Their salient points are presented below.

- Hyperplastic polyps (HPs)
  - They are the most common non-neoplastic polyp.
  - They are mostly diminutive in size (5 mm).
  - They are located in the distal colon and rectum.
  - Larger lesions (≥10 mm) are more proximal and are related to the serrated polyp pathway.
  - 25% or less of HPs measure more than 6 mm.

- 'Mucosal' polyp
  - Normal epithelium in a 'raised' polypoid appearance.
  - Second most frequent nonadenomatous lesion.
  - 90% are diminutive (≤5 mm).

- Juvenile polyp [32, 50]
  - Hamartomatous (benign focal malformation)
  - Composed of tissue element normally found at the site, but are growing in a disorganised mass.
  - Occurs between ages of one and 7 years.
  - Tends to be solitary, pedunculated, and occurs in the rectosigmoid region.
  - Most regress or slough off.
  - May occur in isolation or be associated with polyposis conditions, such as Peutz-Jeghers Syndrome or Cowden Syndrome.
  - Occasionally seen in adults.

- Inflammatory polyps
  - May occasionally be seen as an isolated finding in adults.
- Inflammatory pseudo polyps
  - Usually seen in patients with inflammatory bowel disease, such as ulcerative colitis or Crohn's disease. Due to risk of perforation of the bowel CTC is contraindicated in patients with these diseases (see Table 10.1 in Chap. 10).
  - Pseudo polyps represent islands of inflamed mucosa surrounded by areas of denuded epithelium.
  - Inflammatory pseudo polyps should not be confused with post-inflammatory polyps; the latter are seen in the chronic regenerative phase of inflammatory bowel disease.

14.14 Submucosal Lesions

A submucosal lesion is a 'mass-like' protrusion into the lumen of the colon. It originates deep to the mucosa and manifests as smooth broad-based abnormality. This allows for submucosal lesions to be more easily detected on OC than on CTC. This limits the efficacy of OC in the biopsy of submucosal lesions. The diagnostic yield is relatively low; OC may thus be responsible for patient referral to CTC for suspected submucosal lesions, which in fact represent extrinsic impressions from extracolonic structures at CTC. Examples of CTC images of extracolonic structures are presented in Sect. 11.5 in Chap. 11.

Submucosal lesions classically present with a smooth broad-based bulge that forms obtuse angles with the surrounding mucosal surface. Submucosal lesions involving colon and rectum are presented in Table 14.4 [51].

- Intramural neoplastic causes include lymphoma, lipoma, carcinoid tumour, gastrointes-

Table 14.4 Neoplastic and non-neoplastic causes of submucosal lesions involving colon and rectum[a]

Neoplastic causes		Non-neoplastic causes	
Intramural origin	e.g. secondary deposits	**Intramural origin**	e.g. cystic and vascular lesions
Extramural origin	e.g. extracolonic tumour penetration	**Extramural origin**	e.g. extrinsic impression of uterus

[a] Adapted from Pickhardt and Kim [51]

tinal stromal tumour, and haemangioma; extramural causes include invasion of tumour outside of colon [51].

- Non-neoplastic intramural causes include haematoma, cystic lesions, and vascular lesions; extramural causes include endometriosis and extrinsic impressions (examples of the latter are in Chap. 11) [51].

14.14.1 Neoplastic Intramural Submucosal Lesions

1. Lipoma is an intramural lesion of the gastrointestinal tract; its most common site is the colon, particularly the right side [52]. Occasionally, a lipoma lesion may evolve into a pedunculated lesion and as it grows it may become the lead point for intussusception. On 2D soft-tissue windowing, the fat attenuation is clearly visible. Figure 14.8a (i, ii) shows typical fatty features of a lipoma. As discussed in Chap. 17, lipomas are usually smooth, broad-based lesions.
2. Carcinoid tumour is uncommon and is usually located in the rectum. When it is small, it may be indistinguishable from a mucosal-based lesion. As these tumours grow, they may ulcerate and be a cause of gastrointestinal bleeding. Proximal carcinoid tumours are most frequently seen in the caecum and ascending colon. Carcinoids that involve the appendix are relatively common subcentimetre lesions. They rarely cause symptoms and are usually in the distal appendix [53]. Figure 14.8b shows a carcinoid tumour.
3. Lymphoma of the colon is rare compared with gastric or small intestinal involvement. If present in the large bowel, it is usually a non-Hodgkin's B-cell lymphoma [54]. The ileocaecal region is most often involved, followed by the rectosigmoid region. Associated abdominal lymphadenopathy may be present. Polypoid lesions may predispose to intussusception [55].
4. Haemangiomas are rare benign vascular tumours that most often affect the rectosigmoid region. Rectal bleeding is the most common symptom. The presence of multiple phleboliths at imaging is very suggestive of underlying haemangioma.
5. GIST (gastrointestinal stromal tumour) typically arises in the muscularis propria layer. These tumours are most common in the stomach, followed by the small intestine, anorectal area, and oesophagus. They tend to grow outwards (exoenteric). They may reach a large size, with only subtle changes on the bowel lumen, simulating an extrinsic impression. If malignant, it tends to spread to the liver and peritoneal cavity. A GIST tumour enhances strongly following iv contrast on CT scanning [56].

14.14.2 Non-neoplastic Submucosal Lesions

Non-neoplastic submucosal lesions of intramural origin arise from the wall of the intestine, deep to the mucosa. The most common is vascular causes; internal haemorrhoids (see Chap. 13), rectal varices, and venous malformation, for example. Examples of internal haemorrhoids are presented in Fig. 14.9a (i, ii).

Non-neoplastic causes of extramural origin include endometriosis, and extrinsic impressions.

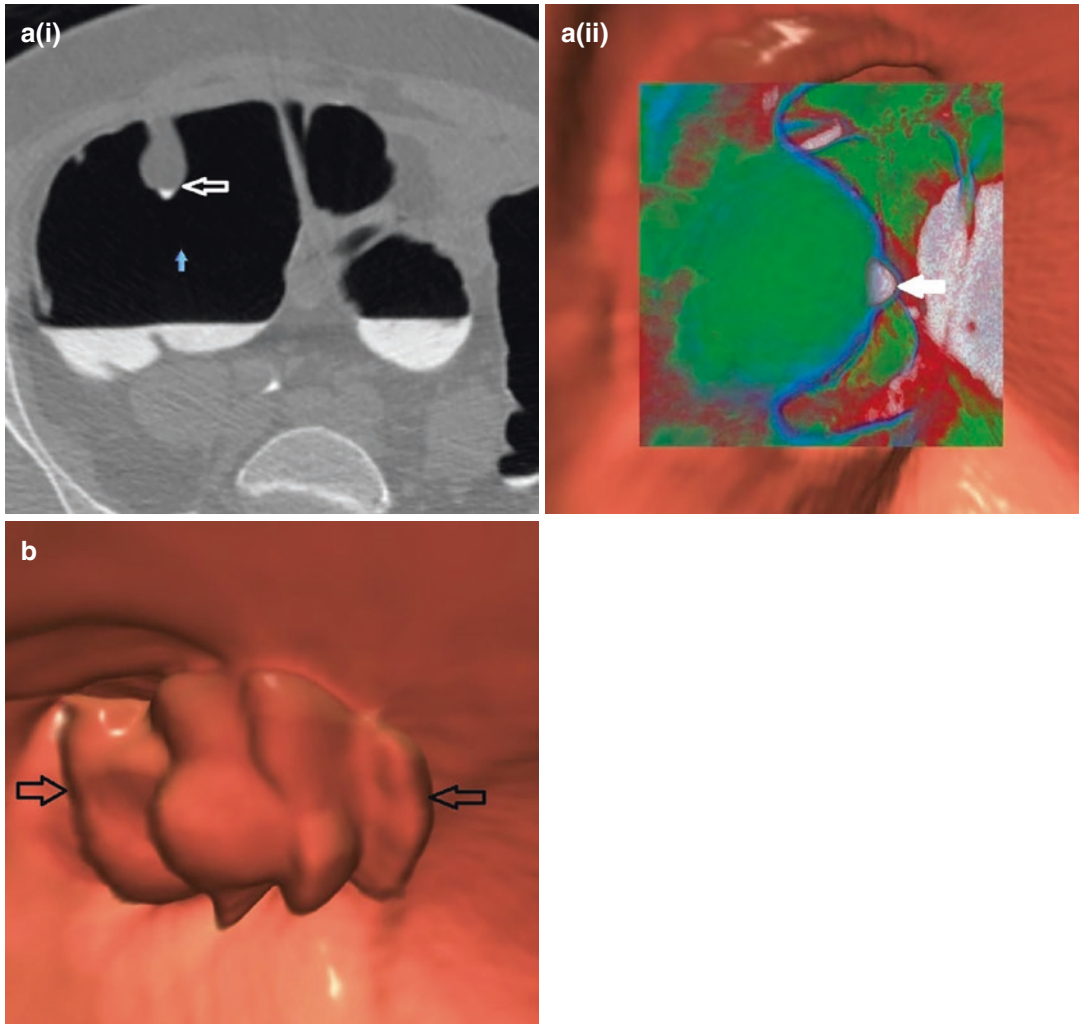

Fig. 14.8 (**a**) (**i**) Axial 2D soft-tissue window view showing tip of barium (open white arrow) on lipoma. (**ii**) Translucent display of lipoma (green = fat). Barium (white arrow) on tip of lipoma. (**b**) 3D view of distal ileum showing a lobulated mass (arrows) on endoluminal flythrough. Histology showed a malignant carcinoid with lymph node involvement

An extrinsic impression, without mural invasion, may be caused by an abnormal extracolonic lesion.

Endometriosis usually occurs in the rectosigmoid region. It is uncommon, but when it does occur there is some serosal implantation with intramural extension. A penetrating lesion may mimic invasive carcinoma. Peritoneal carcinomas may be mimicked if there are soft-tissue masses infiltrating the peritoneum [57].

An extrinsic impression is any structure, which may lie adjacent to the colon, and may cause an extrinsic impression on the lumen. One is able to readily differentiate intramural lesions from extracolonic lesions by means of 2D multiplanar reformatting. Common examples of the latter include aorta, uterus, small intestine, and kidneys [58, 59]. Examples of an extrinsic impression on the colon are presented in Fig. 14.9b (i, ii). More examples are presented in Chap. 11.

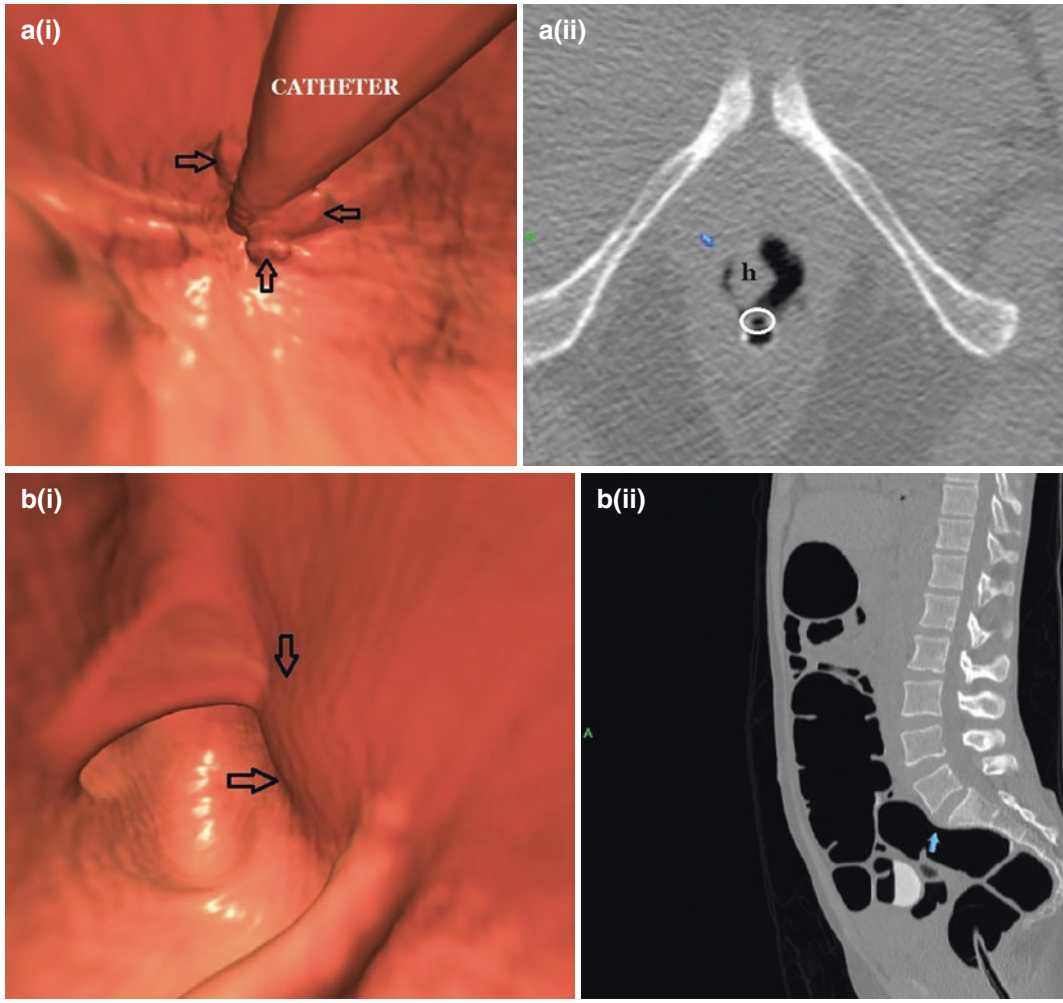

Fig. 14.9 (**a**) (**i**) Internal haemorrhoids (open black arrow). (**ii**) 2D axial prone view showing internal haemorrhoid (h). Rectal catheter (white circle). (**b**) (**i**) 3D endoluminal view showing an external impression from L5 (open black arrows). (**ii**) 2D sagittal view showing mild spondylolisthesis of L5 on S1 causing posterior extrinsic impression on sigmoid colon (blue arrow)

14.15 Dual-Energy CT for Polyp Detection

Recent advances in CT technology have led to the use of dual-energy CT (DECT) in CTC studies [60, 61]. The combination of DECT in CTC studies allows for the differentiation of stool and retained fluid from polypoid lesions [60]. The combined use of DECTC with computer-aided diagnosis (CAD) could be a promising application for detection of polyps [62]. The principles of DECT are discussed in Chap. 26.

14.16 Artificial Intelligence for Polyp Detection

Over the past few years, the role of artificial intelligence (AI), and its subsets machine learning (ML), and deep learning (DL) in CTC, has been underscored in terms of aiding in malignant and benign polyps differentiation [63, 64]. Grosu et al. [64] are of the opinion that ML image analysis, together with conventional imaging reading, could in the future be used as a second reader in all CTC studies. The role of AI for diagnosis and

staging of CRC is discussed in Chap. 15 (see Sect. 15.9). A detailed discussion of AI and machine learning in imaging is presented in Chap. 25.

Key Messages

- Accuracy in detecting and measuring polyp is essential.
- Diminutive polyps ≤5 mm are not reported on.
- If there are more than three small polyps (6–9 mm) diagnosed at CTC, then they are treated with same-day OC, if available, or as soon as possible.
- If there are two or less small polyps (6–9 mm) diagnosed at CTC, then the option of a 3-year surveillance may be offered.
- Advanced adenoma (≥10 mm) are sent for same-day OC.
- Beware of right-sided colonic lesions as they may be of the serrated variety.
- Artificial intelligence is being used to differentiate malignant and benign polyps.
- Clinical audits of polyp measurements and reporting should be done regularly.

14.17 Summary

Being able to readily identify the different types of polyps on a CTC study is important in terms of patient management. Both 2D and 3D images are required to accurately measure polyps. Readers must have a working knowledge of polyp morphology and how to measure polyps, as well as what recommendations to make when polyps are present. A study is considered positive when a lesion ≥6 mm is detected. An advanced adenoma (>10 mm, large polyp) is at higher risk for cancer progression. It represents the key target sign for CRC screening and prevention. Advanced adenomas are sent for same-day OC. CTC is not a replacement for OC; it is an alternative and complementary screening option.

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References

1. Pickhardt PJ, Kim DH. Colorectal cancer screening with CT colonography: key concepts regarding polyp prevalence, size, histology, morphology, and natural history. AJR Am J Roentgenol. 2009;193(1):40–6. https://doi.org/10.2214/ajr.08.1709.
2. Bortz JH. An approach for performing a successful CT colonography examination. S Afr J Rad. 2014;18(1):607, 11 pages. https://doi.org/10.4102/sajr.v18i1.607.
3. Pickhardt PJ. Differential diagnosis of polypoid lesions seen at CT colonography (virtual colonoscopy). Radiographics. 2004;24(6):1535–56.
4. Johnson CD, Chen M, Toledano AY, et al. Accuracy of CT colonography for detection of large adenomas and cancers. N Engl J Med. 2008;359(12):1207–17. https://doi.org/10.1056/NEJMoa0800996.
5. Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing, and Allied Health, 7th ed. 2003. [cited 2022 October 11]. http://medical-dictionary.thefreedictionary.com/prevalence.
6. Farlex Partner Medical Dictionary; 2012. [cited 2022 October 11]. http://medical-dictionary.thefreedictionary.com/incidence.
7. Pickhardt PJ, Choi JR, Hwong I, et al. Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. N Engl J Med. 2003;349(23):2199–200.
8. WHO. Fact-sheets. 2021. [cited 2022 October 11]. https://www.who.int/news-room/fact-sheets/detail/cancer.
9. Levin B, Lieberman DA, McFarland B, et al. Screening surveillance for the early detection of colorectal cancer and adenomatous polyps 2008: a joint guideline from the American Cancer Society, the US Multi-Society Task Force on colorectal cancer, and the American College of Radiology. CA Cancer J Clin. 2008;58(3):130–60. https://doi.org/10.3322/CA.2007.0018.
10. Kim DH, Pickhardt PJ, Taylor AJ, et al. CT colonography versus colonoscopy for detection of advanced neoplasia. N Engl J Med. 2007;357(14):1403–12.
11. Pickhardt PJ, Hassan C, Laghi A, et al. Small and diminutive polyps detected at screening CT colonography: a decision analysis for referral to colonoscopy. AJR Am J Roentgenol. 2008;190(1):136–44.
12. Pickhardt PJ, Hassan C, Laghi A, et al. Clinical management of small (6- to 9-mm) polyps detected at

screening CT colonography: a cost-effectiveness analysis. AJR Am J Roentgenol. 2008;191(5):1509–16.
13. Rex DK, Cutler CS, Lemmel GT, et al. Colonoscopic miss rates of adenomas determined by back-to-back colonoscopies. Gastroenterology. 1997;112(1):24–8.
14. Leufkens AM, van Oijen MG, Vleggaar FP, Siersema PD. Factors influencing the miss rate of polyps in a back-to-back colonoscopy study. Endoscopy. 2012;44(5):470–5. (abstract). https://doi.org/10.1055/s-0031-1291666.
15. Pooler DB, Kim DH, Weiss JM, et al. Colorectal polyps missed with optical colonoscopy despite previous detection and location with CT colonography. Radiology. 2016;278:422–9.
16. Zalis ME, Barish MA, Choi JR, et al. CT colonography reporting and data system: a consensus proposal. Radiology. 2005;236:3–9.
17. Dorland's pocket medical dictionary, 26th ed. Philadelphia: WB Saunders; 2001.
18. Kim DH, Hinshaw L, Lubner MG, Munoz de Rio A, Pooler BD, Pickhardt PJ. Contrast coating for the surface of flat polyps at CT colonography: a marker for detection. Eur Radiol. 2014;24:940–6. https://doi.org/10.1007/s00330-014-3095-z.
19. Tanaka S, Haruma K, Oka S, et al. Clinicopathologic features and endoscopic treatment of superficially spreading colorectal neoplasms larger than 20 mm. Gastrointest Endosc. 2001;54(1):62–6.
20. O'Brien MJ, Winawer SJ, Zauber AG, et al. Flat adenomas in the National Polyp Study: is there increased risk for high-grade dysplasia initially or during surveillance. Clin Gastroenterol Hepatol. 2004;2(10):905–11.
21. Dachman AH, Zalis ME. Quality and consistency in CT colonography and research reporting. Radiology. 2004;230(2):319–23.
22. Pickhardt PJ, Taylor AJ, Jonson GL, et al. Building a CT colonography program: necessary ingredients for reimbursement and clinical success. Radiology. 2005;235(1):17–20.
23. Pickhardt PJ, Lehman VT, Winter TC, Taylor AJ. Polyp volume versus linear size measurements at CT colonography: implications for noninvasive surveillance of unresected colorectal lesions. AJR Am J Roentgenol. 2006;186(6):1605–10.
24. Pickhardt PJ, Kim DH. Performance of CTC for detecting diminutive, small and flat polyps. Gastrointest Endosc Clin N Am. 2010;20(2):209–26.
25. Van Dam J, Cotton P, Johnson CD, et al. AGA future trends report: CT colonography. Gastroenterology. 2004;127:970–84.
26. Ransohoff DF. CON: Immediate colonoscopy is not necessary in patients who have polyps smaller than 1 cm on computed tomographic colonography. Am J Gastroenterol. 2005;100:1905–7.
27. Bond JH. Clinical relevance of the small colorectal polyp. Endoscopy. 2001;33(5):454–7.
28. Schoenfeld P. Small and diminutive polyps: implications for colorectal cancer screening with computed tomography colonography. Clin Gastroenterol Hepatol. 2006;4:293–5.
29. Lieberman D, Moravec M, Holub J, et al. Polyp size and advanced histology in patients undergoing colonoscopy screening: implications for CT colonography. Gastroenterology. 2008;135(4):1100–5.
30. Pickhardt PJ, Wise SM, Kim DH. Positive predictive value for polyps detected at screening CT colonography. Eur Radiol. 2010;20(7):1651–6.
31. Hofstad B, Vatn MH, Andersen SN, et al. Growth of colorectal polyps: redetection and evaluation of unresected polyps for a period of 3 years. Gut. 1996;39(3):449–56. https://doi.org/10.1136/gut.39.3.449.
32. Pickhardt PJ, Choi JR, Hwang I, et al. Nonadenomatous polyps at CT colonography: prevalence, size, distribution, and detection rates. Radiology. 2004;232(3):784–90.
33. Van Stolk RU, Beck GJ, Baron JA, et al. Adenoma characteristics at first colonoscopy as predictors of adenoma recurrence and characteristics at follow-up. Gastroenterology. 1998;115(1):13–8.
34. Bond JH. Clinical evidence for the adenoma-carcinoma sequence, and the management of patients with colorectal adenomas. Sem Gastrointest Dis. 2000;11:176–84.
35. Winawer SJ, Zauber AG. The advanced adenoma as the primary target of screening. Gastrointest Endosc Clin N Am. 2002;12(1):1–9.
36. Macari M, Bini EJ. CT colonography: where have we been and where are we going? Radiology. 2005;237(3):819–33. https://doi.org/10.1148/radiol.22373041717.
37. O'Brien MJ, Winawer SJ, Zauber AG, et al. The National Polyp Study—patient and polyp characteristics associated with high-grade dysplasia in colorectal adenoma. Gastroenterology. 1990;98(2):371–9.
38. Waye JD, Bilotta JJ. Rectal hyperplastic polyps—now you see them, now you don't—a different point. Am J Gastroenterol. 1990;85(12):1557–9.
39. Church JM. Clinical significance of small colorectal polyps. Dis Colon Rectum. 2004;47(4):481–5.
40. Pickhardt PJ, Kim DH, Meiners RJ, et al. Colorectal and extracolonic cancers detected at screening CT colonography in 10,286 asymptomatic adults. Radiology. 2010;255(1):83–8.
41. Pickhardt PJ, Lam VP, Weiss JM, et al. Carpet lesions detected at CT colonography: clinical, imaging, and pathologic features. Radiology. 2014;270:435–43.
42. Rubesin SE, Saul SH, Laufer I, et al. Carpet lesions of the colon. Radiographics. 1985;5(4):537–52.
43. Pickhardt PJ, Kim DH, Robbins JB. Flat (nonpolypoid) colorectal lesions identified at CT colonography in a US screening population. Acad Radiol. 2010;17(6):784–90. https://doi.org/10.1016/j.acra.2010.01.010.
44. Rosty C, Hewett DG, Brown IS, et al. Serrated polyps of the large intestine: current understanding of diagnosis, pathogenesis, and clinical management. J Gastroenterol. 2013;48(3):287–302.
45. Torlakovic E, Skovlund E, Snover DC, et al. Morphological reappraisal of serrated colorectal polyps. Am J Surg Pathol. 2003;27:65–8.

46. Rex DK, Ahren DJ, Baron JA, et al. Serrated lesions of the colorectum: review and recommendations from an expert panel. Am J Gastroenterol. 2012;107:1315–29.
47. Snover DC, Jass JR, Fenoglio-Preiser C, Batts KP. Serrated polyps of the large intestine. Am J Clin Pathol. 2005;124:380–91.
48. East JE, Vieth M, Rex DK. Serrated lesions in colorectal cancer screening: detection, resection, pathology and surveillance. Gut. 2015;64(6):991–1000.
49. Hazewinkel Y, López-Cerón M, East JE, et al. Endoscopic features of sessile serrated adenomas. Validation by international experts using hi-resolution white-light endoscopy and narrow-band imaging. Gastrointest Endosc. 2013;77:916–24.
50. Calva D, Howe JR. Hamartomatous polyposis syndromes. Surg Clin North Am. 2008;88(4):779, vii
51. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009. p. 359.
52. Hancock BJ, Vajcner A. Lipomas of the colon—a clinicopathologic review. Can J Surg. 1988;31(3):178–81.
53. Levy AD, Sobin LH. From the archives of the AFIP. Gastrointestinal carcinoids: imaging features with clinicopathologic comparison. Radiographics. 2007;27(1):237–U19.
54. Wong MJC, Eu KW. Primary colorectal lymphomas. Color Dis. 2006;8(7):586–91.
55. Stanojevic GZ, Nestorovic MD, Brankovic BR, et al. Primary colorectal lymphoma: an overview. World J Gastrointest Oncol. 2011;3(1):14–8.
56. Liegl-Atzwanger B, Fletcher JA, Fletcher CD. Gastrointestinal stromal tumours. Virchows Arch. 2010;456:111–27. https://doi.org/10.1007/s00428-010-0891-y.
57. Zwas FR, Lyon DJ. Endometriosis—an important condition in clinical gastroenterology. Dig Dis Sci. 1991;36(3):353–64.
58. Pickhardt PJ, Levy AD, Rohrmaan CA, et al. Primary neoplasms of the appendix: radiologic spectrum of disease with pathological correlation. Radiographics. 2003;23(3):645–22.
59. Lee AD, Pickhardt PJ, Gopol DN, et al. Venous malformations mimicking multiple mucosal polyps on screening CT colonography. AJR Am J Roentgenol. 2006;186(4):1113–5.
60. Sun K, Han R, Han Y, Shi X, Hu J, Lu B. Accuracy of combined computed colonography and dual energy iodine map imaging for detection of colorectal masses using high-pitched dual-source CT. Sci Rep. 2018;8(1):3790. https://doi.org/10.1038/s41598-018-22188-x.
61. Näppi JJ, Regge D, Yoshida H. Context-specific method for detection of soft-tissue lesions in non-cathartic low-dose dual-energy CT colonography. Proc SPIE Int Soc Opt Eng. 2015;1(9414):94142Y. https://doi.org/10.1117/12.2081284.
62. Nasirudin RA, Tachibana R, Näppi JJ, Mei K, Kopp FK, Rummeny EJ, Yoshida H, Noël PB. A comparison of material decomposition techniques for dual-energy CT colonography. Proc SPIE Int Soc Opt Eng. 2015;21(9412):94124F. https://doi.org/10.1117/12.2081982.
63. Wesp P, Grosu S, Graser A, Maurus S, Schulz C, Knösel T, Fabritius MP, Schachtner B, Yeh BM, Cyran CC, Ricke J, Kazmierczak PM, Ingrisch M. Deep learning in CT colonography: differentiating premalignant from benign colorectal polyps. Eur Radiol. 2022;32(7):4749–59. https://doi.org/10.1007/s00330-021-08532-2.
64. Grosu S, Wesp P, Graser A, Maurus S, Schulz C, Knösel T, Cyran CC, Ricke J, Ingrisch M, Kazmierczak PM. Machine learning-based differentiation of benign and premalignant colorectal polyps detected with CT colonography in an asymptomatic screening population: a proof-of-concept study. Radiology. 2021;299(2):326–35. https://doi.org/10.1148/radiol.2021202363.

15 The Adenoma-Carcinoma Sequence, Management, and Treatment of Colon Cancer

Joel H. Bortz and Hesta Friedrich-Nel

15.1 Introduction

Colorectal cancer (CRC) remains a major health problem around the world. According to the World Health Organisation (WHO) [1], CRC was the third most common site of cancer in both men and women in 2020. The target date, for an overall 25% reduction of mortality in the WHO's roadmap for its global action plan for the prevention and control of noncommunicable diseases (e.g., cancer), is 2025 [2]. The WHO promotes screening programmes for early detection of CRC [1]. CRC in adults in 2022 in the United States of America (USA) has been estimated to be 151,030 [3]. Globally, an estimated 1,880,725 people were diagnosed with CRC in 2020 [3]. Younger people are presenting with CRC [4–8]; hence, the recommendation that screening in average risks people should commence at 45 years and no longer at 50 years [9, 10].

There has been gradual decline in the incidence of cancer as well as the number of deaths in the USA; these declines have been attributed to CRC screening and removal of potentially harmful polyps [11]. Most colon cancers, apart from inherited genetic disorders, such as hereditary non-polyposis CRC, arise from a pre-existing polyp which develops over a period of 10–15 years into a cancer [12]. It is important to detect and remove a polyp, which will ultimately grow, and become an underlying cancer [13]. Knowledge of the adenoma-carcinoma sequence, and the serrated polyp sequence is important for reporting of polyps detected during CTC studies [14–16].

The following abbreviations are used in this chapter.

- 3D: three-dimensional
- AI: artificial intelligence
- CRC: colorectal cancer
- DECT: dual-energy computed tomography
- DL: deep learning
- FAP: familial adenomatous polyposis
- IO: iterative optimisation
- ML: machine learning
- MRI: magnetic resonance imaging
- MSI: microsatellite instability
- OC: optical colonoscopy
- PET/CT: positron emission-computed tomography
- TNM: tumour, nodes, metastases

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

H. Friedrich-Nel
Faculty of Health and Environmental Sciences,
Central University of Technology,
Bloemfontein, South Africa
e-mail: hfried@cut.ac.za

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- USA: United States of America
- WHO: World Health Organisation

15.2 Benign Colorectal Polyps, Precursor Lesions, and Histology

A benign colorectal polyp is the core of CRC screening. Screening for CRC focusses not on early detection of cancer, but rather on the removal of a benign precursor lesion, which, if left unattended, will eventually transform into an underlying cancer [13, 14]. This has been the principle of optical colonoscopy (OC) screening; remove all polyps irrespective of size because only histology will be able to prove which polyp has a high-grade villous component, or a high-grade dysplasia, which will ultimately progress to an underlying carcinoma.

15.3 Colorectal Cancer Pathways

Most sporadic cancers arise from an adenomatous polyp. A few cancers are known to arise from a different precursor, the hyperplastic polyp. Cancer, which arises from an adenomatous polyp, goes through a pathway known as the adenoma-carcinoma pathway [12, 13]. Cancer from a hyperplastic polyp develops along a different pathway: the serrated polyp-carcinoma sequence [15]. There is another less common pathway: hereditary colorectal cancer syndromes [17].

15.3.1 Adenoma-Carcinoma Pathway

The adenoma-carcinoma pathway is that of a cancer that arises from an adenomatous polyp [12]. This pathway sequence is also termed the 'suppressor' or 'chromosomal mobility' pathway. It is characterised by loss or inactivation of large portions of chromosomes. The precursor lesion is the adenoma; this route accounts for 80% of CRCs [18]. It takes between 10 and 15 years for an adenoma to develop into a carcinoma [12, 19]. Over time an adenoma becomes increasingly dysplastic, which is an indication of an early neoplastic process, eventually leading to the formation of underlying cancer. Adenomas grow to a fairly large size before converting into cancer [13]. An advanced adenoma is most likely to undergo progression to cancer. As evident in Fig. 15.1, the main aim of screening CTC is to target lesions which are classified as advanced adenomas. What is an advanced adenoma? There are three criteria of advanced adenoma [13].

- Any adenoma that is large (≥10 mm) and of any histological subtype, namely tubular, tubulovillous, or villous.
- Any adenoma of any size that harbours high-grade dysplasia.
- Any adenoma of any size that contains a significant villous component (≥25% of tubulovillous or villous histology).

A simplified version of the adenoma-carcinoma sequence is basically the conversion of normal colonic mucosa → benign adenoma → advanced adenoma → an invasive cancer. This sequence is due to a number of genetic mutations that cause inactivation of tumour suppressor genes and activation of various oncogenes, which promote tumour growth. Figure 15.1(a) i–f present a range of examples of polypoidal lesions and CRC, as well as an example of metastatic lymph nodes.

15.3.2 Serrated Polyp-Carcinoma Pathway Sequence

Cancer from a hyperplastic polyp develops along a different pathway: the serrated polyp-carcinoma sequence [15, 20] and forms between 15 and 20% of CRCs. It is termed the 'mutator' pathway [21]. It is characterised by microsatellite instability (MS1) due to uncorrected replication errors.

There is a second minor pathway within the serrated polyp-carcinoma sequence, that of low MS1 cancers. This is a newly recognised pathway, and it accounts for 15–20% of sporadic CRC [22]. The precursor lesion is the hyperplastic polyp, which has been considered a non-neoplastic lesion without any malignant potential. A small percentage of them are now believed to have the ability to undergo malignant change over a long period of time. The progression is from a hyperplastic polyp to a polyp with architectural disorganisation: sessile serrated polyp (SSP). As a result of genetic events, the serrated polyp becomes increasingly dysplastic and eventually evolves into a carcinoma. These carcinomas demonstrate microsatellite instability (MS1) and are termed MS1-H tumours. A minority of cancers are MS1-L thus are more stable. There are two pathways: MS1-H (75%) and MS1-L (25%).

Fig. 15.1 An advanced adenoma is the target lesion.

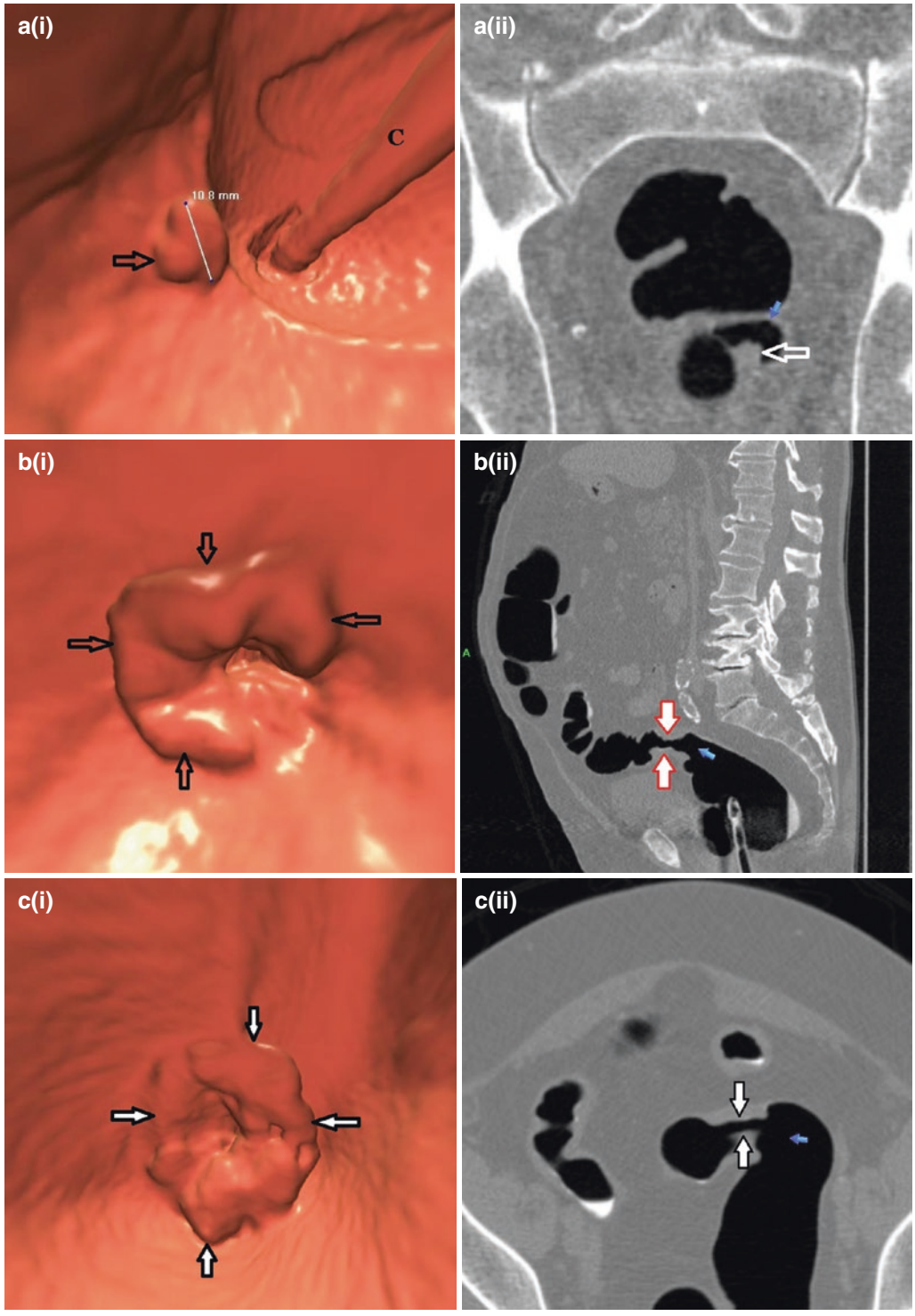

Fig. 15.1 (**a**) (**i**) 3D view of a 10.8 mm polypoidal lesion (open black arrow) close to rectal catheter (C). (**ii**) 2D coronal soft tissue window showing polyp (open white arrow). (**b**) (**i**) 3D endoluminal view showing an almost complete annular carcinoma in the sigmoid colon (open black arrows). (**ii**) 2D sagittal soft tissue view showing the 'apple core' lesion (arrows) in the sigmoid colon. (**c**) (**i**) 3D endoluminal view showing annular cancer (arrows). (**ii**) 2D axial soft tissue view showing annular carcinoma with marked narrowing of lumen (arrows).

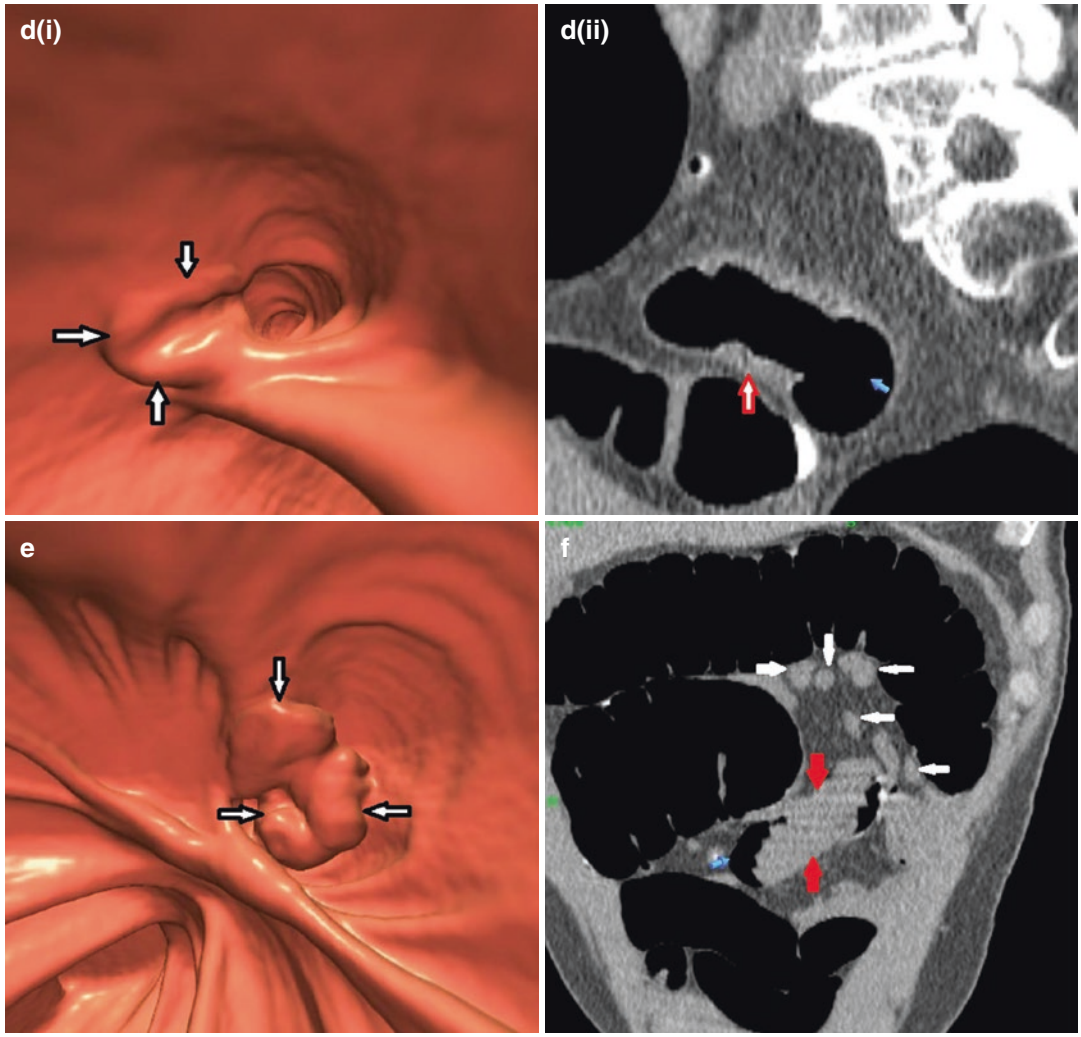

Fig. 15.1 (**d**) (**i**) 3D endoluminal view showing semi-annular carcinoma (arrows). (**ii**) 2D sagittal soft tissue view revealing cancer in the sigmoid colon (arrow). (**e**) 3D view showing large fungating caecal pole mass carcinoma (arrows). (**f**) Coronal 2D soft tissue view showing a large ileal carcinoid (red arrows) and metastatic lymph nodes (white arrows)

15.4 Hereditary Colorectal Cancer Syndromes

The majority of CRCs (95%) arise from pre-existing polyps; the rest (5%) represent hereditary colorectal cancer syndromes [17]. The most classic being familial adenomatous polyposis (FAP), which is inherited in an autosomal dominant fashion with high penetration. Individuals with FAP have hundreds of adenomas that carpet the colon with polyps. The disease tends to occur in persons in their 20s (third decade) and 30s (fourth decade). CRC is inevitable in people with FAP thus total colectomy is recommended. Patients with FAP also suffer from gastric polyps, and small bowel polyps, particularly in the duodenum. Extracolonic tumours, in the thyroid, biliary tree, liver and adrenals, may occur in these patients. Intra-abdominal desmoid tumours will develop in about 33% of patients with FAP. They are related but separate syndromes which are considered under the umbrella of FAP. Gardners'

syndrome: intestinal polyposis and benign bone lesions, such as osteoma of the mandible, and Turcot's syndrome: colonic polyps and central nervous system tumours.

Lynch syndrome (hereditary non-polyposis colorectal cancer) [23] constitutes 3–5% of CRC. Cancer occurs at an early age because this syndrome is inherited as autosomal dominant. There is also a risk during the lifetime of someone with Lynch syndrome of developing multiple cancers. The estimated cancer risks associated with this syndrome are: CRC (80%); stomach cancer (11–19%); hepatobiliary tract cancer (2–7%); urinary tract cancer (4–5%); small bowel cancer (1–4%); and brain and central nervous system (1–3%). The cancer risks for women with the syndrome are: endometrial cancer (20–60%); ovarian cancer (9–12%). There are also higher risks of other cancers, namely pancreatic cancer, kidney cancer, prostate cancer, and breast cancer [23].

15.5 Preoperative CTC in CRC Patients

In order to prepare an effective therapy plan for the treatment of patients diagnosed with CRC, an accurate evaluation preoperatively is essential. This is mainly done for the following reasons: to exclude synchronous cancers; to detect metastases (i.e., nodal and distant) (see Chap. 18); to evaluate local invasion; and for precise localisation of the tumour [24]. The latter is essential because laparoscopic surgery is largely replacing previous abdominal laparotomy. This requires accurate localisation of the tumour lesion [24]. This is where CTC is most useful compared to localisation of the tumour lesion by OC. Literature reports that approximately 6% of CTC cases with CRC have synchronous lesions [25]. In a patient with CRC, there is a wide range of diagnostic tests which may also be used: OC; CTC using intravenous (IV) contrast; magnetic resonance imaging as discussed in Chap. 22; ultrasound as discussed in Chap. 22; and positron emission tomography as discussed in Chap. 23. CTC is useful in both pre- and post-surgical evaluation of CRC [26]. Evaluation of the entire colon is possible with CTC [24]. It is no longer acceptable for double-contrast barium enema screening to be used in this setting [27].

15.6 Imaging Modalities in Preoperative Evaluation of CRC

CTC can play a role in preoperative evaluation of CRC [28]. Kijima et al. [29] compared the effectiveness of different modalities, namely CTC, magnetic resonance imaging (MRI), and positron emission tomography-computed tomography (PET/CT) colonography. These modalities were used to assess the TNM (tumour, node, metastases) staging of colorectal tumours (see Sects. 15.7 and 15.7.2). In terms of CTC, they state that it provides important information for preoperative assessment of tumour surgery.

- Wall deformities usually are indicative of muscular or subserosal metastases.
- Calcification of lymph nodes may occur from CRC; these are best detected by CT.
- Laparoscopic surgery is facilitated by 3DCT (three-dimensional CT) of vascular structures.
- It is useful in the detection of liver metastases, but MRI has a higher accuracy rate.
- It is useful in cases of preoperative colonoscopy. CTC can evaluate the colon proximal to the obstructing tumour, which cannot be seen by OC.
- CRC patients usually have synchronous lesions in 5–11% of cases [30]. These lesions usually occur in different segments of the bowel. They need to be diagnosed at the same time as the original tumour as surgical intervention will be required.
- CRC may be imaged on CTC as a probable mass lesion, usually larger than 10 mm. The tumour may have already infiltrated into the subserosa if there is increased density in the adjacent fatty tissue.

The accuracy of CTC in TNM staging is as follows [29]. Tumour staging (T staging) varies between 73 and 83%. In terms of detection of met-

astatic lymph nodes (N staging) diagnostic CTC, which includes IV contrast media, has an accuracy varying between 50 and 71%. It can demonstrate liver metastases, pulmonary metastases (M staging), and other extracolonic findings (see Chap. 18). Its accuracy for liver metastases is 85%. IV contrast media are not used in screening CTC. However, administration of IV contrast medium is mandatory for staging by CT scanning.

MRI is used mainly for staging of rectal cancer (see Chap. 22) and in the evaluation of liver metastases. According to Kijima et al. [29], PET/CT colonography seems a useful tool (1) for evaluation of CRC in pre-surgical staging and (2) identifying occult metastatic disease and recurrent disease. The therapy of almost a third of patients with advanced primary cancer was changed with the use of PET/CT colonography [31].

15.7 Treatment of CRC

The treatment protocol for CRC depends on aspects such as the stage of the cancer, the performance status of the patient, and the type of tumour. The staging can be done according to, example, the Union for International Cancer Control (UICC), or the TNM classification, or Duke staging [32]. The treatment protocol includes surgery, radiation therapy, chemotherapy, and targeted therapy, such as ablation or embolisation techniques for advanced cancers. Diagnostic imaging (e.g., CT) plays a vital role to stage the disease. For example, whether the disease is local (Stages 0–1), locally advanced (Stages II and III), and/or has spread to distant organs (Stage IV). Local CRC (Stages I–III) can have a high, moderate, or low risk of local recurrence. This information assists in determining the treatment protocol of the patient.

15.7.1 Surgery

Surgery is the most common treatment option but depends on the location of the tumour and is recommended if the tumour is resectable [33]. Polypectomy is a local excision of a polyp by a gastroenterologist during a colonoscopy. If the histopathological evidence indicates that the removal of the polyp was complete, no further treatment may be required. A colectomy is done to remove a part of the colon and surrounding or nearby lymph nodes. This procedure can be done via a laparoscopy (laparoscopic-assisted colectomy) or during open surgery. A mesorectal excision is recommended for a patient fit for surgery and for a tumour in the middle and lower third rectum. Should there be a high risk of local recurrence of the tumour, preoperative chemotherapy is recommended to allow the tumour to shrink before surgery. This option also reduces the risk of local recurrence with an improved survival rate of the patient. Surgery for advanced local, recurrent or metastatic disease includes palliative intraluminal procedures, resection or ablation of metastases in the liver and/or lungs [34].

15.7.2 Chemotherapy and Radiotherapy

Adjuvant chemotherapy and radiotherapy are prescribed for Stage II (T1–4 N0M0) and Stage III (T1–4 N1,2 M0) CRC. Chemoradiotherapy before surgery is indicated for locally advanced and unresectable tumours or tumours that appear as borderline cases to allow the tumour to shrink for an improved tumour response [33].

15.7.2.1 Chemotherapy

Chemotherapy can be used at different times during the treatment process. For a resectable tumour, neoadjuvant multidrug chemotherapy is used before surgery to shrink the tumour. Adjuvant chemotherapy is used after surgery to inhibit tumour recurrence in Stage II and III cancers. Combination chemotherapy is used to improve the survival of patients with metastatic colorectal cancer with good organ function and performance status. Chemotherapy can be administered systemically or regionally. Systemic chemotherapy is injected in a vein or given orally while regional chemotherapy is injected into an artery leading directly to the tumour area. This is done to concentrate the dose of chemotherapy to

the tumour and minimise the exposure of chemotherapy to the normal surrounding tissue.

Chemotherapy may cause side effects such as vomiting, nausea, diarrhoea, neuropathy, or mouth sores. A patient may also feel tired, with an increased risk of infection. Other side effects include neuropathy, tingling, or numbness in feet or hands. Side effects are drug dependent and can be treated with prescribed medication [34].

15.8 Radiation Therapy

External-beam radiation therapy is commonly used for patients with CRC and can take various forms [34]. Endocavitary therapy is applied via the anus and is sometimes used in combination with external-beam radiation therapy. Brachytherapy uses small sources of radioactive material inserted in a tube and placed in or next to the tumour. The advantage of brachytherapy is the high dose to the tumour while the radiation dose to the normal surrounding healthy tissues is minimised. A last radiation therapy treatment option is radioembolisation which is radiation therapy during an embolisation procedure. Preoperative pelvic radiotherapy, with a biologically effective dose of 30 Gy or higher, in combination with surgery has shown to improve the local control of the tumour. A short course of preoperative radiotherapy (e.g., 25 Gy in 5 fractions) can reduce the risk of local recurrence.

Side effects from radiation therapy depend on the size of the area being treated as well as the dose. The effects may include fatigue, mild skin reactions, an upset stomach, and loose bowel movements. Bloody stools from bleeding through the rectum or a blockage of the bowel may also be present. Most of the side effects will disappear as soon as the radiation therapy stops [34].

15.8.1 Treatment of CRC by Stage

There are four stages of CRC [34]. Each stage is briefly described. A stage 0 cancer means that the cancer has not grown beyond the inner lining of the bowel. The cancer is local and does not involve surrounding or nearby lymph tissue. Surgery includes any of the following: polypectomy, local excision through colonoscope, or colectomy.

- For stage I tumours, surgery remains the main treatment option. No other treatment is required if the polyp or tumour is completely removed as indicated by the histopathology report.
- Stage II cancers have grown through the walls of the bowel and may extend into the surrounding tissue but may not be present in the nearby lymph nodes. Recommended therapy includes surgery with adjuvant chemotherapy, specifically for those tumours with a moderate to high risk of local recurrence. Radiation therapy may also be an option if there is a risk of local recurrence.
- Stage III cancer has spread to the nearby lymph nodes but not yet to distant sites such as the liver and the lungs. Surgery is done to remove the tumour, a section of the colon/rectum as well as the surrounding lymph nodes. Surgery is then followed by adjuvant chemotherapy. In some cases, the patient may receive chemotherapy before the surgery. If there is a suspicion of local recurrence, radiation therapy may also be used. Radiation therapy and/or chemotherapy remain a favourable treatment option for a patient who is not strong enough for surgery.
- Stage IV CRC disease has spread to distant organs and tissue such as the liver, peritoneum, lungs, and distant lymph nodes. These patients will receive chemotherapy and/or targeted therapy to control the cancer. Radiation therapy may be used to help relieve symptoms such as pain.

Local or distant recurrence of the tumour is treated with surgery, chemotherapy, and /or radiation therapy as it depends on the site and extent of the recurrence.

15.9 Dual-Energy Computed Tomography

The principle of dual-energy computed tomography (DECT) is based on the photo-electric effect (low energy photon interactions) and Compton effect (high energy photon interactions). These phenomena facilitate the analysis of soft tissue, calcium, and iodine [35]. Single or dual detectors and single or double X-ray tube sources assist to obtain data at two different energy levels, often between 80 and 120 kVp [35]. This results in qualitative and quantitative data of the tissue composition which facilitates the grouping of different pathologies based on photon absorption and Compton scattering at different energy levels [35]. The principles of DECT are discussed in Chap. 26.

The advantage of DECT is tissue differentiation, identification, and quantification. For example, iodine, calcium, or barium can be separated from other tissues using one acquisition scan [36]. Tissue identification and quantification refer to assessment and the presence and amount of, for example, iodine in a specific anatomical region. The measurement of iodine content in tissue, for example, helps to differentiate between benign and aggressive CRCs [37]. As such DECT can also distinguish between stool and a polyp without compromising the sensitivity and specificity of the examination [35, 38]. Additionally, the iodine density measurements can also assist in assessing treatment responses such as determining the size of the tumour in response to treatment. These features make DECT useful in oncology imaging without an increase in the radiation dose to the patient [36] (see Chap. 26). Although CTC is regarded as a reliable screening tool [39] and as a gold standard procedure because of the high sensitivity, DECT has the advantage that bowel preparation and/or bowel distention of the patient is not required [35]. This option is therefore pleasant for a patient and provides a positive patient experience [36].

Although DECT is unable to distinguish between an adenoma and carcinoma, it is however useful for preoperative screening for CRCs. Successful differentiation between metastatic and non-metastatic lymph nodes of rectal cancer was also reported [40, 41]. This is due to the lower iodine concentration in metastatic lymph nodes. DECT is useful for CRC grading [42].

15.10 Artificial Intelligence for Diagnosis and Staging of CRC

A limitation of CTC is that a reader is not able to differentiate benign and malignant lesions. Over the past few years, the role of artificial intelligence (AI) in medicine has been underscored. For example, according to Yu and Helwig [43] AI has a role for epidemiology of CRC as well as an imaging tool for diagnosis of CRC. Literature reports on the role of AI (machine learning/deep learning) for polyp detection and differentiation in imaging [44, 45]. In addition, literature describes the use of AI in the diagnosis, staging, and treatment of CRC [46, 47]. Kacew et al. [48] are of the opinion that AI can contribute to cutting costs in CRC genotyping. A detailed discussion of AI and machine learning in imaging is presented in Chap. 25.

15.11 AI Applications in Radiation Therapy

Developments in the use of AI in radiation therapy were published recently in a review paper [49]. Santoro et al. [49] retrieved 71 papers of AI applications in radiation therapy planning. These included three papers on iterative optimisation (IO), 25 papers on machine learning (ML), and 43 papers on deep learning (DL). The ML technique is used to identify patient specific dose-volume constraints and custom design radiation therapy options and solutions. As these approaches may be time consuming when done manually, utilising IO procedures and auto-planning techniques can reduce the treatment planning time. The advantage of this approach is that there is a consistent production

of quality plans with minimal inter-planning variations [49].

Another application is for patient positioning and monitoring, thus to verify that the patient remains in the simulated treatment position. DL-based methods are used that enable accurate patient positioning. As such AI can be used for dynamic motion management models to improve tumour tracking. Irradiation can be interrupted if there is patient motion, or inadequate target positioning. Such algorithms can track and accommodate real-time breathing motion to track the tumour position in advance, adding to the accuracy and custom delivery of the radiation therapy [49]. Santoro et al. [49] concluded that more research is required to explore the use of AI, such as auto-planning techniques and its application in the clinical environment. Also, there is a need to develop and implement reliable and trustworthy AI tools as well as looking into the ethical principles implementing AI in the radiation therapy environment. The WHO [50] underscores the importance of key ethical principles of AI in health.

Key Messages

- Most sporadic cancers arise from an adenomatous polyp.
- It takes between 10 and 15 years for an adenoma to develop into a carcinoma.
- The adenoma-carcinoma pathway is of a cancer that arises from an adenomatous polyp.
- The serrated polyp-carcinoma sequence forms between 15 and 20% of CRCs.
- The onset of CRC is increasing in younger people.
- Treatment options for CRC include surgery, chemotherapy, radiation therapy, and targeted therapy that is usually offered in combination.
- The treatment protocol depends on the stage of the CRC and the performance status of the patient.
- Chemotherapy and radiation therapy have side effects. These symptoms can be treated with prescribed medication.
- DECT may be useful for CRC grading.
- Diagnostic CTC, MRI, and PET/CT play a role in TNM staging of CRC.
- Artificial intelligence is playing an important role in the diagnosis, treatment, and prognosis of CRC.

15.12 Summary

Colorectal cancer (CRC) remains a major health problem around the world. Apart from inherited genetic disorders, such as hereditary non-polyposis colorectal cancer, most CRCs arise from a pre-existing polyp which develops over a period of 10–15 years into a cancer. Knowledge of CRC pathways is important for reporting of polyps detected during CTC studies. Understanding treatment and management of CRC underscore that concerted efforts should be made to reduce persons developing CRC by correctly identifying and reporting advanced adenomas on CTC studies.

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References

1. WHO. Cancer. 2022. [cited 2022 September 10]. https://www.who.int/news-room/fact-sheets/detail/cancer.
2. WHO Implementation roadmap 2023–2030 for the global action plan for the prevention and control of NCDs 2013–2030. [cited 2022 September 10]. https://www.who.int/teams/noncommunicable-diseases/governance/roadmap.
3. American Society of Clinical Oncology. 2022. [cited 2022 September 10]. https://www.cancer.net/cancer-types/colorectal-cancer/statistics.
4. Rajagopalan A, Antoniou E, Rajagopalan E, Arachchi A, Chouhan H, Nguyen TC, Teoh W. Is colorectal cancer associated with altered bowel habits in young patients? ANZ J Surg. 2021;91:943–6.
5. Kim J, Dobson B, Ng Liet Hing C, Cooper M, Lu CT, Nolan G, Von Papen M. Increasing rate of colorectal cancer in younger patients: a review of colonoscopy findings in patients under 50 at a tertiary institution. ANZ J Surg. 2020;90:2484–9. https://doi.org/10.1111/ans.16060.
6. Cavestro GM, Zuppardo RA, Mannucci A. Early-onset of colorectal cancer: trends and challenges.

Lancet Gastroenterol Hepatol. 2019;4(7):F491–2. https://doi.org/10.1016/S2468-1253(19)30146-3.
7. Exarchakou A, Donaldson LJ, Girardi F, Coleman MP. Colorectal cancer incidence among young adults in England: trends by anatomical sub-site and deprivation. PLoS One. 2019;14(12):e0225547. https://doi.org/10.1371/journal.pone.022554.
8. Araghi M, Soerjomataram I, Bardot A, Ferlay J, Cabasag CJ, Morrison DS, De P, et al. Changes in colorectal cancer incidence in seven high-income countries: a population-based study. Lancet Gastroenterol Hepatol. 2019;4:511–8.
9. American Cancer Society. Guidelines for colorectal cancer screening. [cited 2022 September 18]. https://www.cancer.org/cancer/colon-rectal-cancer/detection.
10. Screening for colorectal cancer US Preventive Services Task Force recommendation statement. JAMA. 2021;325(19):1965–1977.
11. Johnson DA. Landmark developments in gastroenterology. Medscape. 2015. [cited 2022 September 10]. http://www.medscape.com.
12. Muto T, Bussey HJR, Morson BC. The evolution of cancer of the colon and rectum. Cancer. 1975;36:2251–70. https://doi.org/10.1002/cncr.2820360944.
13. Kim DH, Pickhardt PJ, Taylor AJ. Characteristics of advanced adenomas detected at CT colonographic screening: implication for appropriate size thresholds for polypectomy versus surveillance. AJR. 2007;188(4):940–4.
14. Bortz JH. CT colonography: an approach for a successful examination. S Afr J Rad. 2014;18(1):607, 11 pages. https://doi.org/10.4102/sajr.v18i1.607SAJR2014.
15. Obaro AE, Burling D, Plumb AA. The role of imaging screening special feature: review article. Br J Radiol. 2018;91:20180307. [cited 2022 September 10]. https://doi.org/10.1259/bjr.20180307.
16. Fillon M. Proximal serrated polyps increase the future risk of colorectal cancer. CA Cancer J Clin. 2020;70(5):317–8. https://doi.org/10.3322/caac.21624.
17. Lynch HJ, de la Chapelle A. Genomic medicine—hereditary colorectal cancer. N Engl J Med. 2003;348(10):919–32.
18. Robbins DH, Itzkowitz SH. The molecular and genetic basis of colon cancer. Med Clin North Am. 2002;86(6):1467–95.
19. Winawer SJ, Zauber A, Diaz B. Temporal sequence of evolving colorectal cancer from the normal colon (abstr). Gastrointest Endosc. 1987;33:167.
20. Obuch JC, Pigott CM, Ahnen SJ. Sessile serrated polyps, detection, eradication, and prevention of the evil twin. Curr Treat Options Gastroenterol. 2015;13(1):156–70.
21. Pickhardt PJ, Arluk GM. Atlas of gastrointestinal imaging: radiologic-endoscopic correlation. Philadelphia: Saunders; 2007. p. 24.
22. O'Brian MJ. Hyperplastic and serrated polyps of the colorectum. Gastroenterol Clin North Am. 2007;36:947–68.
23. Lynch syndrome approved by the cancer.net. Editorial Board, 12/2014. [cited 2022 September 10]. http://www.cancer.net/cancer-types/lynch-syndrome.
24. Sali L, Falchini M, Taddei A, Mascalchi M. Role of preoperative CT colonography in patients with colorectal cancer. World J Gastroenterol. 2014;20(14):3795–803. https://doi.org/10.3748/wjg.v20.i14.3795.
25. Flor N, Ceretti AP, Luigiano C, Brambillasca P, Savoldi AP, Verrusio C, Ferrari D. Performance of CT colonography in diagnosis of synchronous colonic lesions in patients with occlusive colorectal cancer. AJR. 2020;214(2):348–54. https://doi.org/10.2214/AJR.19.21810.
26. Hong N, Park SH. CT colonography in the diagnosis and management of colorectal cancer: emphasis on pre- and post-surgical evaluation. World J Gastroenterol. 2014;20(8):2014–22. https://doi.org/10.3748/wjg.v20.i8.2014.
27. Laghi A, Neri E, Regge D. Editorial on the European Society of Gastrointestinal Endoscopy (ESGE) and European Society of Gastrointestinal and Abdominal Radiology (ESGAR) guideline on clinical indications for CT colonography in the colorectal cancer diagnosis. Radiol Med. 2015;120:1021–3. https://doi.org/10.1007/s11547-015-0537-x.
28. Maupoey Ibáñez J, Pàmies Guilabert J, Frasson M, Boscà Robledo A, Giner Segura F, García-Granero XE. Accuracy of CT colonography in the preoperative staging of colon cancer: a prospective study of 217 patients. Color Dis. 2019;21(10):1151–63. https://doi.org/10.1111/codi.14724.
29. Kijima S, Sasaki T, Nagata K, et al. Preoperative evaluation of colorectal cancer using CT colonography, MRI, and PET/CT. World J Gastroenterol. 2014;20(45):16964–75.
30. Cunliffe WJ, Hasieton PS, Tweedie DE, Schofield PF. Incidence of synchronous and metachronous colorectal carcinoma. Br J Surg. 1984;71(12):941–3.
31. Heriot AG, Hicks RJ, Drummond EG, Keck J, Mackay J, Chen F, Kalff V. Does positron emission tomography change management in primary rectal cancer? A prospective assessment. Dis Colon Rectum. 2004;47(4):451–8. https://doi.org/10.1007/s10350-003-0089-3.
32. Stintzing S. F1000Prime Rep. 2014;6:108. Published online 2014 Nov 4. [cited 2022 September 17]. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4229728/. https://doi.org/10.12703/P6-108.
33. SIGN (Scottish Intercollegiate Guidelines Network) 126. 2011. Diagnosis and management of colorectal cancer. A national clinical guideline. [cited 2022 September 17]. http://www.sign.ac.uk/pdf/sign126.pdf.
34. Colorectal cancer: treatment options approved by the cancer.net Editorial Board, 09/2014. [cited 2022 September 17]. http://www.cancer.net/cancer-types/colorectal-cancer/treatment-options.
35. Virarkar MK, Swarupa S, Vulasala R, Gupta AV, Gopireddy DR, Kumar S, Hernandez M, Lall C,

Bhosale P. Virtual non-contrast imaging in the abdomen and the pelvis: an overview. Semin Ultrasound CT MRI. 2022;43(4):293–310. https://doi.org/10.1053/j.sult.2022.03.004.
36. Ersahin D, Rasla J, Singh A. Dual energy CT applications in oncological imaging. Semin Ultrasound CT MR. 2022;43(4):344–51. https://doi.org/10.1053/j.sult.2022.04.004.
37. Sato K, Morohashi H, Tsushima F, Sakamoto Y, Miura T, Fujita H, Umemura K, Suzuki T, Tsuruta S, Kura R, Ono S, Aoki M, Hakamada K. Dual energy CT is useful for the prediction of mesenteric and lateral pelvic lymph node metastasis in rectal cancer. Mol Clin Oncol. 2019;10(6):625–30. https://doi.org/10.3892/mco.2019.1834.
38. Özdeniz İ, İdilman İS, Köklü S, Hamaloğlu E, Özmen M, Akata D, Karçaaltıncaba M. Dual-energy CT characteristics of colon and rectal cancer allows differentiation from stool by dual-source CT. Diagn Interv Radiol. 2017;23(4):251–6. https://doi.org/10.5152/dir.2017.16225.
39. Ricci ZJ, Kobi M, Flusberg M, Yee J. CT colonography in review with tips and tricks to improve performance. Semin Roentgenol. 2021;56(2):140–51. https://doi.org/10.1053/j.ro.2020.07.007.
40. Yang Z, Zhang X, Fang M, Li G, Duan X, Mao J, Shen J. Preoperative diagnosis of regional lymph node metastasis of colorectal cancer with quantitative parameters from dual-energy CT. AJR Am J Roentgenol. 2019;213(1):W17–25. https://doi.org/10.2214/AJR.18.20843.
41. Qiu L, Hu J, Weng Z, Liu S, Jiang G, Cai X. A prospective study of dual-energy computed tomography for differentiating metastatic and non-metastatic lymph nodes of colorectal cancer. Quant Imaging Med Surg. 2021;11(8):3448–59. https://doi.org/10.21037/qims-20-3.
42. Gong HX, Zhang KB, Wu LM, Baigorri BF, Yin Y, Geng XC, Xu JR, Zhu J. Dual energy spectral CT imaging for colorectal cancer grading: a preliminary study. PLoS One. 2016;11(2):e0147756. https://doi.org/10.1371/journal.pone.0147756.
43. Yu C, Helwig EJ. The role of AI technology in prediction, diagnosis and treatment of colorectal cancer. Artif Intell Rev. 2022;55(1):323–43. https://doi.org/10.1007/s10462-021-10034-y.
44. Rasouli P, Dooghaie Moghadam A, Eslami P, Aghajanpoor Pasha M, Asadzadeh Aghdaei H, Mehrvar A, Nezami-Asl A, Iravani S, Sadeghi A, Zali MR. The role of artificial intelligence in colon polyps detection. Gastroenterol Hepatol Bed Bench. 2020;13(3):191–9.
45. Grosu S, Wesp P, Graser A, Maurus S, Schulz C, et al. Machine learning–based differentiation of benign and premalignant colorectal polyps detected with CT colonography in an asymptomatic screening population: a proof-of-concept study. Radiology. 2021;299:326–35. https://doi.org/10.1148/radiol.2021202363.
46. Bedrikovetski S, Dudi-Venkata NN, Kroon HM, Seow W, Vather R, Carneiro G, Moore JW, Sammour T. Artificial intelligence for pre-operative lymph node staging in colorectal cancer: a systematic review and meta-analysis. BMC Cancer. 2021;21(1):1058. https://doi.org/10.1186/s12885-021-08773-w.
47. Liang F, Wang S, Zhang K, Liu TJ, Li JN. Development of artificial intelligence technology in diagnosis, treatment, and prognosis of colorectal cancer. World J Gastrointest Oncol. 2022;14(1):124–52. https://doi.org/10.4251/wjgo.v14.i1.124.
48. Kacew AJ, Strohbehn GW, Saulsberry L, Laiteerapong N, Cipriani NA, Kather JN, Pearson AT. Artificial intelligence can cut costs while maintaining accuracy in colorectal cancer genotyping. Front Oncol. 2021;11:630953. https://doi.org/10.3389/fonc.2021.630953.
49. Santoro M, Strolin S, Paolani G, Della Gala G, Bartoloni A, Giacometti C, Ammendolia I, Morganti AG, Strigari L. Recent applications of artificial intelligence in radiotherapy: where we are and beyond. Appl Sci. 2022;12(7):3223. https://doi.org/10.3390/app12073223.
50. Ethics and governance of artificial intelligence for health: WHO guidance, 2021.

Colonic Diverticular Disease

16

Joel H. Bortz

16.1 Introduction

Diverticular disease (DD) is the most common benign colonic abnormality in patients over the age of 50 years, who present for initial screening studies. The disease is endemic in Western populations; it is therefore considered to be a normal finding on CTC. It is a common gastrointestinal (GIT) disorder largely due to dietary factors. Hence, 50% of all screening adults will show moderate or severe DD, predominantly in the sigmoid colon, and to a lesser extent in the descending colon and right side of the colon [1]. The incidence of DD increases with age with equal prevalence in men and women [2]. Over the last few decades, the prevalence of DD has increased. Approximately 40% of adults below the age of 40 years have the disease. This rises to 50–70% in adults up to age of 70 years and reaches 85% in persons 80 years or older [1]. Asians are more prone to develop colonic DD on the right side of the colon [3].

The following abbreviations are used in the chapter.

- 2D: two-dimensional
- 3D: three-dimensional
- CO_2: carbon dioxide
- CRC: colorectal cancer
- DD: diverticular disease
- DDSS: diverticular disease severity score
- FDA: Food and Drug Administration of the US
- GIT: gastrointestinal tract
- LLD: left lateral decubitus
- OC: optical colonoscopy
- RLD: right lateral decubitus
- USA: United States of America

16.2 Acute Diverticulitis Is Contraindicated in a CTC Study

Acute diverticulitis is an absolute contraindication for performance of a CTC study [4] because it means that a perforation of a diverticulum has occurred. It may be extremely small. A perforation causes an inflammatory reaction in surrounding mesentery due to a leak of faecal material. If the perforation is larger, this means that greater amounts of faecal material may leak into the peritoneal cavity causing abscess formation. This is a serious situation which requires use of antibiotics. If there is a large volume of fluid in the abscess cavity, percutaneous drainage may be required. Abscess formation may result in loops of small and large bowel sticking together; this may eventually result in a fistula between them (colo-enteric) or a fistula between colon and colon (colo-colic) and also between colon and bladder (colo-vesical) as well as between uterus and colon (colo-uterine).

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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16.3 Pathogenesis and Cause of Colonic Diverticular Disease

What is pathogenesis? It is the biologic mechanisms that lead to a disease state. A diverticulum forms as a result of herniation of the mucus membrane lining through a defect in the muscular portion of the bowel wall. DD pathogenesis is thus acquired by herniation (out-pouching) of mucosa and submucosa through the muscularis propria in an area of weakness where the nutrient arteries extend through the submucosa [5]. Figure 16.1 shows outpouching of multiple diverticula.

The cause of colonic DD is not well understood. Several theories have been mooted [2, 6, 7]. Low fibre diets that are high in refined carbohydrates and low in dietary fibre result in less bulky stools that retain less water [5]. This may alter the GIT transit time and may increase intracolonic pressure. Other causes include disordered colonic mobility [2], high red meat and low fat consumption, and frequent use of anti-inflammatory drugs [7].

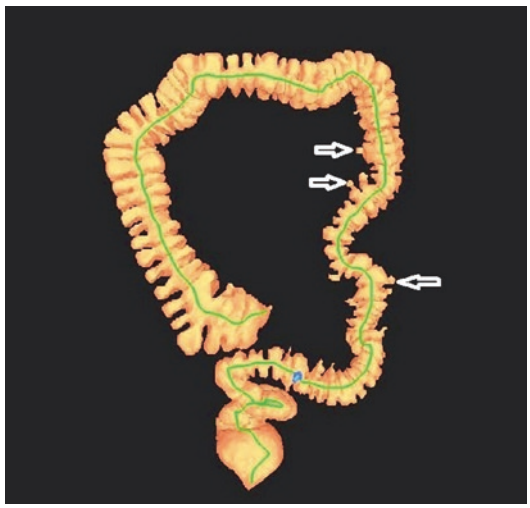

Fig. 16.1 Example of outpouching of diverticula (open white arrows) on supine colon-map view

16.4 Chronic Diverticular Disease Pathological Features

There are several features of the disease [6].

- Myochosis (muscle thickening) and elastin deposition
- Thickening of the circular muscle
- Shortening of the taeniae
- Decreased compliance
- Luminal narrowing.

16.5 Severity Score of Diverticular Disease

Literature does include a GDD severity score (DDSS) from 1 to 4 for CTC studies [8]. The score is based on the maximum wall thickness and minimum lumen diameter. For example, DDSS 1 = maximum wall thickness of <3 mm and minimum lumen diameter of ≥15 mm and DDSS 4 = ≥8 mm and <5 mm, respectively [8]. However, to determine a DDSS requires intravenous administration of 100 ml of non-ionic contrast media followed by a 50 ml saline flush immediately after the standard CTC study in order to obtain images during the portal venous stage [8].

16.6 CTC in Patients with Diverticular Disease

Patients with DD are usually asymptomatic when presenting for CTC screening for detection of colorectal cancer (CRC). Moderate or advanced severity DD is diagnosed in at least 50% of patients who are 50 years or older [9]. The sigmoid colon, followed by the descending colon, and then the ascending colon, are mainly the areas of involvement. According to Pickhardt and Kim [10] in view of its high prevalence, it is not surprising that the disease represents the leading cause of non-diagnostic segmental evaluation at CTC. Diverticula are

not problematic in terms of a reader being able to diagnose the disease on CTC studies (see Fig. 16.2a (i) and (ii)). However, inadequate lumen distension, as discussed in Sect. 16.9, and thickened folds may cause possible pitfalls, as discussed in Sect. 12.2.3. Diverticula may become filled with inspissated stool and/or barium. When this happens, the diverticula may then bulge into the colonic lumen causing a polypoidal defect on 3D endoluminal views. Figure 16.2b (i)–d (ii) are examples of impacted diverticula.

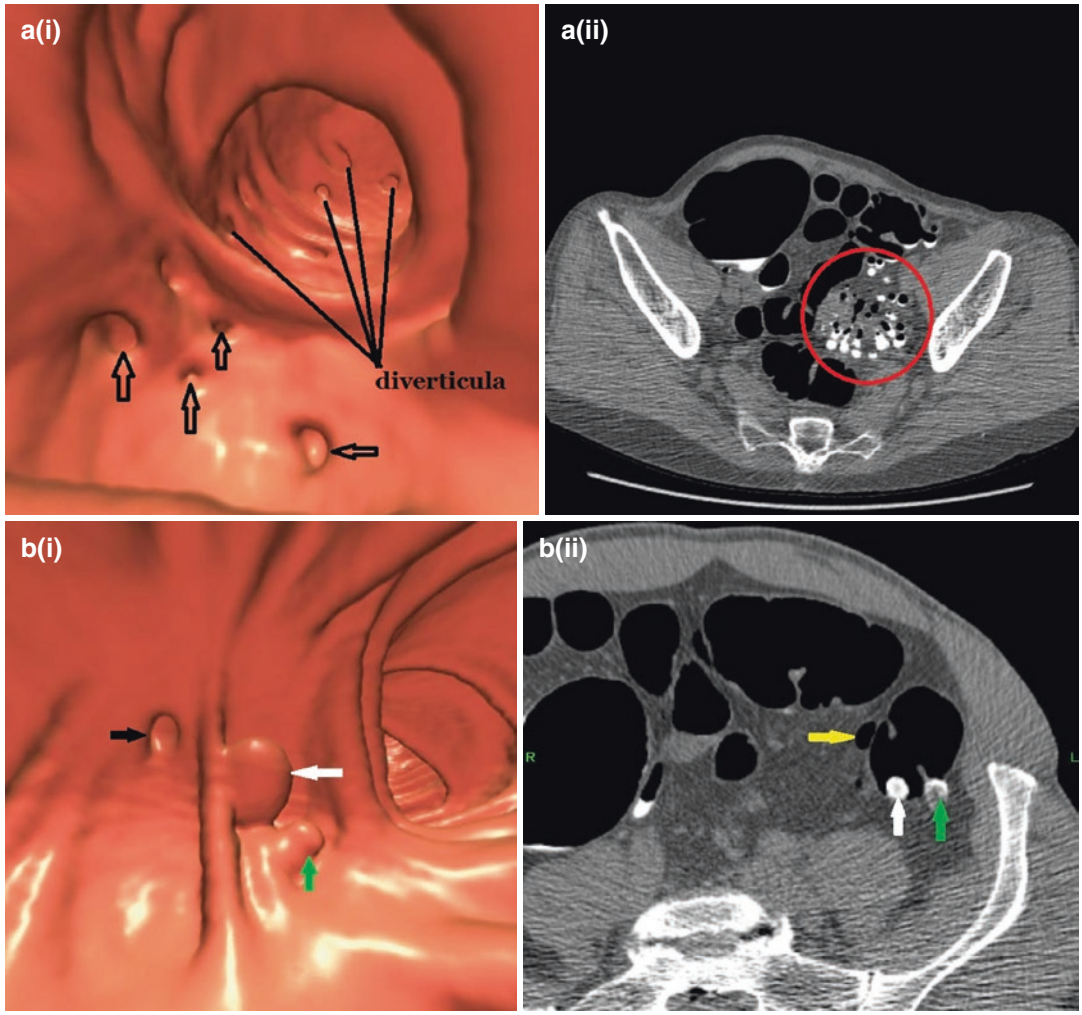

Fig. 16.2 (**a**) (**i**) 3D view of multiple diverticula filled with barium and air (open black arrows). (**ii**) 2D axial view of multiple diverticula (red circle). (**b**) (**i**) 3D view showing diverticulum (black arrow) and impacted diverticulum (green arrow). Polypoidal defect due to stool (white arrow). (**ii**) 2D axial view shows stool (white arrow) and impacted diverticulum (green arrow). Yellow arrow shows diverticulum.

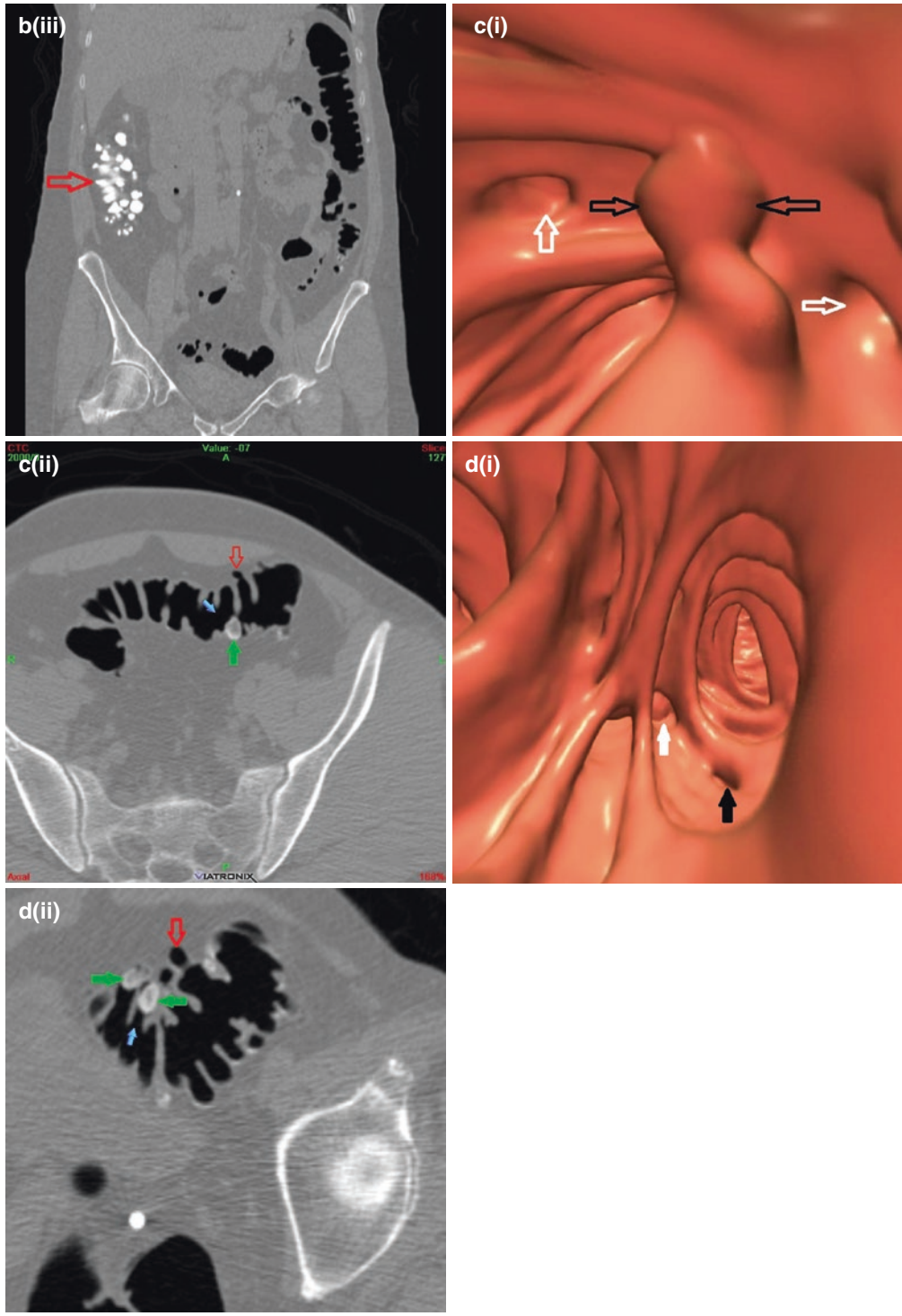

Fig. 16.2 (**iii**) 2D coronal view shows multiple diverticula filled with barium (open red arrow). (**c**) (**i**) 3D view of polypoidal lesion due to polyp (open black arrows) and uncomplicated diverticula (open white arrows). (**ii**) 2 D axial showing impacted diverticulum (green arrow) and an air-filled diverticulum (red arrow). (**d**) (**i**) 3D endoluminal view of impacted diverticulum (white arrow) and diverticulum (black arrow). (**ii**) 2D axial shows impacted diverticula (green arrows) and air-filled diverticulum (red arrow)

16.7 Visualisation of Diverticula on 2D and 3D CTC Images

Most sigmoid diverticula are associated with thickening of the circular muscle layer and shortened taeniae (myochosis). This may result in luminal narrowing and an 'accordion-like appearance' [11]. The thickening of the folds as well as luminal narrowing, due to muscular hypertrophy from DD, can cause a confusing picture on both 2D (two-dimensional) as well as 3D (three-dimensional) visualisation. Thick folds may be interpreted as polyps or even possible masses on both 2D and 3D endoluminal views [12]. If in doubt, an additional view in the right lateral decubitus (RLD) position, may resolve the image interpretation issue. The presence of mucosal prolapse may also prevent a correct diagnosis being made. Such a prolapse results in a thickened redundant fold which may be impossible to distinguish from a true polyp.

Diverticula are easily diagnosed in both 2D and 3D endoluminal views. On 3D views, the orifices are surrounded by a recognisable black ring (Fig. 16.3a (i)). On 2D views, the diverticulum extends beyond the colon wall and is usually

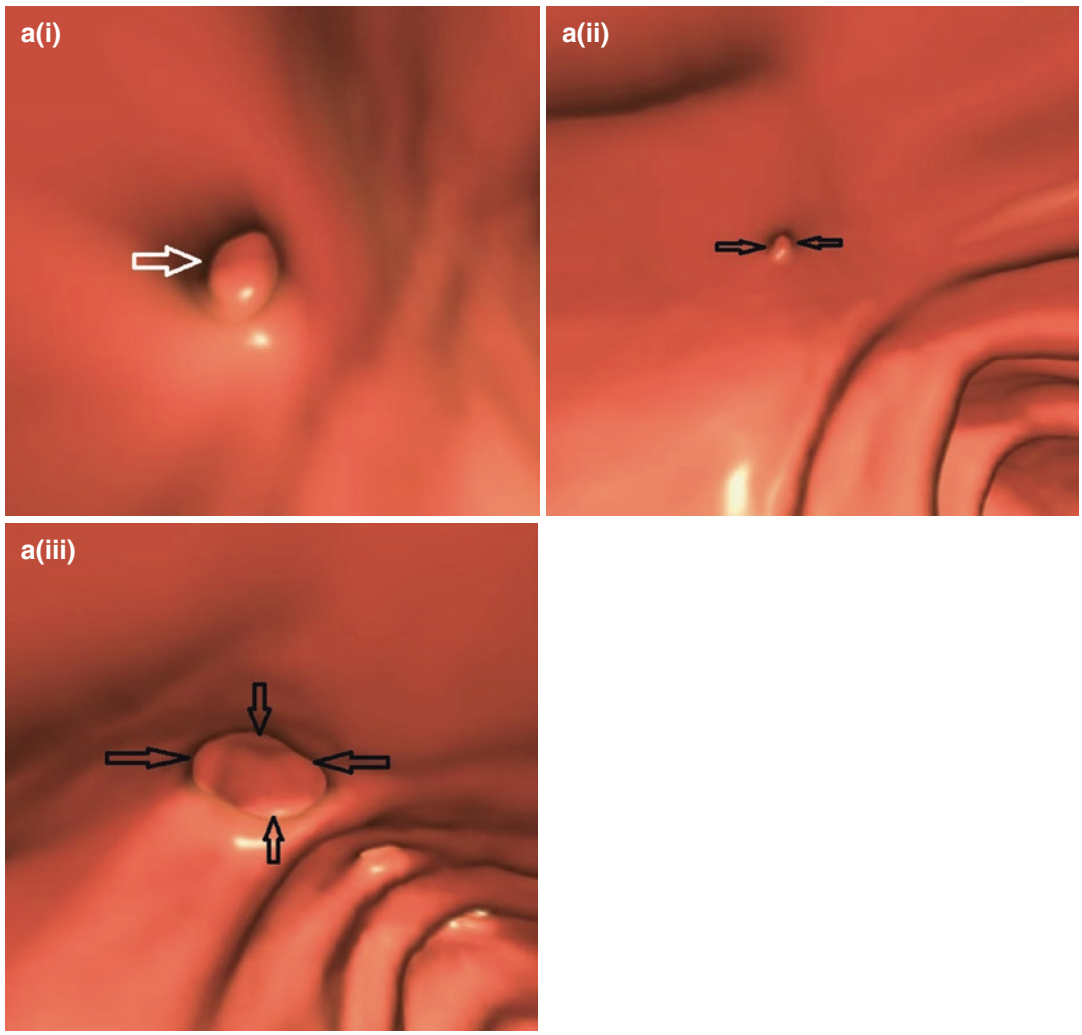

Fig. 16.3 (**a**) (**i**) 3D view shows orifice of diverticulum as a black ring (open white arrow). (**ii**) 3D view of a narrow neck diverticulum (open black arrows). (**iii**) 3D view of a wide neck diverticulum (open black arrows)

filled with air. Size of diverticula may vary; usually between 5 and 10 mm. The ostium (opening) of a diverticulum may vary in size, from a narrow neck to a wide orifice. See Fig. 16.3a (ii) and (iii).

A diverticulum may become filled with stool or barium; it may appear as a 'polyp' on a 3D endoluminal view; on a 2D view it is easily recognised for what it is. An impacted diverticulum is one that is filled with stool or barium.

16.8 Role of Antispasmodics

CTC procedures are not complicated in countries where Buscopan (hyoscine butylbromide) is available [13] (see Chap. 8), but it does have side effects and can cause hypotension in patients. It can cause urinary retention in elderly males with enlarged prostates. It is contraindicated in patients with glaucoma. Furthermore, it may induce glaucoma in patients who are unaware that they may have this condition as the glaucoma could be still in its early stages with no clinical signs.

Buscopan does not have FDA (Food and Drug Administration of the USA) approval in the United States of America (USA) [13]; this prolongs the duration of the procedure and makes it more difficult to perform. If spasm prevents the colon from being adequately distended during insufflation, this could result in additional views, such as RLD and LLD (left lateral decubitus) projections, being performed to distend the sigmoid. Glucagon is available in the USA, but it has been found not to be a suitable substitute for Buscopan. It is known to cause nausea and vomiting and does not allow good bowel distention.

16.9 Inadequate Luminal Distension

A fairly recent publication by Nagata et al. [14] compared the effects of automated carbon dioxide ($CO_{2)}$ insufflation, with and without the administration of intravenous (IV) Buscopan, on colonic distension at CTC. Their findings were interesting because colonic distension was statistically significantly improved by automated CO_2 insufflation on its own, but not by administration of Buscopan.

In a well-performed study where CO_2 is used for insufflation, it is very uncommon to encounter poor distension in a patient who is able to retain the gas, and who does not suffer from chronic DD. If adequate distension is not achieved with use of standard two view study, then additional views may be required: RLD and possibly LLD. On occasion, distension may not be adequate even with the use of all four views; the author then performs an additional supine scan approximately 10 min after commencement of the study. This delayed scan is often successful as the bowel has had time to relax and satisfactory distension attained. If a stricture is the underlying cause of poor bowel distension, it may then be necessary to refer the patient for endoscopy. Figure 16.4 (i) shows poor bowel distension. Figure 16.4 (ii) shows a thick colon wall and a bowel stricture.

16.9.1 Possible Causes of Inadequate or No Luminal Distension in the Presence of Pain

As discussed in Chap. 10, pain is not a feature of a CTC examination. Some patients do occasionally experience discomfort, but not pain after insufflation of 2 litres (L) of CO_2 [13]. It is important to therefore re-emphasise what must be done if a patient complains of severe pain at the commencement of a CTC study. The gas must be immediately switched off. The inguinal regions are then inspected and palpated. The rationale being that herniation of the sigmoid colon into the inguinal canal may be present. A scout view and full supine study must then be performed. If bowel is seen distended in the inguinal region, this indicates the presence of a hernia as shown in Fig. 16.5 (i) and (ii). The examination must be abandoned. The referring clinician must immediately be informed of this CT finding [13].

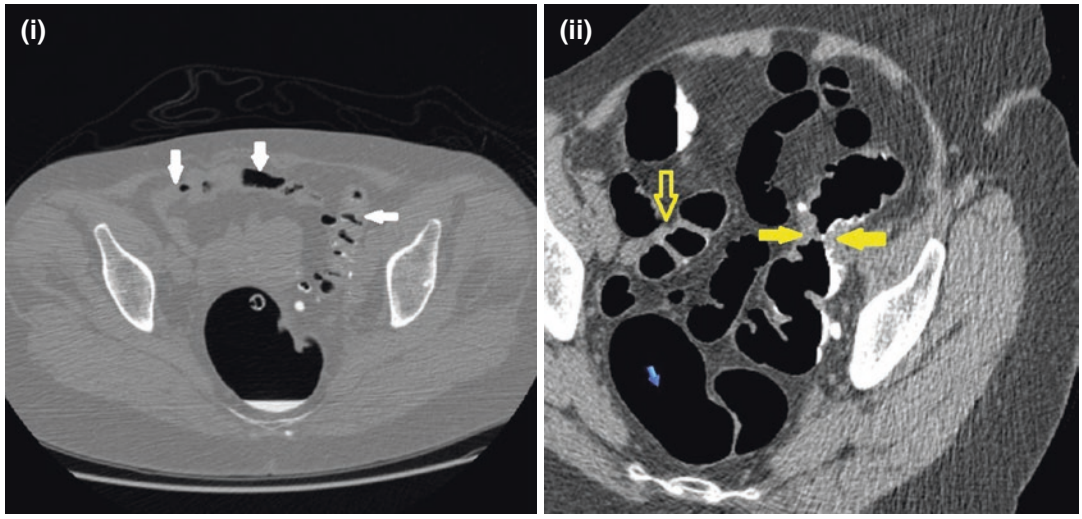

Fig. 16.4 (**i**) 2D axial view shows poor distension of sigmoid colon (white arrows). (**ii**) 2D left lateral decubitus view shows stricture (closed yellow arrows) and thick colon wall (open yellow arrow)

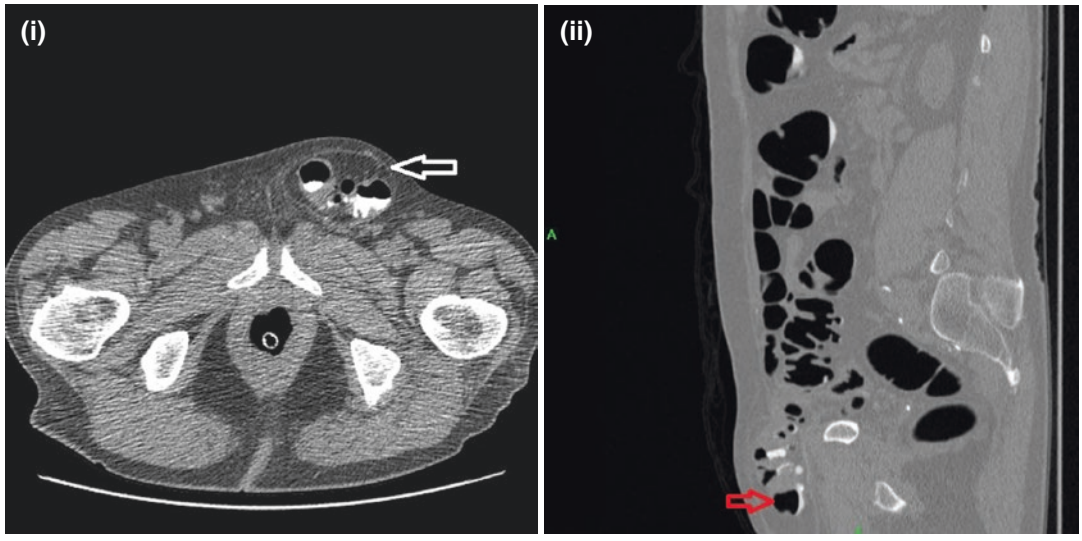

Fig. 16.5 (**i**) 2D axial view of left inguinal hernia containing sigmoid colon (open white arrow). (**ii**) 2D sagittal view shows left inguinal hernia of sigmoid colon (red arrow)

As discussed in Chap. 10, it is important before commencing insufflation in female patients to always check the position of the rectal catheter. Non-distension in female patients could be that the rectal catheter may have been inadvertently inserted into the vagina. Such a scenario could have potential medico-legal ramifications.

16.10 Complications of Diverticular Disease

The most usual complication of DD is diverticulitis. It affects between 10 and 25% of patients [15]. How does this inflammation begin? It is similar to that of appendiceal inflammation. A diverticulum becomes obstructed in its neck by

an inspissated stool [16].The faecalith (the hard mass inspissated stool) abrades the mucosa of the sac. This then results in the following.

1. Inflammation of the mucosa
2. Increase in bacterial flora
3. Localised ischaemia

This may lead to a perforation, which may be a 'micro-perforation' and may be contained by the pericolic fat and mesentery; this may cause a small pericolic abscess. If the perforation is large in size, it may cause an extensive abscess, which could continue around the bowel wall and form a large inflammatory mass (phlegmon). The inflammatory mass could also extend to other organs, and ultimately result in fistulous communications. For example, colo-colic fistula (communication between two parts of bowel); colo-enteral fistula (communication between colon and small bowel), and colo-vesical fistula or colo-uterine fistula if there is communication with the bladder or uterus. Figure 16.6 (i) and (ii) are of a colo-vesical fistula. If the perforation is extremely large, it could spread into the peritoneum causing frank peritonitis, but this would be a rare occurrence [6].

16.10.1 Clinical Features of Diverticulitis

Diverticulitis most commonly occurs in the sigmoid colon. People who develop diverticulitis usually present with pain in the left lower quadrant. The sigmoid colon could be redundant, thus the location of pain may be supra-pubic or even right sided. Lower right-sided pain, particularly in the Asian population, may be due to right-sided diverticula [17]. Pain may be constant or intermittent; it is usually a feature of diverticulitis. Fever (pyrexia) is a constant feature. Anorexia, nausea, and vomiting may also occur. Rectal examination may reveal a tender mass if a pelvic abscess is present. Blood may be present in the stool. With right-sided symptoms underlying appendicitis needs to be excluded, and on the left side underlying carcinoma must be excluded.

16.10.2 Chronic Diverticulitis

At CTC, the features favouring chronic diverticulitis include: a long segment (≥10 cm) of involvement; a thick fascia sign (75%) without evidence of lymphadenopathy; bowel wall which is usu-

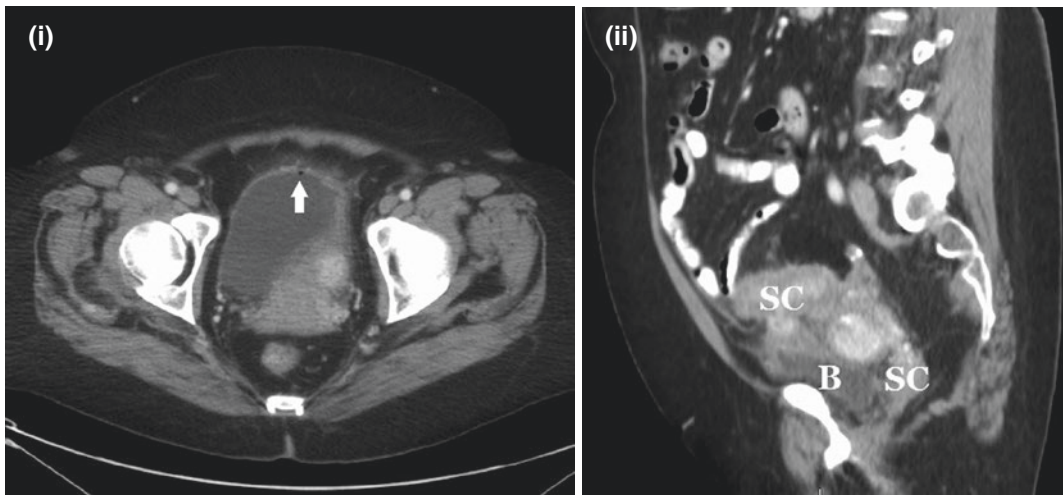

Fig. 16.6 (**i**) 2D soft tissue axial view shows small amount of air in bladder (white arrow) due to colo-vesical fistula (Image courtesy of Professor D Kim, University of Wisconsin). (**ii**) 2D sagittal view shows contrast in sigmoid colon (SC) in close apposition to bladder (B). (Image courtesy of Professor D Kim, University of Wisconsin)

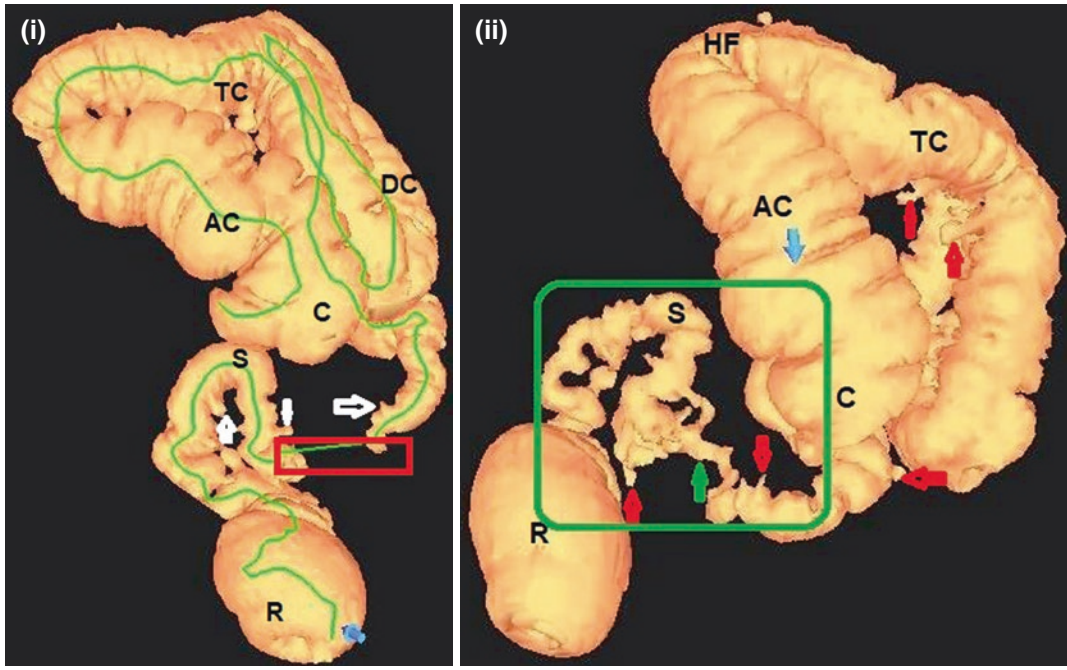

Fig. 16.7 (**i**) Supine right side raised colon-map showing non-filling of the proximal sigmoid (red rectangle). White arrows = diverticula in sigmoid. *R* rectum, *S* sigmoid colon, *C* caecum, *AC* ascending colon, *TC* transverse colon, *DC* descending colon. (**ii**) Colon-map of left lateral decubitus with the patient slightly oblique demonstrates the entire sigmoid area (green square). *S* sigmoid colon. Narrowed region of sigmoid (green arrow). Red arrows = diverticula in transverse colon (TC) and in the sigmoid. *C* caecum, *AC* ascending colon, *HF* hepatic flexure

ally mildly thickened; tapered margins; distorted mucosal folds that are preserved; pericolonic infiltration (75% of cases); diverticula in the affected segment or adjacent to it; and abscesses or fistulae [8]. Figure 16.7 (i) and (ii) are colon-maps showing a narrowed segment of sigmoid colon.

16.11 Diagnostic Modalities for Acute Diverticulitis

The choice of diagnostic modalities changed significantly over the last 25 years [6]. There is only very limited value to plain-film chest and abdomen radiographs. Small amounts of free air will not be detected on an abdominal series. If there is enough free air it may be visualised beneath the diaphragm on an erect chest radiograph [6]. Literature includes the use of ultrasound and CT for the diagnosis of acute diverticulitis [4]. The imaging modality of choice is a CT scan of the abdomen with or without the use of an intravenous contrast medium, as well as oral and rectal contrast media [6]. Overall CT interpretation has a sensitivity of 99%; a specificity of 99%; a negative predictive value (NPN) of 99%; and an overall accuracy of 99% [18].

Diagnosis is made by the following being visualised on the CT scans.

- Pericolic infiltration of fatty tissue
- Thickening of the colonic wall >4 mm
- Possible abscess formation
- Fat stranding
- Thick fascia sign
- Free air
- Air in the peritoneal cavity outside the bowel
- Intramural sinus tract
- Free fluid

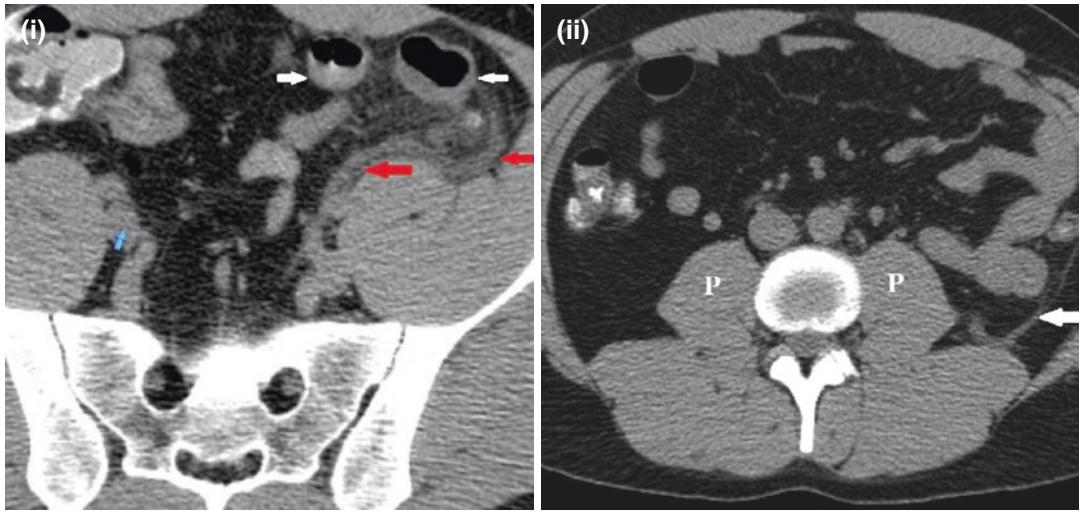

Fig. 16.8 (**i**) 2D axial view showing thick wall (white arrows) and thick fascia line (red arrows). (**ii**) 2D axial view showing thick fascia line (white arrow). Psoas muscle (P)

Figure 16.8 (i) and (ii) are CT images of acute diverticulitis showing thick fascia lines and thickening of the bowel wall.

16.11.1 Contrast Enemas

Barium enema was once the diagnostic gold standard in the investigation of suspected diverticulitis [6]. However, contrast-enhanced CT scanning is now the gold standard, with both CTC and optical colonoscopy (OC) positively contraindicated. Diverticulitis is primarily an extraluminal process. Colonoscopy is contraindicated while the infection is present due to risk of perforation. This risk also applies to insufflation during a barium enema. Furthermore, the use of barium sulphate is contraindicated; water-soluble contrast should be used if an enema is undertaken. The following are positive findings of diverticulitis.

- Extravasated contrast media outlining an abscess cavity.
- Fistulas: Although barium enema has been phased out as an imaging modality, water -soluble contrast studies may be useful in defining fistulae and intramural sinus tracts [19].

16.11.2 Imaging and Treatment Options for Complicated Diverticulitis

Abscess occurs with perforation of a diverticulum. It may remain localised or it can spread further to form a large local abscess or distant abscesses. The clinical symptoms are pyrexia and a tender palpable mass. CT is the modality of choice; it can be used to monitor the course of an abscess. Most abscesses resolve with the use of antibiotics, and a liquid diet, to give the bowel a rest. Percutaneous drainage is preferred to surgery if further treatment is required. There are three complications: fistulas, haemorrhage, and obstruction.

- Fistulas can arise if an abscess or phlegmon extends or ruptures into an adjacent organ. Males are affected two times more commonly than females. Colo-colic and colo-vaginal fistulas are most common.
- Haemorrhage can be due to a variety of causes of lower GIT bleeding; colitis or neoplasm, for example. DD is responsible for 40% of lower GIT bleeding [20].
- Obstruction can occur. Partial obstruction is not uncommon because of luminal narrow-

ing caused by pericolic inflammation or compression of the bowel lumen by abscess formation. Small bowel obstruction or ileus may occur if a loop of small intestine becomes incorporated into the inflammatory mass.

In addition recurrent attacks of diverticulitis, which can occur in up to 30% of cases, can result in progressive fibrosis and stricturing of the bowel wall. Surgery will eventually be required if this occurs.

16.12 Differentiation of Chronic Diverticular Disease from an Underlying Tumour

Chronic DD may cause a diagnostic dilemma in distinguishing between an underlying carcinoma versus a chronic DD mass. What are the distinguishing features at CTC between chronic DD and tumour? Literature includes criteria to enable a CTC reader to differentiate between chronic DD and an underlying carcinoma [21, 22]. A summary of the main distinguishing features are presented in Table 16.1. However, we must bear in mind that problem cases will still be present at CTC, and OC with biopsy then becomes mandatory.

There are four important features.

- A thick fascia sign is a good discriminator as this is evident in 77% of patients with chronic DD, compared with 10% of patients with tumours.
- Larger lymph nodes favour tumours: 7–10 mm nodes are found in 60% of patients, whereas 2–10 mm nodes are found in 38% of patients with chronic DD.
- Bowel wall thickening is more pronounced in patients with tumours >20 mm;
- Tapered margins are found in 67% of chronic DD and none in tumour disease.

The most important morphological sign to distinguish the two diseases is the presence or absence of diverticula within the affected segment; there is 93% accuracy for diagnosis of cancer in the absence of diverticula within an affected segment. The features of an adenocarcinoma are depicted in Fig. 16.9 (i) and (ii). There are no malignant features in Fig. 16.9 (iii) and (iv).

Table 16.1 Differential diagnosis: chronic diverticulitis vs adenocarcinoma

Chronic diverticulitis	Adenocarcinoma
Presence of diverticula Tapered margins (67%) of patients	Absence of diverticula Shoulder phenomenon *These two signs have diagnostic accuracy of 93% for cancer
Long segment of disease usually ≥10 mm 100% specificity	Short segment usually <3.5 cm
Wall thickening (mild)	Wall thickening ++≥20 mm (found in 30% of cases)
Pericolic infiltration: 85% of cases	Pericolic infiltration ± 60% of cases
Thick fascia sign (77%)	Thick fascia sign (10%)
Preserved fold (76% of cases)	Distorted and destroyed folds
Curvature of bowel preserved	Straightened growth pattern due to scirrhous nature of tumour
Lymph nodes smaller 2–10 mm in 40% of cases	Larger lymph nodes found in 60% of cases

Adapted from [21, 22]

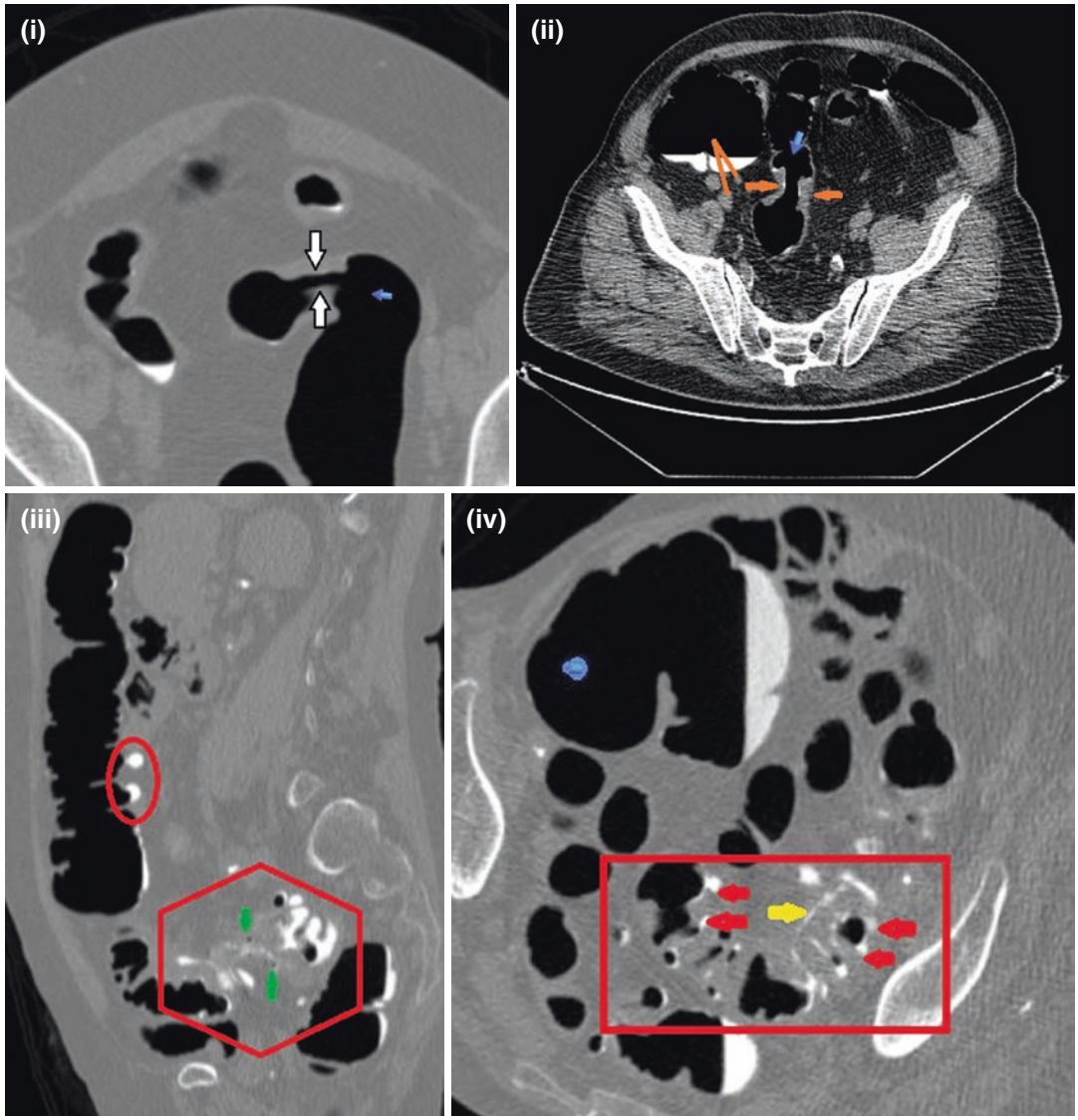

Fig. 16.9 (**i**) 2D axial view shows features of adenocarcinoma. Diverticula not present. Lesion with shoulder phenomenon involves a short segment of bowel (white arrows). (**ii**) 2D axial shows small nodes (orange lines) and a lesion with shoulder phenomenon in the sigmoid colon (orange arrows). (**iii**) 2D supine sagittal view showing diverticula in the sigmoid with distortion of the folds (red hexagon) and small air-filled diverticula (green arrows). Red circle = barium filled diverticula. (**iv**) 2D left lateral decubitus view showing sigmoid colon to the best effect (red square). Note thickening of colon with multiple diverticula throughout the sigmoid colon (red arrows). Yellow arrow = presence of an intramural sinus tract which indicates a linear collection of fluid within the thickened wall

Key Messages

Diverticular disease has several potential complications.

- Abscess formation.
- Presence of diverticulitis.
- Formation of a cancer within a segment of chronic diverticular disease.
- Fistula formation between colon and colon; colon and bladder; colon and vagina; colon and uterus; and skin and colon.
- Bleeding.

- Stricture formation: May be partial or severe with repeated attacks of diverticulitis.

16.13 Summary

Diverticular disease might be visualised on screening CTC examinations. 3D and 2D views demonstrate the extent and site of the diverticular in the colon. CTC is contraindicated in acute diverticulitis. CT is useful for examination of the abdomen and to monitor the course of an abscess.

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References

1. Comparato G, Pilotto A, Franzè A, Franceschi M, Di Mario F. Diverticular disease in the elderly. Dig Dis. 2007;25(2):151–9.
2. Stollman NH, Raskin JB. Diverticular disease of the colon. J Clin Gastroenterol. 1999;29:241–52.
3. Jun S, Stollman N. Epidemiology of diverticular disease. Best Pract Res Clin Gastroenterol. 2002;16:529–42.
4. Flor N, Maconi G, Cornalba G, Pickhardt PJ. The current role of radiologic and endoscopic imaging in the diagnosis of colonic diverticular disease. AJR. 2015;31:95–105.
5. Morson BC. Pathology of diverticular disease of the colon. Clin Gastroenterol. 1975;4:37–52.
6. Stollman N, Raskin JB. Diverticular disease of the colon. Lancet. 2004;363:631–9.
7. Deckmann RC, Cheskin LJ. Diverticular disease in the elderly. J Am Geriatr Soc. 1993;41(9):986–93. https://doi.org/10.1111/j.1532-5415.1993.tb06766.x.
8. Flor N, Rigamonti P, Ceretti AP, et al. Diverticular disease severity score based on CT colonography. Eur Radiol. 2013;23:2723–9. https://doi.org/10.1007/s00330-013-2882-2.
9. Sandford MF, Pickhardt PJ. Diagnostic performance of primary 3-D computed tomography colonography in the setting of colonic diverticular disease. Clin Gastroenterol Hepatol. 2006;4(8):1031–47.
10. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009. p. 272.
11. Yee J. Virtual colonoscopy. Philadelphia: Lippincott, Williams & Wilkins; 2008. p. 138.
12. Macari M, Bini EJ, Jacobs SL, Lange N, Lui YW. Filling defects at CT colonography: pseudo- and diminutive lesions (the good), polyps (the bad), flat lesions, masses, and carcinomas (the ugly). Radiographics. 2003;23(5):1073–91. https://doi.org/10.1148/rg.235035701.
13. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Rad. 2014;18(1):607, 11 pages. https://doi.org/10.4102/sajr.v18i1.607SAJR2014.
14. Nagata K, Fujiwara M, Shimamoto T, Iida N, Mogi T, Mitsushima T. Colonic distention at CT colonography: randomised evaluation of both iv hyoscine butylbromide and automated carbon dioxide insufflation. AJR. 2015;204(1):76–82. https://doi.org/10.2214/AJR.14.12772.
15. Parks TG. Natural history of diverticular disease of the colon. Clin Gastroenterol. 1975;4:53–69.
16. Berman LG, Burouk D, Heitzman ER, et al. A critical reappraisal of sigmoid diverticular. Surg Gynecol Obstet. 1965;127:481–91.
17. Markham NI, Li AK. Diverticulitis of the right colon—experience from Hong Kong. Gut. 1992;33(4):547–9.
18. Kircher MF, Rhea JT, Kihiczak D, et al. Individual signs of diverticulitis on thin section helical CT with colonic contrast material: experience with 312 cases. AJR. 2002;178:1313.
19. Doringer E. Computerised tomography of colonic diverticulitis. Crit Rev Diagn Imaging. 1992;33:421–33.
20. Peura DA, Lanza FL, Gostout CJ, Foutch PG. The American College of Gastroenterology bleeding registry: preliminary findings. Am J Gastroenterol. 1997;92:924–8.
21. Lips L, Cremers PTJ, Pickhardt PJ, et al. Sigmoid cancer versus chronic diverticular disease: differentiating features at CT colonography. Radiology. 2015;275(1):127–35. https://doi.org/10.1148/radiol.14132829.
22. Gryspeerdt S, Lefere P. Chronic diverticulitis vs. colorectal cancer findings on CT colonography. Abdom Imaging. 2012;37:1101–9. https://doi.org/10.1007/s00261-012-9858-6.

Lipomas of the Colon

17

Joel H. Bortz

17.1 Introduction

Lipoma is the most common of the non-epithelial tumours of the gastrointestinal tract (GIT). On the other hand, an adenomatous polyp, which may be sessile, pedunculated, or flat, is the most common benign epithelial tumour as discussed in Chap. 14. The highest incidence of lipoma is in the colon. According to Zhang et al. [1], despite the technological advances in imaging, colon lipoma is still underemphasised and misdiagnosed. Colon lipoma is usually clinically silent or mildly symptomatic [1, 2]. Complications of large lipoma include haemorrhage, obstruction, intussusception, or prolapse [3].

Barium examinations played a major role in the investigation of suspected lipomas in the GIT before the advent of CT studies [4]. The upper GIT and small bowel were visualised by barium meal studies; barium enema studies visualised the lower GIT. Endoscopy gradually replaced barium enema as the method of choice following the advent of the colonoscope in the mid-1970s [5, 6]. In the early 1980s, there was a shift from endoscopy to CT for visualisation of lipoma. Compared with endoscopy, CT does not require anaesthesia; it is non-invasive; there is no risk of perforation or bleeding [4]. On CT images, the appearance of a lipoma is uniform, with a fat equivalent density range between −80 and −120 Hounsfield units (HU) [7]. CT is also of value when a lipoma grows to >35 mm (3.5 cm) and starts to cause symptoms, such as change in bowel habits, abdominal pain, diarrhoea, rectal bleeding, and melaena [3]. The greatest value of CT is to visualise intussusception or perforation. The latter is a complication of lipoma removal during endoscopy and small amounts of intraperitoneal air can be readily observed on CT scans [8]. Three-dimensional (3D) and two-dimensional (2D) views are used to evaluate a lipoma during a CTC study. Treatment options are endoscopic removal of lesions <30 mm, or surgical resection for benign larger tumours or those that result in intussusception [9].

The following abbreviations are used in this chapter.

- 2D: two-dimensional
- 3D: three-dimensional
- GIT: gastrointestinal tract
- HU: Hounsfield unit
- ICV: ileocaecal valve
- TD: translucent display

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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17.2 Lipoma Symptoms and Sites in the Colon

The majority of lipomas arise from submucosa. These lesions can protrude into the lumen [9]. Symptoms of colonic lipomas are rare despite them being the most common non-epithelial lesion in the GIT. Although lipomas are found in the GIT, their highest incidence is in the colon [8]. Lipomas usually remain clinically silent [7]. When there are symptoms, they are not specific to a lipoma. A lipoma may cause abdominal pain, increasing constipation, and bleeding [3]. When a lipoma is >30–35 mm, the symptoms become more prominent; the patient may present with massive haemorrhage, obstruction, intussusception, or prolapse [3]. Bleeding may be the result of ulceration of the overlying mucosa; colicky abdominal pain may be due to intermittent intussusception [10].

17.3 Gender Prevalence and Incidence

Lipomas are more common in females compared to males [11]. Lipomas occur particularly in the sixth decade (50–60 years of age) [12]. There are no associated epidemiological factors for lipomas in the colon nor are there specific predisposing factors According to Vagholkar and Bendre [13], lipoma incidence has been reported between 0.2 and 4.4%.

17.4 Anatomical Sites and Morphology of Lipomas

Table 17.1 presents the morphology and location of colon lipomas. As evident in Table 17.1, most lipomas occur in the ascending colon. In 90% of cases, lipomas arise from the submucosal layer [1]; the remainder arise from the intermuscular layer and subserosal layer [12]. Lipomas may be sessile or pedunculated [11] as shown in Table 17.1 A pedunculated lipoma usually occurs when it increases in size. Its weight then causes a pedunculated appearance. Lipomas are almost always asymptomatic until their size becomes approximately 35 mm (3.5 cm) [14]. Clinical symptoms are directly related to size. Lipomatosis of the ileocaecal valve (ICV) may be present. This is easily diagnosed on CTC using translucent display (TD), which shows uniform green colour indicating fat. If a lipoma is present on the ICV, it is usually visualised as a separate 'lump' and not part of a uniform fatty infiltration of the valve. Figure 17.1a (i–vi) shows 2D and 3D views of a lipoma on a haustral fold of the ascending colon. Figure 17.1b (i, ii) shows CTC views of a lipoma on the ICV.

Table 17.1 Morphology and location of $n = 59$ lipomas[a]

Morphology	**Number**	**Percent (%)**
Sessile	34	58
Pedunculated	25	42
Total	59	100
Location	**Number**	**Percent (%)**
Ileocaecal	7	12
Caecum	7	12
Ascending colon	23	39
Transverse colon	11	19
Descending colon	6	10
Sigmoid colon	4	7
Rectum	1	1
Total	59	100

[a] Adapted from Roknsharifi et al. [11]

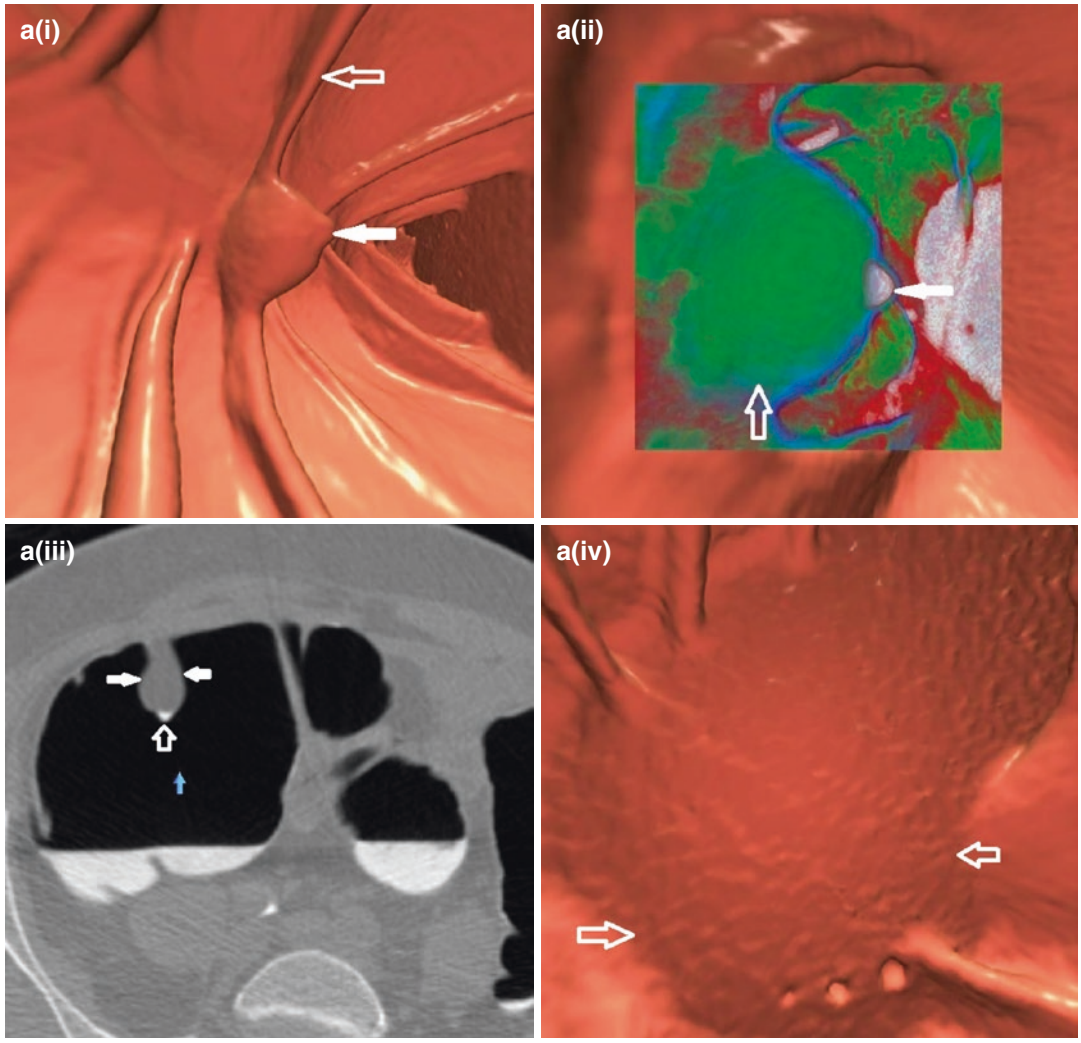

Fig. 17.1 (**a**) (**i**) 3D endoluminal view showing polypoidal lesion (closed white arrow) arising from haustral fold (open white arrow). (**ii**) 3D translucent display of lipoma. Green = fat (open white arrow) and barium on tip (closed white arrow). (**iii**) Axial 2D soft tissue window view showing tip of barium (open white arrow) on lipoma (closed white arrow). (**iv**) 3D prone image shows barium covering lipoma (open white arrows).

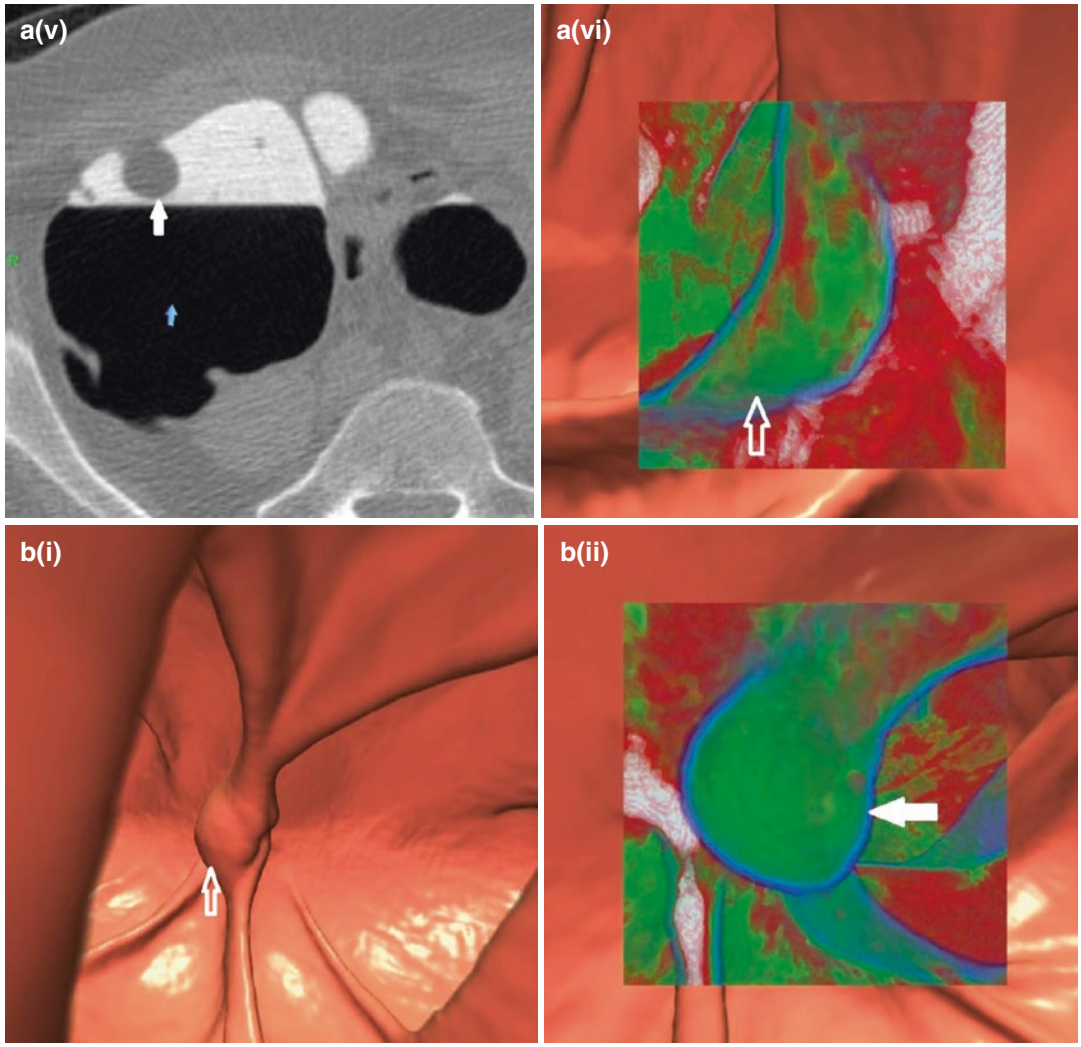

Fig. 17.1 (**v**) Prone 2D axial soft tissue window view showing filling defect lipoma (closed white arrow) in barium pool. (**vi**) Translucent display showing diffuse infiltration of ICV (open white arrow) indicating caecal lipomatosis with minimal high tissue intensity (red). (**b**) (**i**) 3D view shows a lipoma on ICV (open white arrow). (**ii**) Translucent display shows dense green colouration (closed white arrow), which is in keeping with fat (lipoma)

17.5 Lipoma 'Signs' at Optical Colonoscopy

During optical colonoscopy, the following signs of lipoma may be present.

1. The 'tenting' sign means gripping the mucosa with forceps and 'pulling' or 'tenting' it away from the underlying mass [4, 11].
2. The 'cushion' or 'pillow' sign reflects the spongy nature of the mass when indented with a closed biopsy forceps. As the forceps is withdrawn, the tumour will spring back to resume its previous original shape [15].
3. 'Naked fat sign' means the adipose tissue may protrude through the biopsy site which reveals the fatty characteristic of the tumour [16].

Key Messages

There are several points to bear in mind when evaluating CTC studies.

- Lipomas are more common in women in their sixth decade.
- The right colon is the most common site.
- The incidence of lipoma has been reported between 0.2 and 4.4%.
- There is usually a solitary colonic lipoma.
- A lipoma may be sessile or pedunculated.
- Lipoma size may vary: from <20 to >40 mm.
- Symptoms are usually related to the size of the lipoma: those less than 30 mm are usually symptom free, but if the size increases to >40 mm, the patient may become symptomatic.

17.6 Summary

CTC is useful for detecting and demonstrating colonic lipomas on 2D and 3D views. These benign lesions usually cause no symptoms until they reach a large size. Small lesions can be safely left in the colon, but as size increases >30 mm, symptoms may the occur. There are two treatment options: endoscopic removal of lesions <30 mm, or surgical resection for benign larger tumours or those that result in intussusception.

References

1. Zhang H, Cong J, Chen C, Qiao L, Liu E. Submucous colon lipoma: a case report and review of the literature. World J Gastroenterol. 2005;11(20):3167–9.
2. Tascilar O, Cakmak GK, Gün BD, Ucan H, Balbaloglu H, et al. Clinical evaluation of submucosal colonic lipomas: decision making. World J Gastroenterol. 2006;12(31):5075–7. [cited 2022 September 20]. www.wignet.com.
3. Agrawal A, Singh KJ. Symptomatic intestinal lipomas: our experience. MJAFI. 2011;67(4):374–6. https://doi.org/10.1016/S0377-1237(11)60090-7.
4. Heiken JP, Forde KA, Gold RP. Computed tomography as a definitive method for diagnosing gastrointestinal lipomas. Radiology. 1982;142:409–14.
5. Ott DJ, Gelfand DW. The future of barium radiology. BJR. 1997;70:S171–6.
6. Bortz JH. In the era of CT colonography, is there any role left for barium enema in the investigation of colonic disorders? SAR. 2014;52(2):13–20.
7. Mohamed A, Hassan N, Bhat N, Abukhater M, Uddin M. Caecal lipoma, unusual cause of recurrent appendicitis, case report and literature review. Internet J Gastroenterol. 2008;8(1). [Cited 2022 September 20]. https://ispub.com/IJGE/8/1/10579.
8. Nebbia J, Cucchi J, Novellas S, Bertrand S, Chevallier P, Bruneton JN. Lipomas of the right colon: report on six cases. Clin Imaging. 2007;31(6):390–3. https://doi.org/10.1016/j.clinimag.2007.06.021.
9. Krishnan P, Adlekha S, Chadha IT, Babu AK. Rectal lipoma associated with genital prolapse. Ann Med Health Sci Res. 2013;3(Suppl 1):S18–20. https://doi.org/10.4103/2141-9248.121212.
10. Motamedi AK, Dehestani A, Kadivar M. Colon lipoma: a case report and review of the literature. Med J Islam Repub Iran. 2006;20(3):151–4.
11. Roknsharifi S, Ricci Z, Kobi M, Huo E, Yee J. Colonic lipomas revisited on CT colonography. Abdom Radiol. 2022;47(5):1788–97. https://doi.org/10.1007/s00261-022-03489-2.
12. Nallamothu G, Adler DG. Large colonic lipomas. Gastroenterol Hepatol. 2011;7(7):490–2.
13. Vagholkar K, Bendre M. Lipomas of the colon: a surgical challenge. Int J Clin Med. 2014;5:309–13. https://doi.org/10.4236/ijcm.2014.56046.
14. Jiang L, Jiang LS, Li FY, Ye H, Li N, Cheng NS, Zhou Y. Giant submucosal lipoma located in the descending colon: a case report and review of the literature. World J Gastroenterol. 2007;13(42):5664–7. https://doi.org/10.3748/wjg.v13.i42.5664.
15. Ryan J, Martin JE, Pollock DJ. Fatty tumours of the large intestine: a clinicopathological review of 13 cases. Br J Surg. 1989;76(8):793–6.
16. Notaro JR, Masser PA. Annular colon lipoma: a case report and review of the literature. Surgery. 1991;110(3):570–2.

18 Extracolonic Findings, Their Clinical Significance, and the Role of Opportunistic Screening

Joel H. Bortz

18.1 Introduction

Extracolonic findings (ECFs) are not the goal of CT colonography (CTC). However, radiologists, and radiographers who have been trained to provide a preliminary report [1–3] are responsible for evaluating both intracolonic and extracolonic findings. Should a CTC study be of non-diagnostic quality (e.g., poor bowel preparation or distension or a combination of the two) we are still able to do a full inspection of all extracolonic structures. We would not report on the poor quality CTC, but we definitely must report all ECFs as a CT scan includes the lower chest, abdomen, and pelvis.

CTC is an acknowledged method of investigation of asymptomatic individuals for colorectal cancer (CRC) who are 45 years or older. It has the added ability to detect extracolonic lesions in the abdomen and pelvis. These lesions are classified as either clinically important or unimportant [4]. The definition of a clinically important finding is one that necessitates further diagnostic studies or medical/surgical follow-up. ECFs were identified in 63% of patients in a study by Yee et al. [4]. Fourteen percent had lesions that were considered clinically important, and most of these findings had not been previously diagnosed. It is important to clearly balance the benefit and harm that comes from ECFs [5]. Findings of a review of 24 studies were that approximately 20% of indeterminate renal masses detected with CTC were ultimately malignant [6].

Since the extracolonic abdomen and pelvis are screened with a low-dose technique without the use of an intravenous (IV) contrast medium, radiologists, and appropriately trained radiographers, must be aware of the potential pitfalls [7]. The benefit of detecting important or significant findings in a small minority of patients is huge, particularly in finding cancers that can be treated at an early pre-symptomatic stage. Possible downside includes undue anxiety and added costs incurred by additional studies [8].

There is a very low rate of detected significant findings (usually <10%) in most CTC studies in asymptomatic individuals. In a study by Pickhardt et al. [9], the prevalence of polyps (≥10 mm) was 7%; the prevalence of colon cancer was 0.2% (2 per thousand); and prevalence of ECFs was 0.35%. A disclaimer should be in CTC reports, namely that the lack of IV contrast material and low-dose technique limit the evaluation of CT findings outside the colon.

For many years, the costs of investigating ECFs have been debated. Concern has been expressed that if multiple benign ECFs are investigated, then costs will be driven-up significantly without influencing the final outcome.

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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Another debate pertains to causing unnecessary worry that a lesion may be malignant, but turns out to be benign. A study of 264 patients in 2000 reported: (1) out of the 41% of the patients with ECFs, 115 were considered significant findings, and (2) the additional cost of the work-up of the ECFs was $28 per CTC examination [10]. ECFs were identified in 69% of patients in a study of 681 asymptomatic patients: 10% of the ECFs were highly significant findings. The additional cost of investigating these patients was $34.33 per CT examination performed [11].

Extracolonic evaluation at CTC entails the following technique.

- Use of 1.25 mm collimation during CT scanning
- Exposure selection: 120 kVp and 50–75 mAs
- No IV contrast media
- Automatic reconstruction of 5 mm contiguous CT slices.
  - Advantage of 5 mm contiguous reconstruction include:
    (a) Fewer number of slices (<100) as opposed to approximately 1000 slices
    (b) Decreased image noise
    (c) Easier retrieval and archiving in a PACS system.

ECFs are assessed using a low-dose CT technique as well as the absence of IV contrast [7]. CTC screening for CRC is a low-dose examination which may compromise the detection of extracolonic abnormalities due to increased image noise. An IV contrast medium is not routinely used in CTC screening for several reasons.

1. It does not increase polyp detection.
2. It adds to cost of the examination.
3. It extends the time of examination.
4. It increases risk to the patient in terms of possible adverse reactions.

For viewing of ECFs, automatic reconstruction of the supine study to 5 mm contiguous images is performed in all cases. There are several advantages in making the images 5 mm thick, namely

- fewer images to review
- decreased image noise
- easier to archive and retrieve the images

However, IV contrast media are used when a study becomes diagnostic or when a carcinoma is identified, either within or outside the colon; an increase in tube current is then required which means increased dose to the patient [4]. CTC unavoidably targets the pelvic tissues and extracolonic abdominal tissues [6]. In other words, CTC potentially detects disease in organs other than the colon. For example, 20% of indeterminate renal masses detected at CTC are malignant. The majority of ECFs are not of clinical importance, whilst a small percentage (7–11%) of patients undergo further testing because of the initial ECF [5, 12, 13]. An almost equal number of extracolonic cancers and intracolonic cancers were identified in a 2010 study of 2277 patients undergoing CTC screening [14]. Extracolonic detections increased with age. Macari et al. [15] reported 74% of patients >65 years had extracolonic abnormalities compared with 55.4% in younger patients. In a UK study, 67% of older symptomatic patients had extracolonic abnormalities [16].

The following abbreviations are used in this chapter.

- AAA: abdominal aortic aneurysm
- AAC: abdominal aortic calcification
- AI: artificial intelligence
- BMD: bone mineral density
- CRC: colorectal cancer
- DXA: dual-energy X-ray absorptiometry
- E1: not of clinical importance
- E2: low clinical importance
- E3: moderate clinical importance
- E4: high clinical importance
- ECFs: extracolonic findings
- FRAX: fracture risk assessment tool
- HU: Hounsfield unit
- ML: machine learning
- ROI: region of interest
- TBS: trabecular bone score

18.2 Benefits of Visualising Extracolonic Organs and Tissues

Significant pathology may be identified in approximately 10% of cases. For example, early cancers of the kidney and ovary, as well as abdominal or pelvic lymphadenopathy in underlying lymphoma. Abdominal aortic aneurysms >30 mm in transverse diameter may be detected incidentally [11, 14]. Visualisation of such pathology is not possible with other CRC screening tests. It is however important to balance the benefits and harms when ECFs are noted at CTC. In a study undertaken by Plumb et al. [5], it was found that patients were prepared to tolerate an extremely high rate (>99.8%) of unnecessary additional imaging or invasive testing to reap the potential benefits of finding an early stage extracolonic malignancy. Conversely healthcare professionals were less tolerant as only 40% of physicians accepted the need for follow-up studies, and only 5% accepted the need for further invasive studies. In terms of patient care, the false-positive rate of screening CTC for ECFs is highly acceptable; for both patients and healthcare professionals. Patients, for example, would tolerate over 4000 false-positive diagnosis to avoid a single missed CRC [17].

18.2.1 Negative Aspects of ECFs

The negative aspects of extracolonic findings include:

(a) added diagnostic cost
(b) time consuming to evaluate these findings, thus adding to overall reporting time
(c) patients may be subjected to increased anxiety and risks. Especially following biopsies, or exploratory surgery for what turns out subsequently to be an insignificant finding [4].

18.3 Clinical Importance of ECFs: Low, Moderate, and High

It is useful to divide ECFs in asymptomatic patients into three categories: low, moderate, and high importance. Benign lesions, such as kidney cysts, are of low clinical importance and do not impact on patient management. Those that do impact on management, and are therefore of high importance, include extracolonic malignancies such as renal or ovarian neoplasms, and abdominal aortic aneurysms. Lesions, especially renal carcinoma, that are identified early tend to be more curable [18]. It has been shown that more extracolonic cancers are detected than colon cancers during CTC. The former are identified in 3.5 cases/1000 whereas colon cancer is identified in 2.1 cases/1000 cases [19]. More than half of patients with symptoms of CRC are found to have extracolonic pathologies by CTC analysis [20].

Abdominal aortic aneurysms (AAAs) are most commonly located in the infra-renal portion of the aorta. Development of an AAA usually occurs in males, and in patients older than 65 years with a history of smoking or hypertension. The majority of cases of AAA (62%) are incidental findings [4]. A contrast medium is not used in screening CTC studies to diagnose AAAs. In order to be diagnosed, they must measure at least 30 mm (3 cm) in their widest diameters. The risk of a rupture of an AAA increases as it grows in size; surgery or endovascular repair is required when an AAA is >50 mm.

18.4 Classification of ECFs

Zalis et al. [21] classified ECFs in terms of their clinical importance, namely

- low importance: low clinical importance thus no immediate impact on patient management
- moderate importance: usually benign but may require further work-up
- significant importance (= medically important)

ECFs may be either clinically insignificant or significant, depending on whether additional work-up is required. For example, if a pleural effusion is visualised it would be classified as E3: moderate clinical importance. Visualisation of a simple renal cyst would be classified as E2: low clinical importance. Examples of ECFs for each level of clinical importance are presented in Table 18.1. A revised classification of ECFs is a work in progress and should be published within the next few months.

Table 18.1 E classification[b]

E0	**Limited examination**	
E1	**Not of clinical importance** Normal examination or anatomic variant	No extracolonic abnormalities visible Anatomic variant, for example, retro-aortic left renal vein, BMD >160 HU, air in vagina normal causes
E2	**Low clinical importance** Clinically unimportant findings	No work-up indicated. Examples are presented below. Liver, kidney: simple cysts Non-obstructing renal stones Non-obstructing gall stones Gallbladder: cholelithiasis without cholecystitis Vertebra: haemangioma Arterial calcification Calcified granuloma Uncomplicated hernias (inguinal, hiatal, femoral, enterocoele) Various skeletal abnormalities Adrenal adenomas Renal calculi Fatty liver Lipoma Uterine fibroids BMD between 100 and 160 HU
E3	**Moderate clinical importance** Likely unimportant finding and likely to be benign. Incompletely characterised NB: In nearly all cases of asymptomatic patients, these lesions prove to be benign	Further work-up may be indicated Kidney: minimally complex or homogeneously hyper-attenuating cyst Complicated renal cysts Prominent adnexal lesions in women Indeterminate pulmonary nodules Indeterminate liver lesions Pleural effusions Cardiomegaly Splenomegaly Complicated hiatus hernias BMD <100 HU Air in vagina due to pathology Metabolic-associated fatty liver disease (see Chap. 19)
E4	**High clinical importance** Potentially important finding. Communicate to referring physician as per accepted practice guidelines NB: Appendicitis, diverticulitis, pancreatitis, irreducible inguinal hernia, pneumothorax, pneumoperitoneum must be communicated to the referring physician/ health practitioner	Kidney: solid renal mass Liver masses Lymphadenopathy ≥10 mm Vasculature: aortic aneurysms >50 mm Lung: non-uniformly calcified pulmonary nodule ≥10 mm Irreducible inguinal hernia containing large bowel

[a] It must be remembered that an extracolonic evaluation is limited by lack of IV contrast and the low-dose CT technique
[b] Adapted from Zalis et al. [21]

18.5 Examples of ECF Images

It is important that every organ and bony structure is carefully evaluated on every CTC image [22]. The E-classification in Table 18.1 is used to present examples in each classification. As evident in these examples, the majority are classified as being of low clinical importance (E2). Only a few are classified as being of significant clinical importance (E4).

18.5.1 E1: Not of Clinical Importance

Figure 18.1a–g are examples of ECFs that are not of clinical importance.

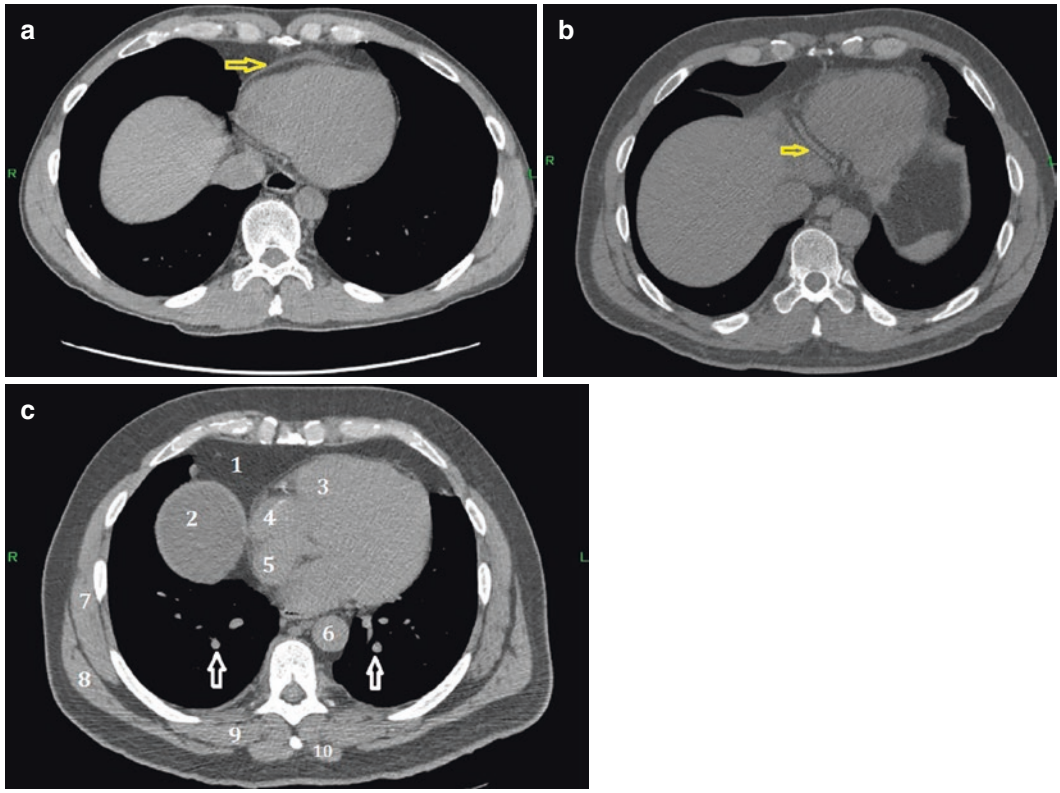

Fig. 18.1 (**a**) 2D axial shows normal pericardium surrounding the heart (yellow arrow). (**b**). 2D axial showing normal right posterior descending coronary artery (yellow arrow). (**c**) 2D axial view showing pulmonary vessels (open white arrows). 1 = anterior mediastinal fat; 2 = liver; 3 = right ventricle; 4 = right atrium; 5 = inferior vena cava; 6 = aorta; 7 = serratus anterior; 8 = latissimus dorsi muscle; 9 = quadratus lumborum; 10 = erector spinae muscles.

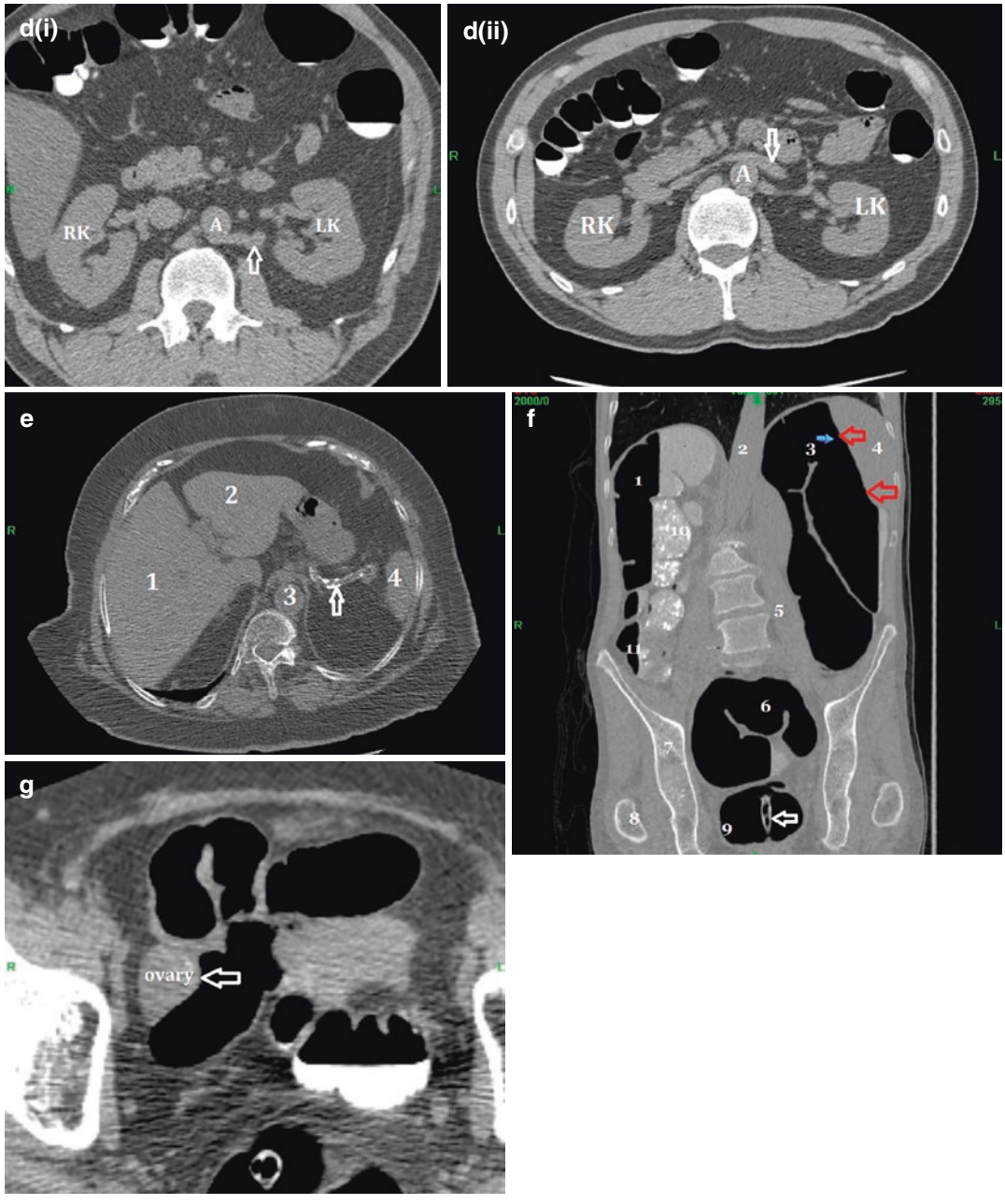

Fig. 18.1 (**d**) (**i**) 2D axial view showing retro-aortic left renal vein (open white arrow). LK = left kidney; RK = right kidney; A = aorta. (**ii**) 2D axial view showing normal renal vein (open white arrow). RK = right kidney; LK = left kidney; A = aorta. (**e**) 1 = right lobe of liver; 2 = left lobe of liver; 3 = aorta; 4 = spleen; Open white arrow = splenic artery calcification. (**f**) 2D coronal view of a left lateral decubitus study showing splenic impression on splenic flexure of colon (open red arrows). Open white arrow = rectal catheter; 1 = hepatic flexure of colon; 2 = aorta; 3 = splenic flexure; 4 = spleen; 5 = psoas muscle; 6 = sigmoid colon; 7 = ischium of pelvis; 8 = greater trochanter of femur; 9 = rectum; 10 = contrast in ascending colon; 11 = caecum. (**g**) 2D axial shows ovary pressing on bowel (open white arrow)

18.5.2 E2: Low Clinical Importance

Figure 18.2a–aZ (ii) are examples of ECFs that are of low clinical importance.

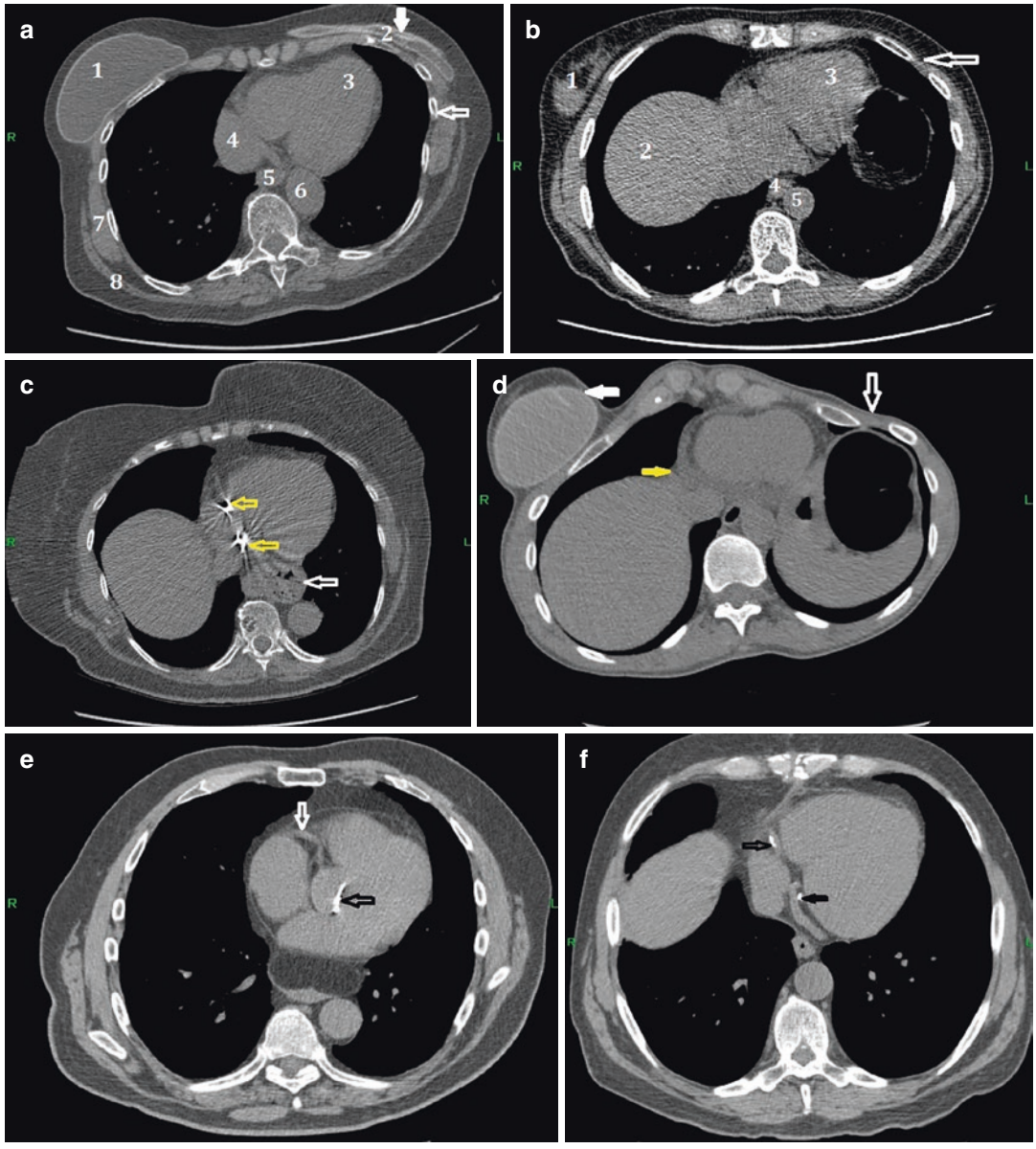

Fig. 18.2 (**a**) 2D axial view. 1 = breast implant; 2 = collapsed left breast prosthesis (closed white arrow); 3 = left ventricle; 4 = right atrium; 5 = distal oesophagus; 6 = descending aorta; 7 = serratus anterior muscle; 8 = latissimus dorsi muscle. Rib = open white arrow. (**b**) 2D axial view of a patient who had a left mastectomy (open white arrow). 1 = right breast; 2 liver; 3 = left ventricle; 4 = distal oesophagus; 5 = descending aorta. (**c**) 2D axial view shows artefact from pacemaker wires (open yellow arrows). Small hiatus hernia below the heart (open white arrow). (**d**) 2D axial view shows small pericardial effusion (yellow arrow). Note breast prosthesis (closed white arrow). Absent left breast (open white arrow). (e) 2D axial view shows right posterior descending coronary artery (open white arrow) and partial calcification of leaflet of aortic valve (closed black arrow). (f) 2D axial view shows mild calcification of part of right posterior descending coronary artery (open black arrow) as well as mild calcification of the circumflex artery (closed black arrow).

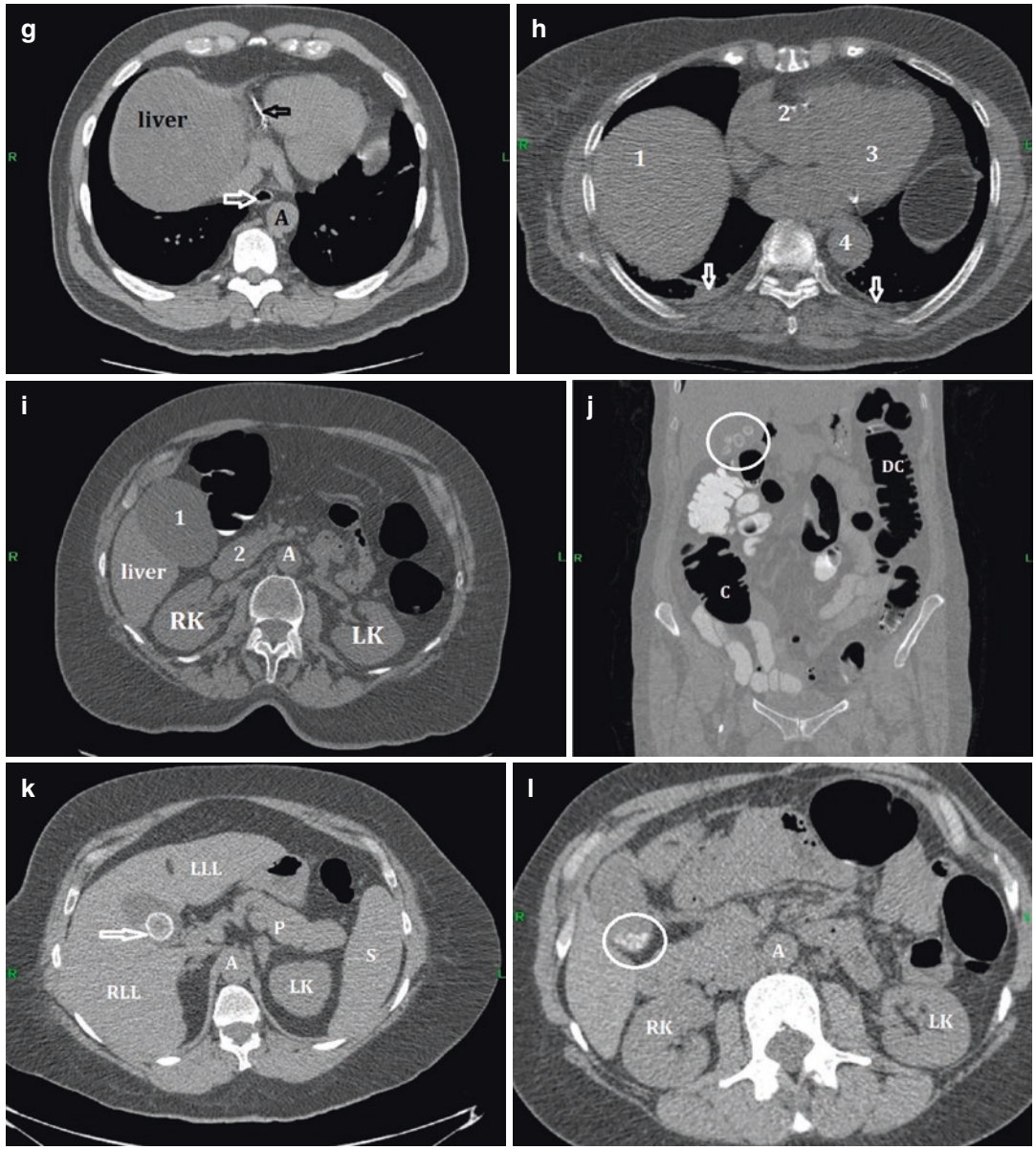

Fig. 18.2 (**g**) 2D axial shows calcification right posterior descending coronary artery (open black arrow) and fatty liver. A = aorta. Distal oesophagus (open white arrow). (**h**) 2D axial view showing pleural thickening base of lungs (open white arrows). 1 = liver; 2 = right ventricle; 3 = left ventricle; 4 = aorta. (**i**) Distended gallbladder = 1; Duodenum = 2; A = aorta; RK = right kidney; LK = left kidney. (**j**) 2D coronal view shows four gallstones (circle). C = caecum; DC = descending colon. (**k**) Solitary calcified gallstone (open white arrow). LLL = left lobe of liver; RLL = right lobe of liver; P = pancreas; A = aorta; LK = left kidney; S = spleen. (**l**) Multiple gallstones with gas (circle). RLL = right lobe of liver; A = aorta.

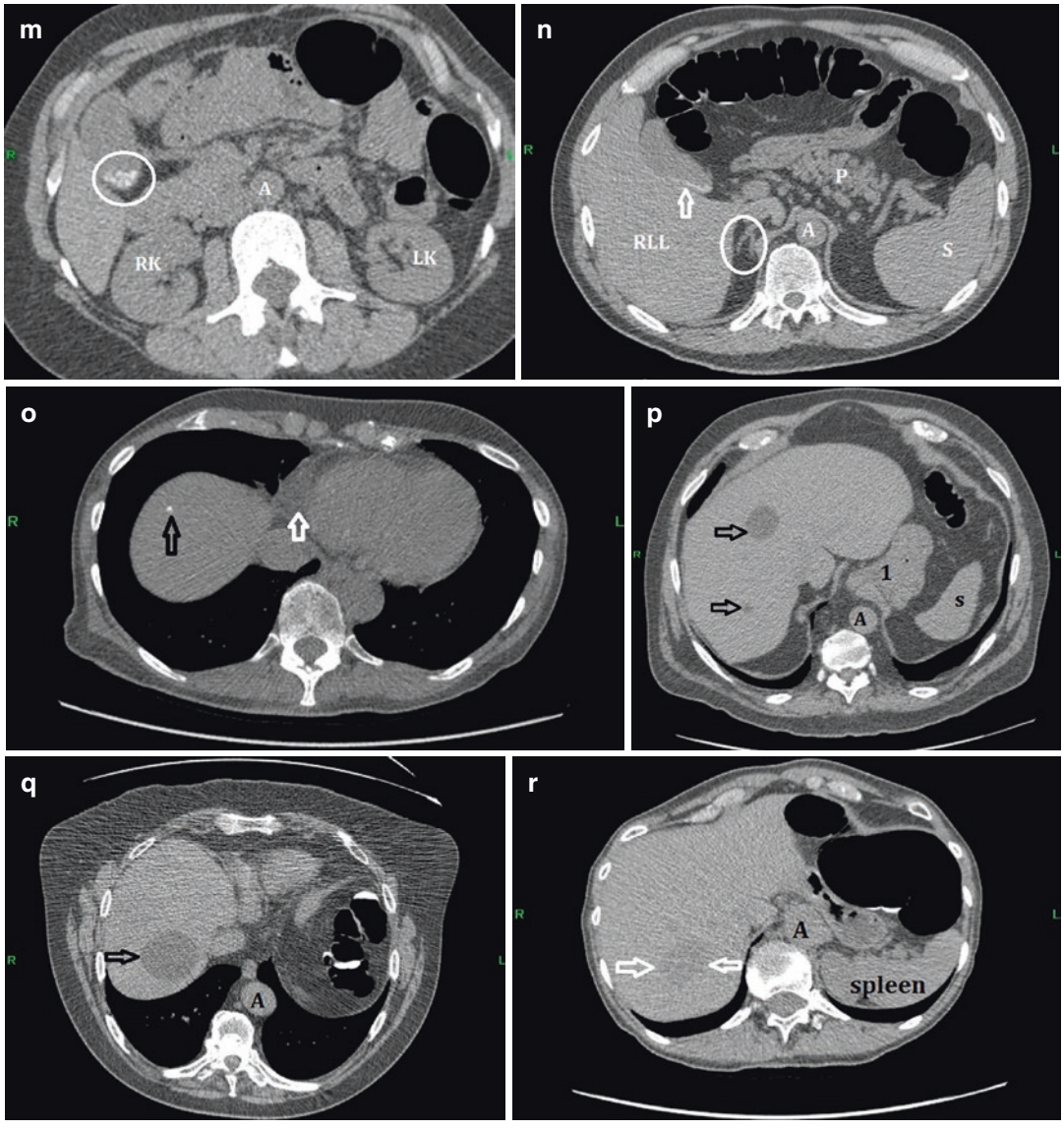

Fig. 18.2 (**m**) Multiple calcified gallstones (circle). RK = right kidney; LK = left kidney; A = aorta. (**n**) Milk of calcium bile (open white arrow). Right adrenal gland (circle); RLL = right lobe of liver; P = pancreas; A = aorta; S = spleen. (**o**) Liver granuloma (open black arrow). Small pericardial effusion (open white arrow). (**p**) Liver cysts (open black arrows). A = aorta; S = spleen; 1 = stomach. (**q**) Liver cyst right lobe (open black arrow). A = aorta. (**r**) Ill-defined low density area right lobe (open white arrows). Differential diagnosis is metastasis versus haemangioma. Proven haemangioma. A = aorta.

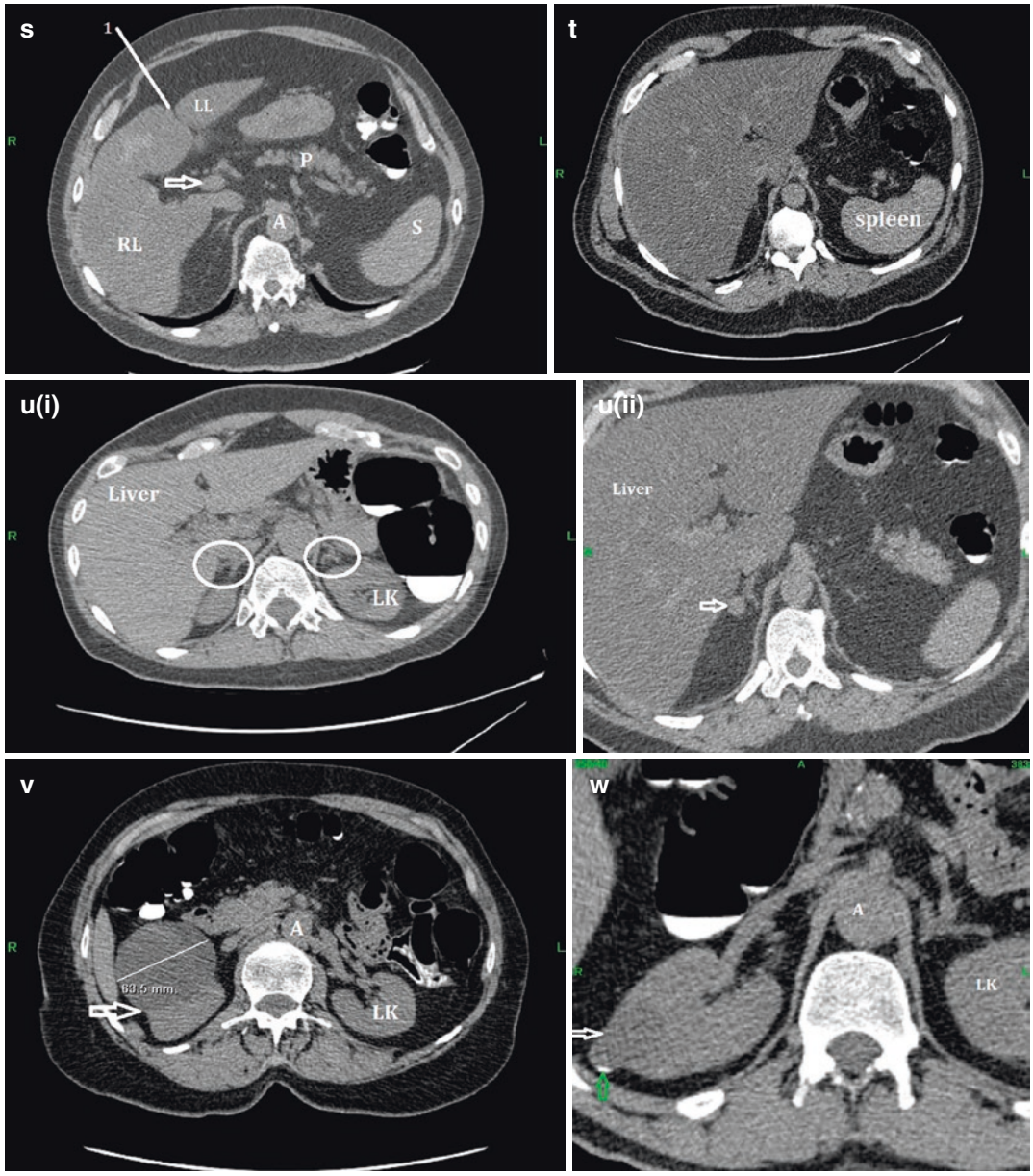

Fig. 18.2 (**s**) Fatty infiltration of liver. LL = left lobe of liver; RL = right lobe of liver; 1 = fissure for ligament; P = pancreas; S = spleen; A = aorta; Right adrenal gland (open white arrow). (**t**) Fatty infiltration of liver. Note marked decrease in liver density compared with spleen. (**u**) (**i**) Normal adrenal glands E1 (circles). LK = left kidney. Compare the right adrenal with the one in Fig. 18.2u(ii). (**ii**) Nodule on right adrenal gland (open white arrow). Fatty liver. (**v**) 2D axial showing 65 mm cyst in right kidney (open white arrow). A = aorta; LK = left kidney. (**w**) Cyst mid-pole right kidney (open white arrow) with calcification (open green arrow). A = aorta; LK = left kidney.

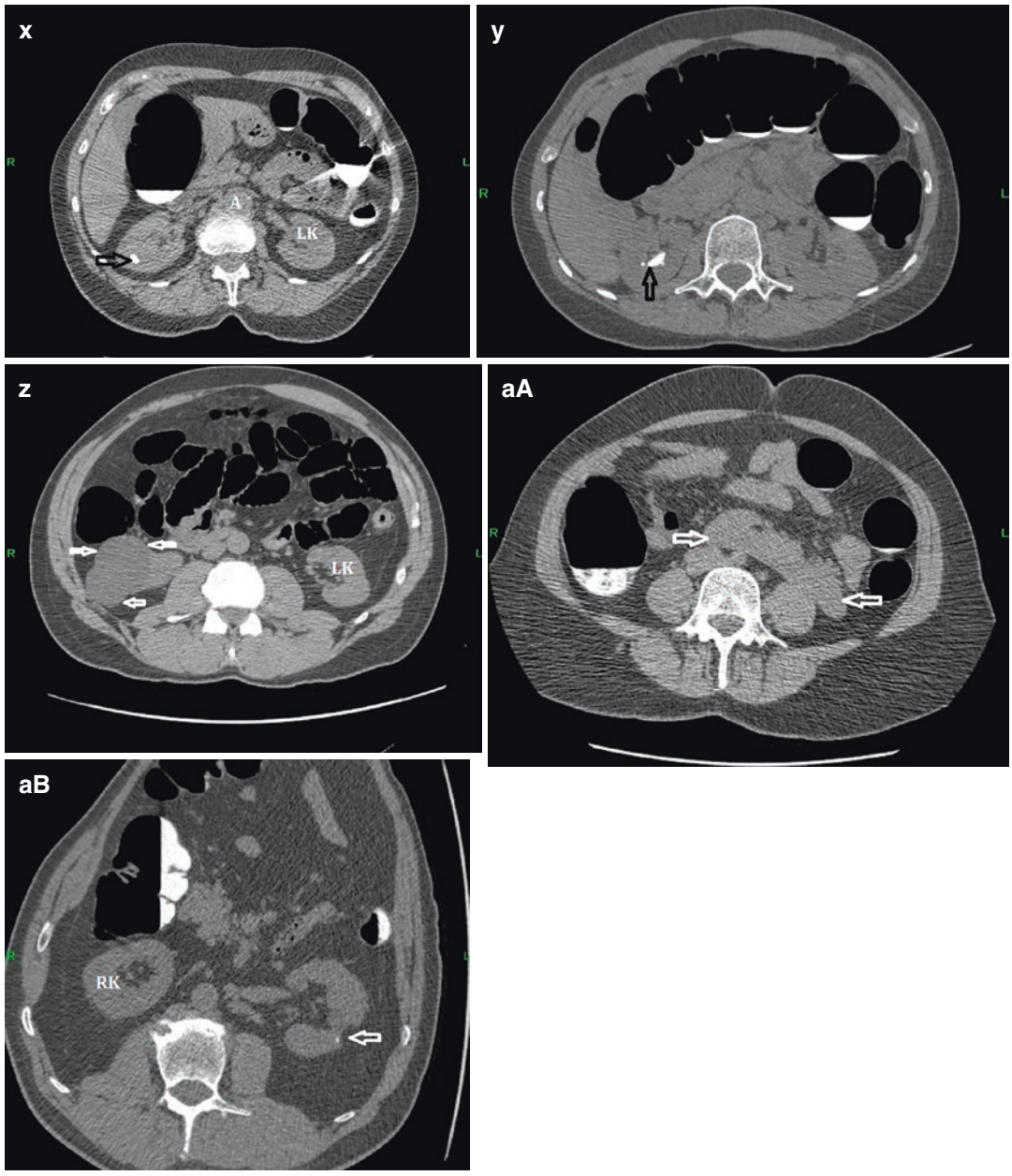

Fig. 18.2 (**x**) Right lower pole renal calculus (6 mm). A = aorta; LK = left kidney. (**y**) Large calculus right kidney (open black arrow). (**z**) Lobulated cyst right kidney (open white arrows). LK = left kidney. (**aA**) Horseshoe kidney (open white arrows). (**aB**) Pyelonephritic scarring left kidney with a small focus of dystrophic calcification (open white arrow). RK = right kidney.

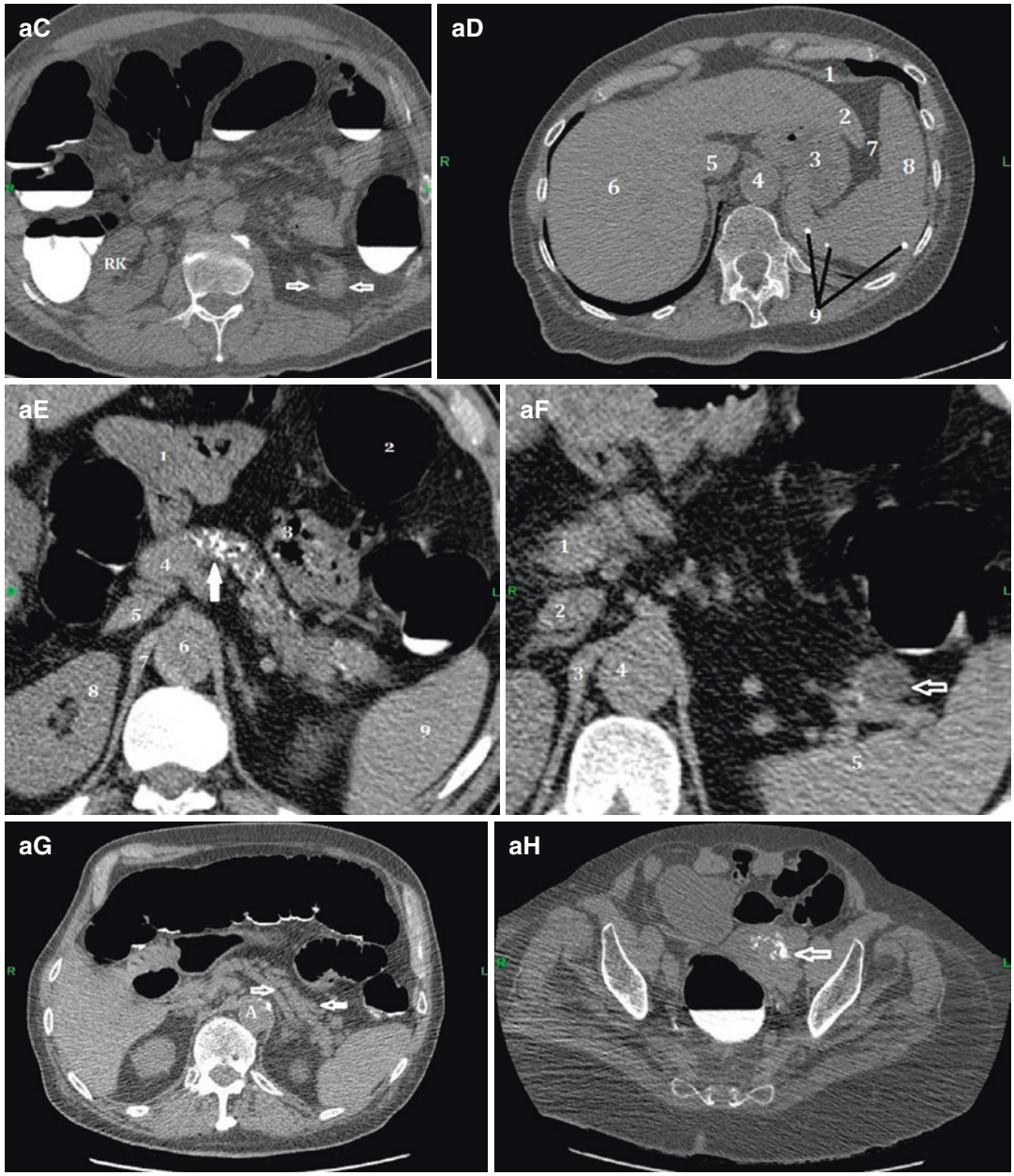

Fig. 18.2 (**aC**) Atrophic left kidney (open white arrows). RK = right kidney. (**aD**) 2D axial view. 1 = crus of diaphragm; 2 = left lobe of liver; 3 = stomach; 4 = aorta; 5 = caudate lobe of liver; 6 = liver; 7 = peritoneal space; 8 = spleen; 9 = granulomata. (**aE**) 2D axial view showing calcification of body of pancreas (white arrow) due to previous pancreatitis. 1 = small bowel; 2 = gas in large bowel; 3 = air in small bowel; 4 = head of pancreas; 5 = IVC; 6 = aorta; 7 = right crus of diaphragm; 8 = right kidney; 9 = spleen. (**aF**) 2D axial view showing cyst in tail of pancreas (open white arrow). 1 = small bowel; 2 = IVC; 3 = crus of right diaphragm; 4 = aorta; 5 = spleen. (**aG**) 2 D axial view showing an atrophic pancreas (open white arrow). A = aorta. (**aH**) 2 D axial view shows a calcified fibroid (open white arrow).

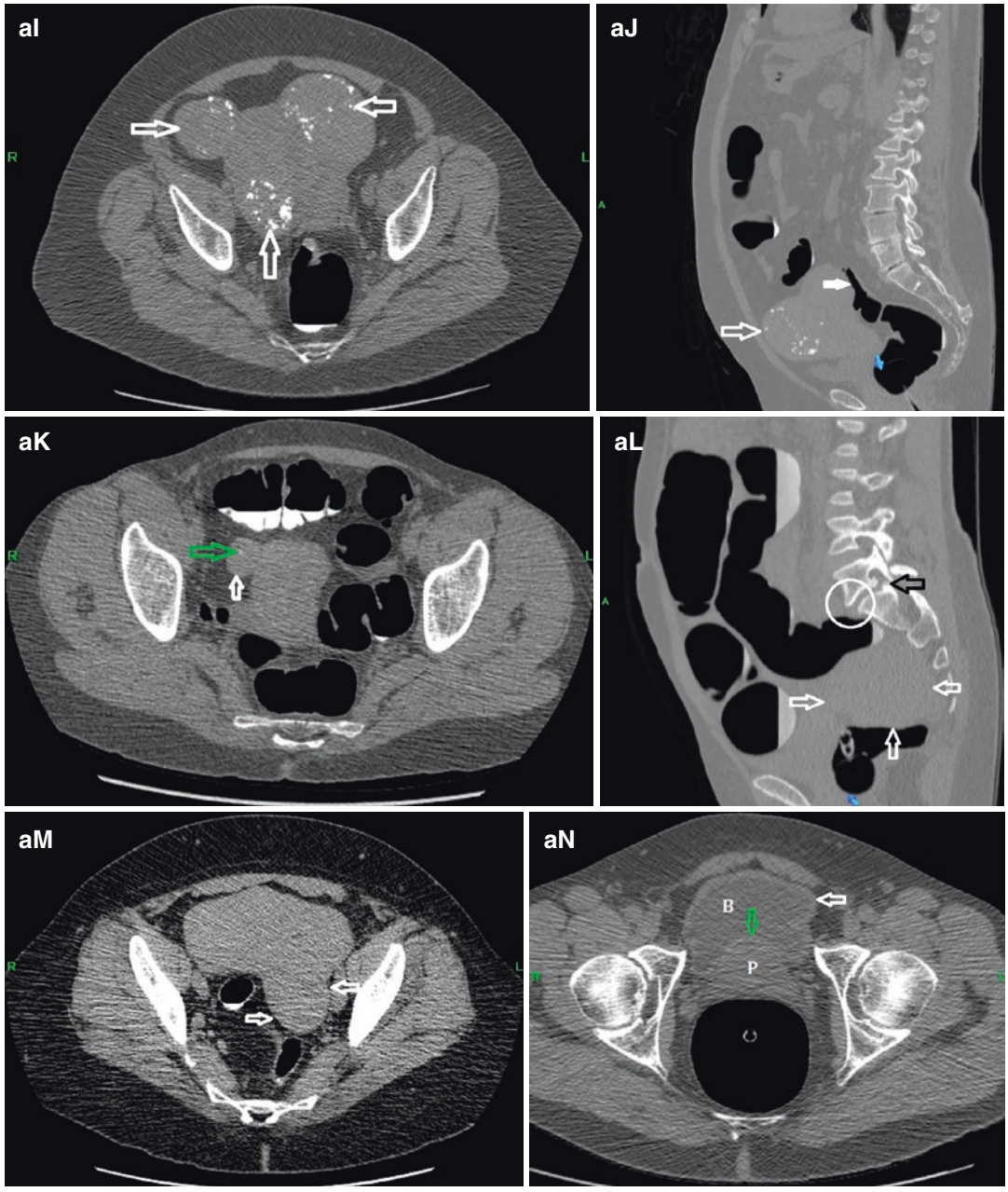

Fig. 18.2 (**aI**) 2D axial view shows three calcified fibroids (open white arrows) giving a 'Mickey Mouse' appearance. (**aJ**) 2D sagittal view shows anterior calcified fibroid (open white arrow) causing narrowing of the sigmoid colon (closed white arrow). (**aK**) 2D axial view shows a pedunculated fibroid (open white arrow) with some calcification (open green arrow). (**aL**) 2D sagittal view shows large retroverted uterus (open white arrows). White circle = spondylolisthesis L5 with defect through pars interarticularis (open black arrow). (**aM**) 2D axial shows a prolapsed fibroid (open white arrows). (**aN**) Open green arrow shows enlarged prostate (P) pressing on bladder (B). Note bladder wall thickening (open white arrow).

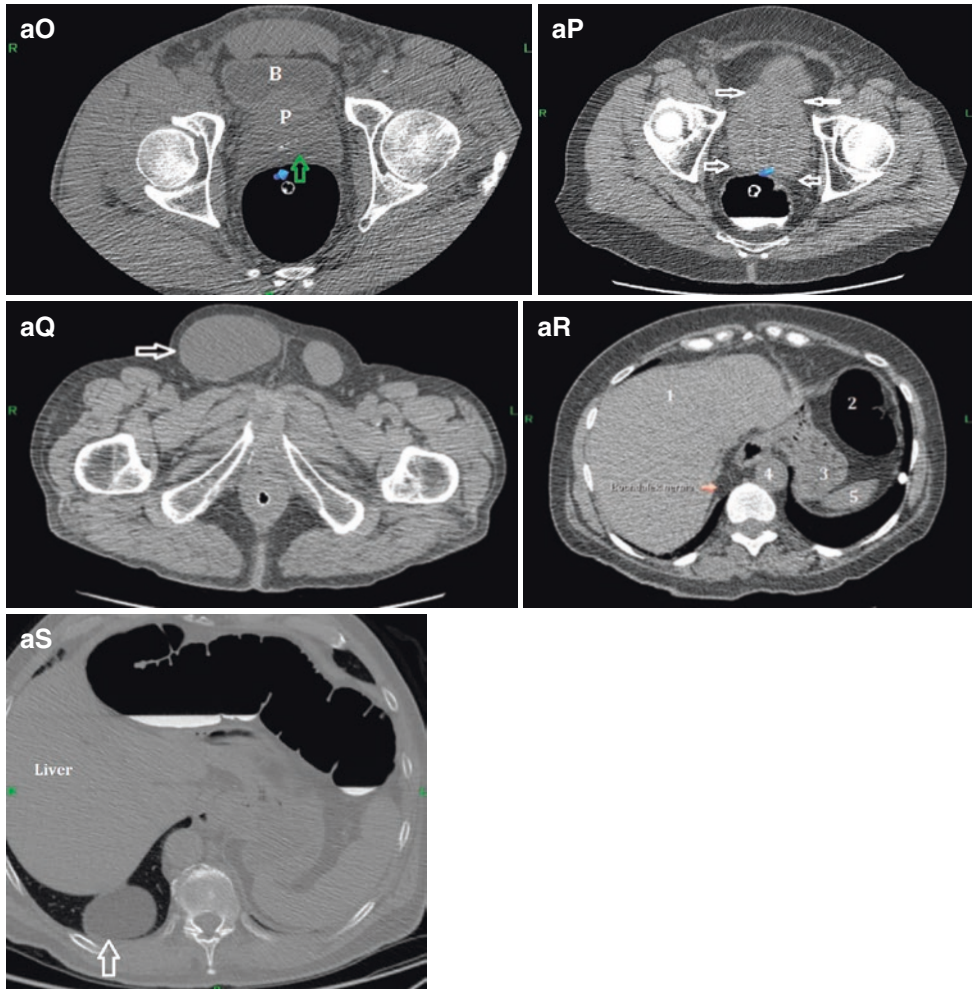

Fig. 18.2 (**aO**) Enlarged prostate (P) pressing on base of bladder (B). Mild dystrophic calcification noted (open green arrow). (**aP**) Enlarged prostate (open white arrows). (**aQ**) Hydrocele right (open white arrow). Left testis normal. (**aR**) Bochdalek hernia (red arrow). 1 = liver; 2 = DC; 3 = stomach; 4 = aorta; 5 spleen. (**aS**) Bochdalek hernia containing fat (open white arrow).

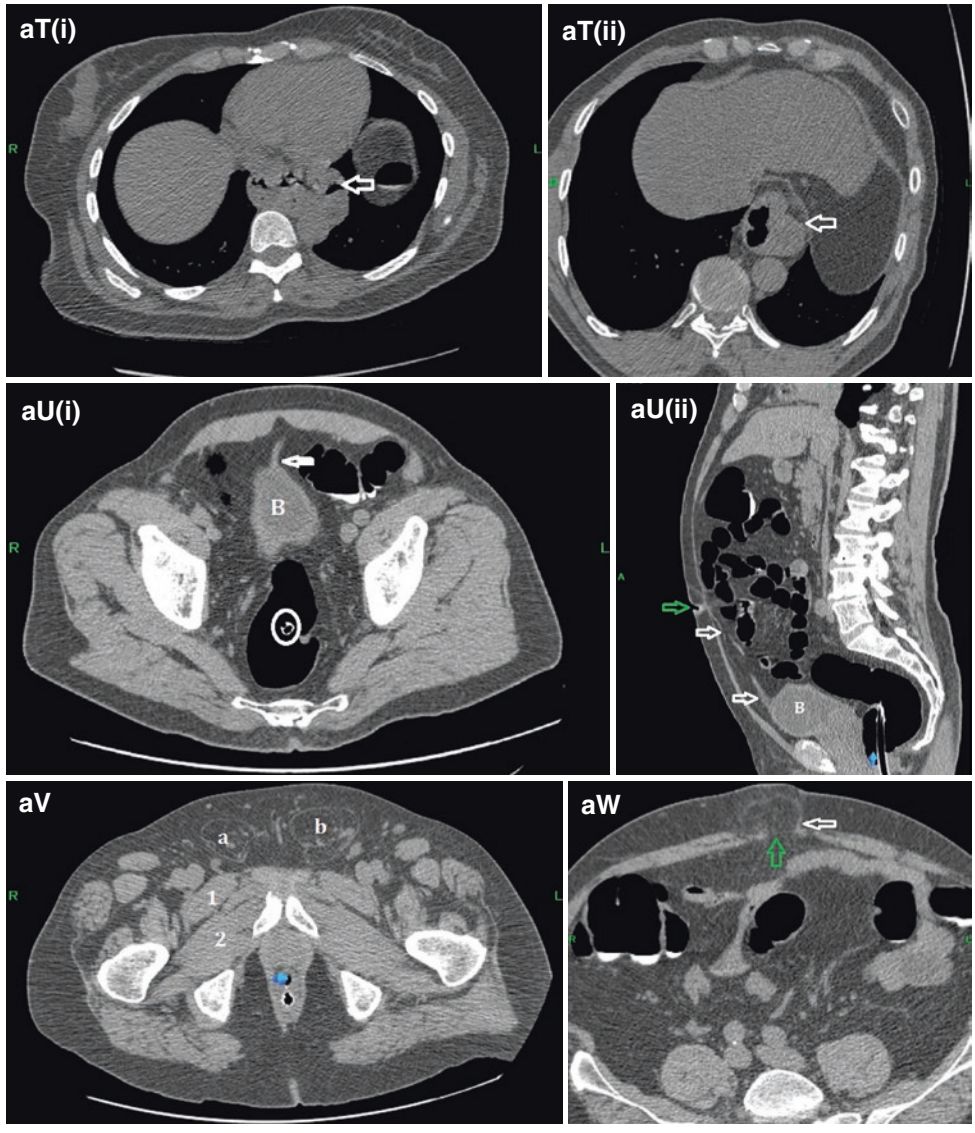

Fig. 18.2 (**aT**) (**i**) Moderate hiatus hernia. (**ii**) Small hiatus hernia. (**aU**) (**i**) 2D axial showing urachal remnant (open white arrow). B = bladder; Rectal catheter (circle). (**ii**) 2D sagittal showing urachal tract (open white arrow) from bladder (B) to umbilicus (open green arrow). (**aV**) Bilateral small inguinal hernias (a and b) containing fat, but no loops of bowel. 1 = pectineus muscle; 2 = obturator externus. (**aW**) Small umbilicus hernia. Open white arrow shows margin of the hernia. Open green arrow shows defect in musculature.

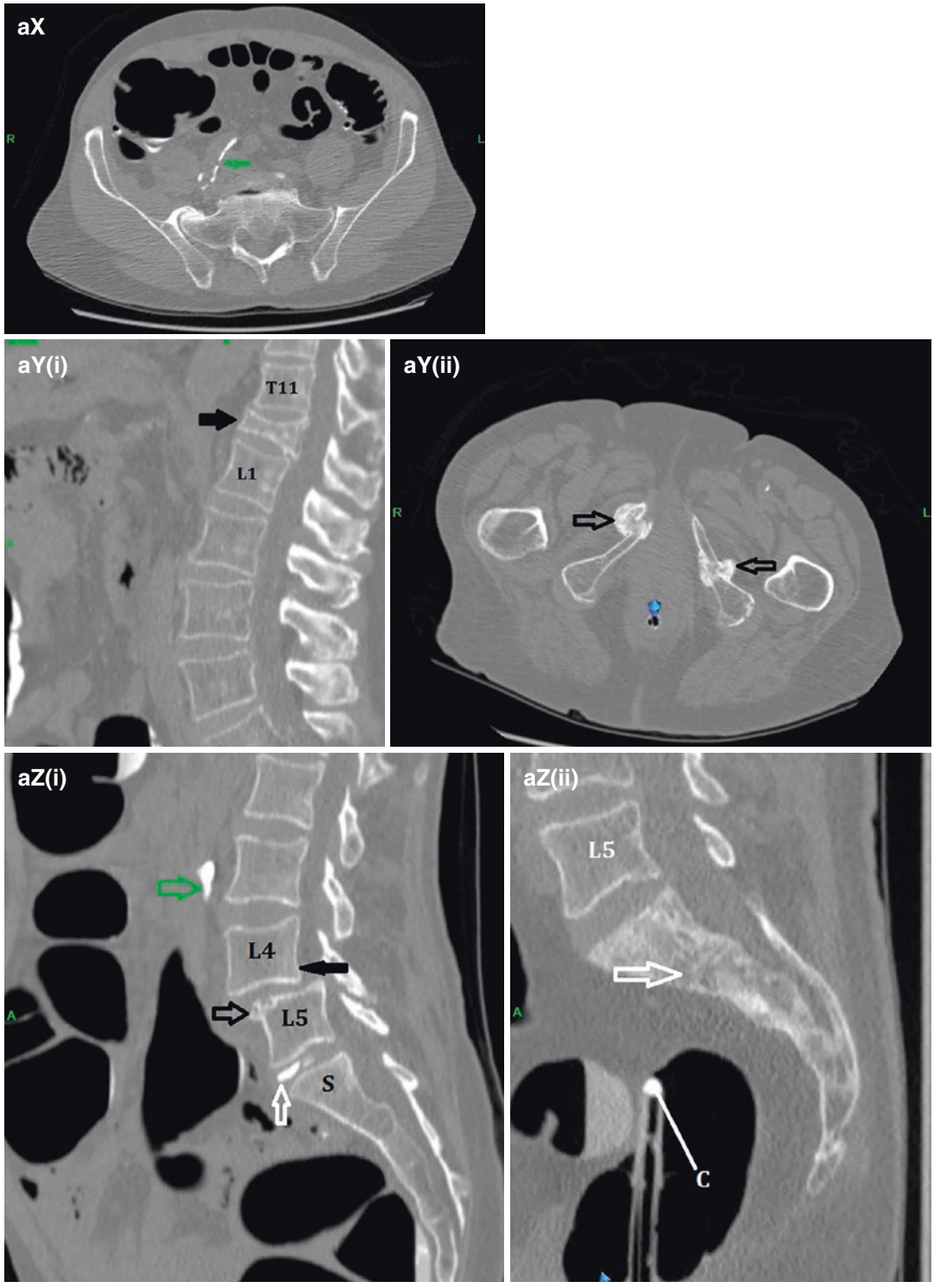

Fig. 18.2 (**aX**) Calcification of right iliac artery (open green arrow). (**aY**) (**i**) Compression fracture T12 (arrow). (**ii**) Healed osteoporotic fractures (open black arrows). (**aZ**) (**i**) Spondylolisthesis L4 on L5 (closed black arrow). Open black arrow = ununited apophysis of L5. S = sacrum. Open white arrow shows calcified of L5/S1 disc Open green arrow shows calcification of aorta. (**ii**) Lesion sacrum (open white arrow) shows Paget's disease. C = rectal catheter

18.5.3 E3: Moderate Clinical Importance

Figure 18.3a–l are examples of ECFs of moderate clinical importance.

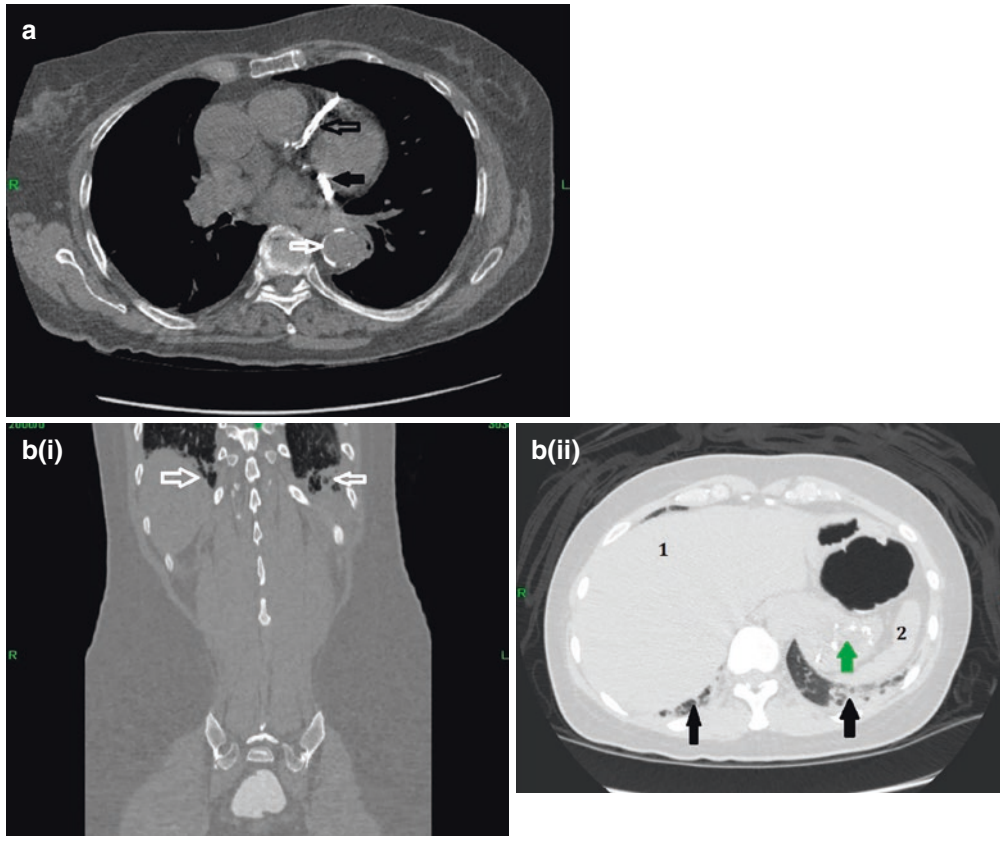

Fig. 18.3 (**a**) 2D axial view shows heavy calcification left anterior descending artery (open black arrow) and circumflex coronary artery (closed black arrow) and calcification of thoracic aorta (open white arrow). (**b**) (**i**) 2D coronal view showing basal lung infective changes bilaterally (open white arrows). (**ii**) 2D axial showing basal lung changes (closed black arrows). Patient known to be suffering from SLE (systemic lupus erythematosus). 1 = liver; 2 = spleen. Granules due to ingested medication in stomach (green arrow).

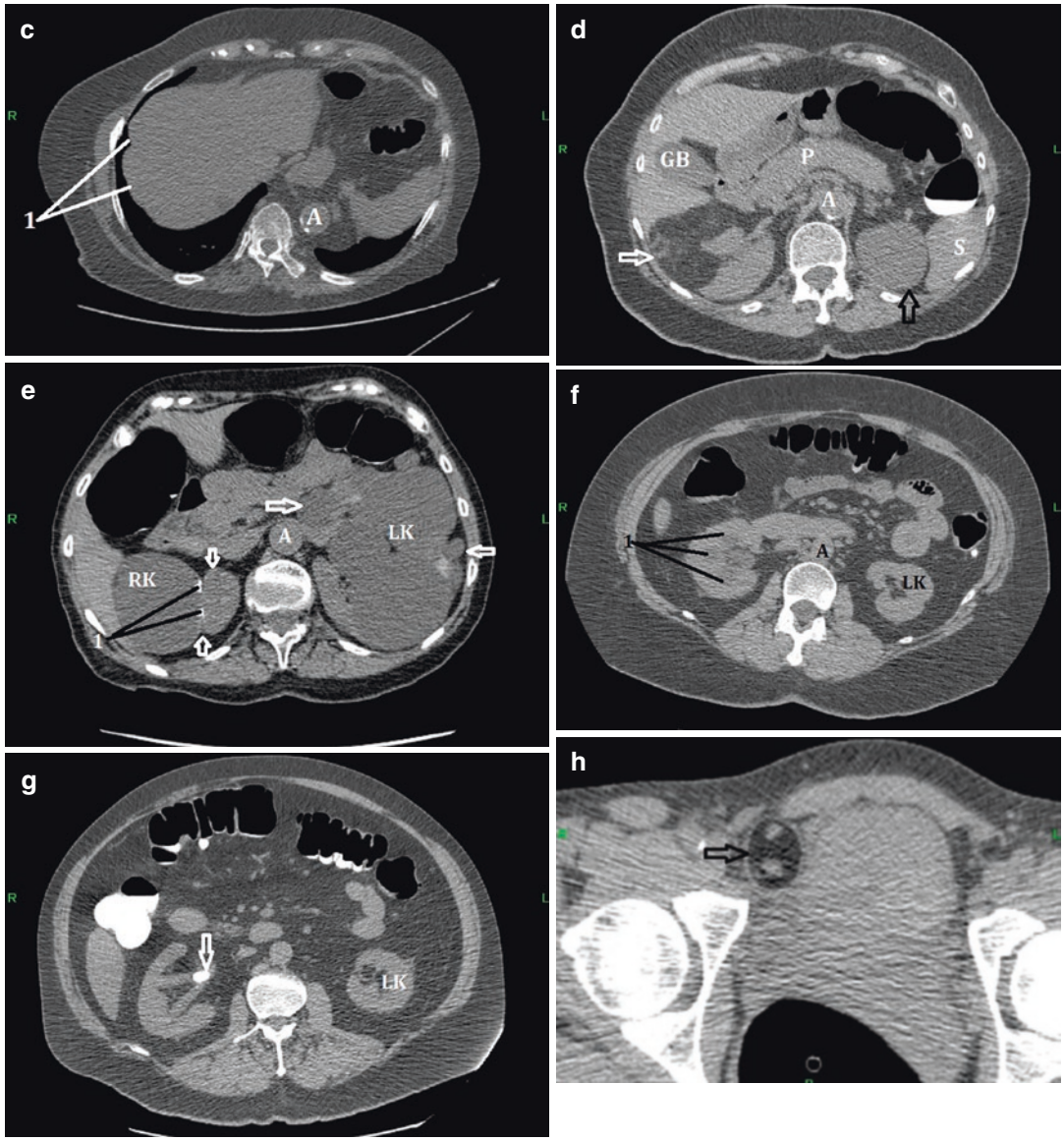

Fig. 18.3 (**c**) Lobular liver (1) due to cirrhosis. A = aorta. (**d**) Angiomyolipoma (open white arrow) showing a 'rat-eaten appearance' due to invasion by fatty tissue, vascular and muscle tissue. Cyst left kidney (open black arrow). GB = gallbladder; P = pancreas; S = spleen; A = aorta. (**e**) Polycystic kidneys (open white arrows) with rim calcification (1) in right kidney (RK). LK = left kidney. (**f**) Hydronephrotic change right kidney (1); A = aorta; LK = left kidney. (**g**) Calculus in ureteropelvic junction (UPJ) of right kidney (open white arrow). LK = left kidney. Mild hydronephrosis. (**h**) 2D axial view shows a dermoid cyst of the right ovary (open black arrow) containing fat and soft tissue.

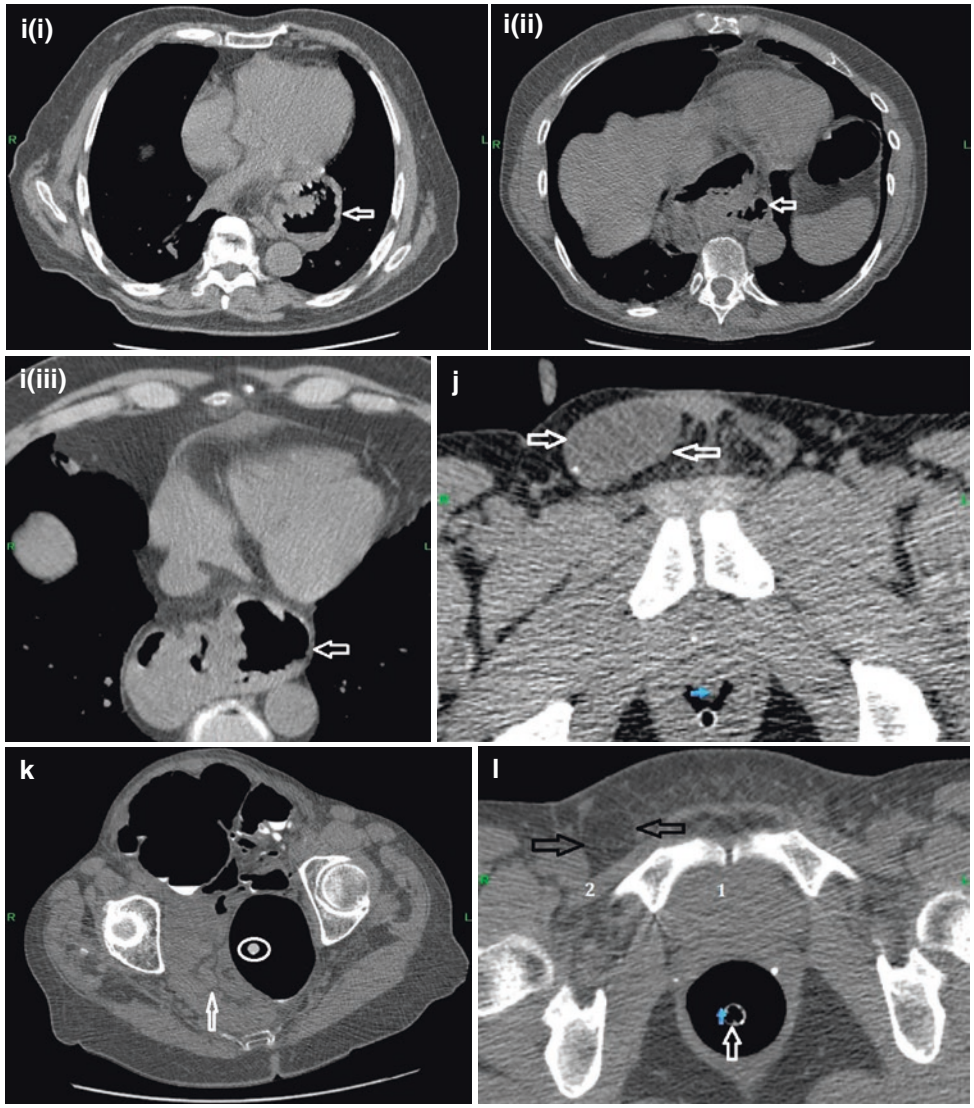

Fig. 18.3 (**i**) (**i**) Incarcerated hiatus hernia. (**ii**) Large incarcerated hiatus hernia containing part of stomach. (**iii**) Large hiatus hernia. (**j**) Density inguinal canal (open white arrows) due to testis. (k) 2D axial showing enterocoele (open white arrow) post hysterectomy. Rectum displaced to the left. Rectal catheter (circle). (**l**) Femoral hernia (open black arrows). Rectal catheter (open white arrow); 1 = bladder; 2 = pectineus muscle

18.5.4 E4: High Clinical Importance

Figure 18.4a (i)–i (ii) are examples of ECFs of high clinical importance.

Potentially important (E4) ECFs of asymptomatic patients (n = 7952) who underwent first time screening CTC for CRC from 1 April 2004 to 30 June 2012 were analysed in a retrospective study [23]. The results were that only 2.5% of patients had a significant ECF (E4). Almost 70% of these findings proved to be clinically significant and required treatment or surveillance: malignancies and aneurysms, for example [23]. Table 18.2 is a summary of the findings of the study.

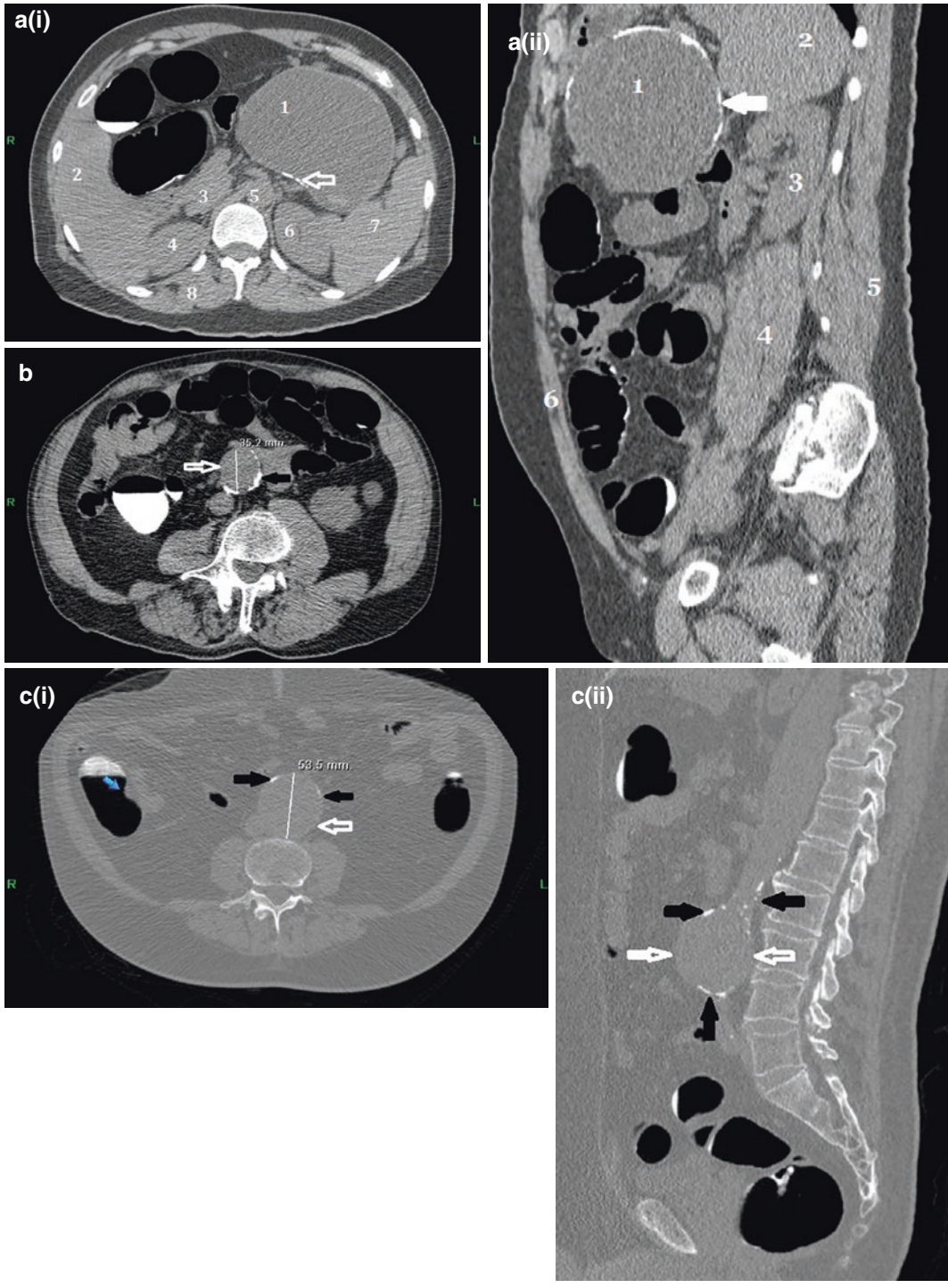

Fig. 18.4 (**a**) (**i**) 2D axial view showing pancreatic mass 1 = with calcification of part of the wall (open white arrow). 2 = right lobe of liver; 3 = inferior vena cava; 4 = right kidney; 5 = abdominal aorta; 6 = left kidney; 7 = spleen; 8 = quadratus lumborum muscle. (**ii**) 2D sagittal view showing large pancreatic cyst 1 = with wall calcification (closed white arrow). 2 = spleen; 3 = left kidney; 4 = psoas muscle; 5 = quadratus lumborum muscle; 6 = anterior abdominal wall muscles. (**b**) Open white arrow = abdominal aortic aneurysm (AAA) measuring 35 mm (3.5 cm). Note partial calcification (closed black arrow). (**c**) (**i**) AAA (open white arrow) measuring 53 mm (5.3 cm) with partial calcification (closed black arrows). (**ii**) Sagittal view of the AAA (open white arrows) showing partial calcification (closed black arrows).

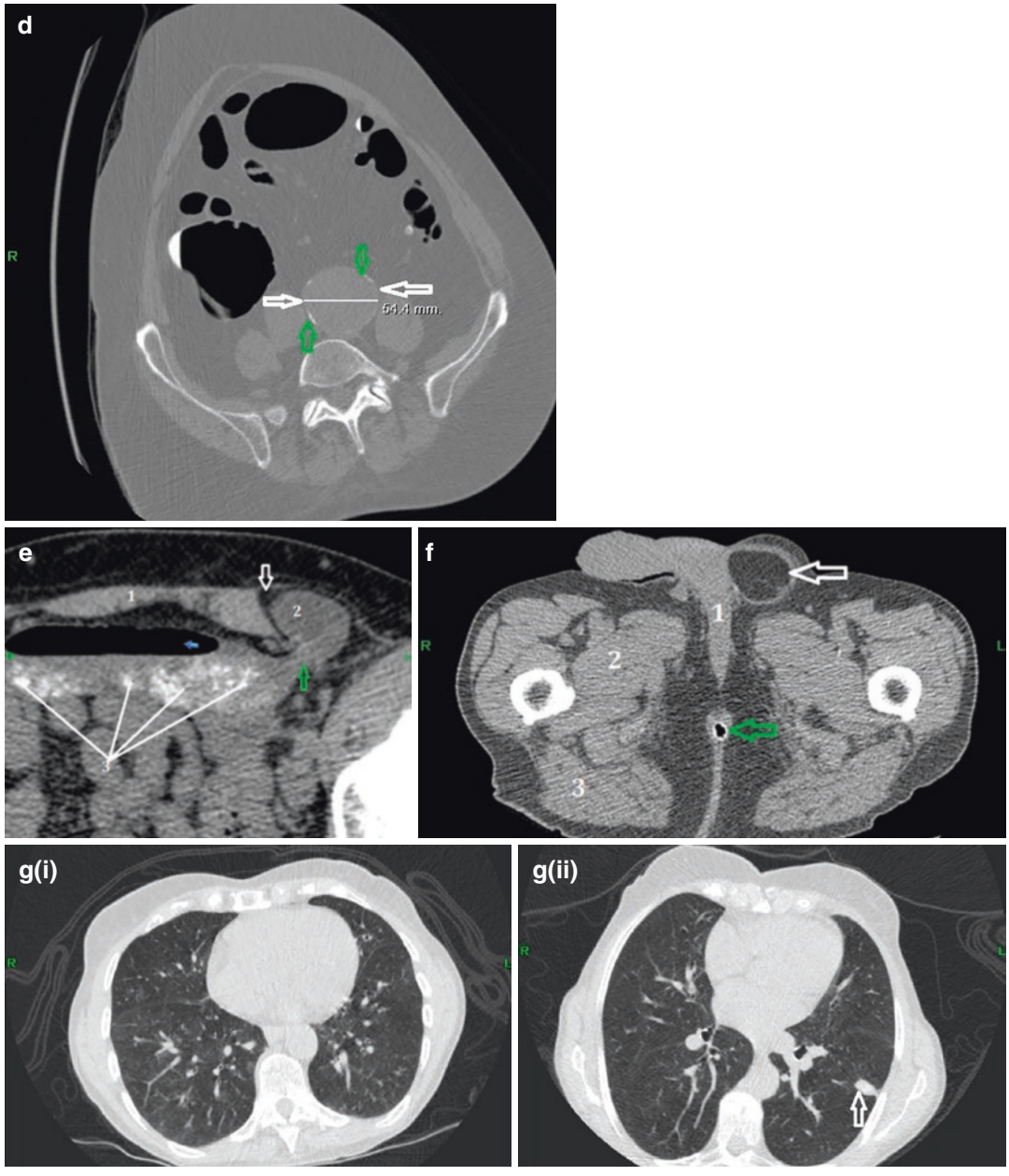

Fig. 18.4 (**d**) Left iliac artery aneurysm (open white arrows) measuring 54.4 mm (5.44 cm) with slight calcification (open green arrows). (**e**) 2D axial view showing pressure effect on rectus abdominis muscle (1). Dilated small bowel (2) trapped in a direct inguinal hernia causing obstruction. Green arrow = transition point. Granules from ingested tablets (3). (**f**) Loop of bowel in scrotum (open white arrow). Rectal catheter (open green arrow). 1 = corpus cavernosum; 2 = obturator externus; 3 = gluteus maximus. (**g**) (**i**) No pathology evident on 2D axial supine view. (**ii**) 2D axial prone view of same patient showing a non-calcified lesion in left lung (open white arrow). This is due to greater coverage of the lung fields in the prone position.

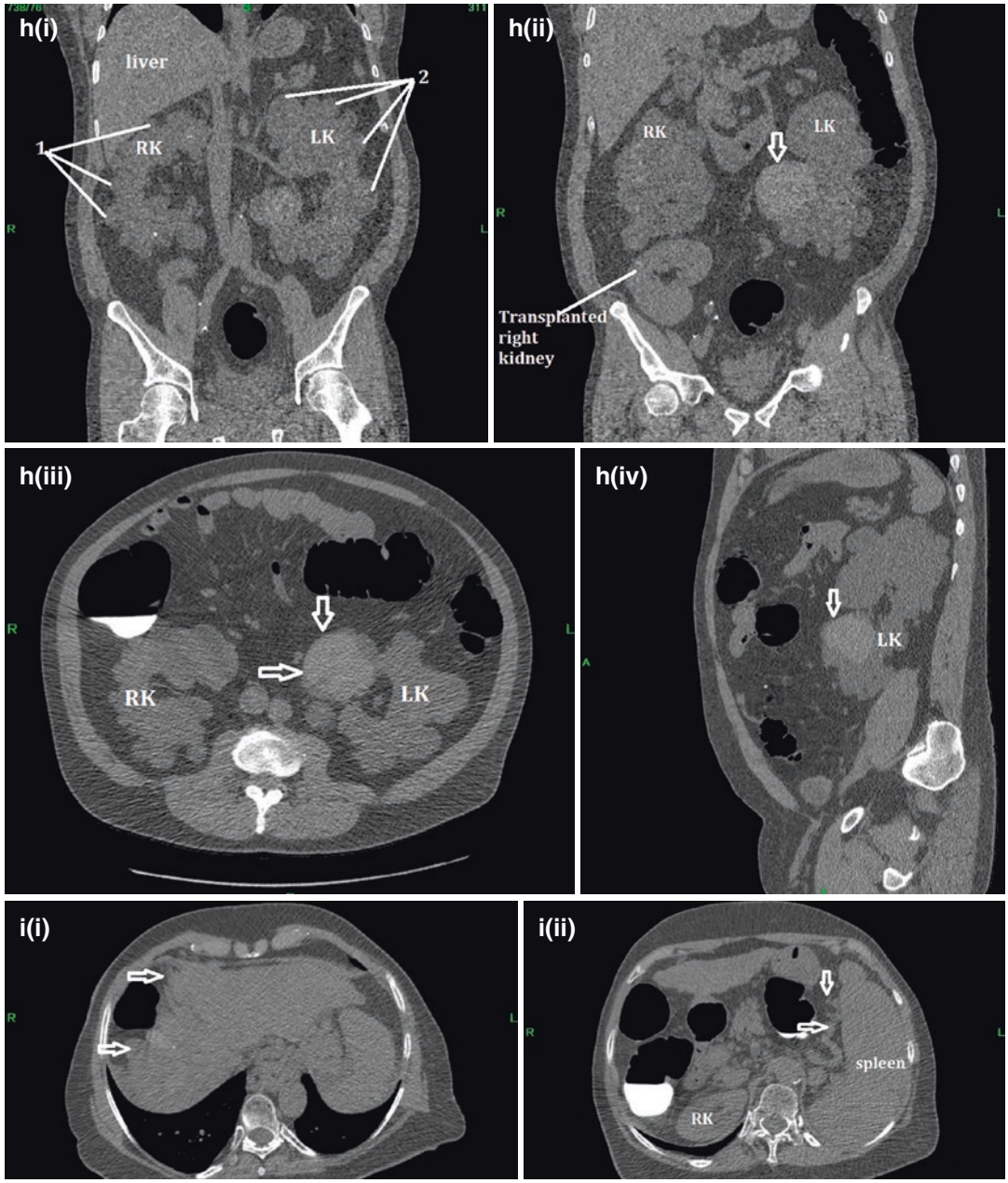

Fig. 18.4 (**h**) (**i**) This patient presented with pain in his right inguinal region and left kidney area. He declined an optical colonoscopy and chose to undergo a screening CTC study. 2D coronal view shows multiple cysts (1 and 2) in polycystic kidneys. RK = right kidney. LK = left kidney. (**ii**) 2D coronal view shows bilateral polycystic kidneys. RK = right kidney; LK = left kidney with a haemorrhagic cyst (open white arrow). Note the normal transplanted kidney in the right pelvic area. (**iii**) 2D axial view shows the haemorrhagic cyst (open white arrows). RK = right kidney. LK = left kidney. (**iv**) 2D sagittal view shows the haemorrhagic cyst (open white arrows) in the left kidney (LK). (**i**) (**i**) 2D axial view of liver showing shrunken and lobulated right lobe of liver (open white arrows). The lobulated appearance of the liver margin is secondary to infarction of the liver following selective catheterisation of the hepatic artery with chemotherapeutic agents for hepatocellular carcinoma. (**ii**) 2D axial view shows a markedly enlarged spleen (splenomegaly) due to portal hypertension with associated splenic varicosities (open white arrows). RK = right kidney

Table 18.2 Main organs and systems in the E4 findings[a]

System and organ	Percentage of $n = 7952$
Vascular system (e.g., abdominal aortic aneurysms, iliac aneurysms)	26%
Genitourinary system	18%
Liver	15%
Gastrointestinal system	10%
Lungs	9%
Gynaecologic system	7%
Pancreas, adrenal glands, and breast	4%
Others (e.g. lymphoma, sarcoidosis, early acute appendicitis)	11%

[a] Adapted from the text of Pooler et al. [23]

18.6 Bone Mineral Density Assessment

Usually opportunistic has negative connotations [24] (e.g., unprincipled, exploitation). In 1995, opportunistic screening was described as offering a test for an unsuspected pathology which is not related to the reason for the examination [25]. In radiology, opportunistic screening, according to Pickhardt [24], is the practice of maximum use of imaging data, unrelated to the clinical indication, for risk profiling and prevention of relevant disease. According to Boutin and Lenchik [26], the use of opportunistic screening for osteoporosis and sarcopenia at CT is a value-added benefit for patients. Opportunistic screening at screening CTC benefits men and women if an early diagnosis of osteoporosis is made [26–28]. Men and women who present for screening CTC would benefit if an early diagnosis of osteoporosis is made. Osteoporosis is a silent disease and pathological fractures impact on health services and the mortality of the elderly [29]. Literature reports that testing and treatment rates in men are low despite them having high prevalence of osteoporosis, osteopenia, and fractures; morbidity and mortality are significant in men with osteoporotic hip fractures [30].

Dual-energy X-ray absorptiometry (DXA or DEXA) is the most used modality to determine BMD. Two scores (i.e., T-score and Z-score) are usually presented. Both are used for women and men. A T-score indicates a comparison of the BMD of healthy 30 year old: −1.0 = normal, −1.0 to −2.5 = osteopenia, and ≥−2.5 = osteoporosis; and a Z-score compares amount of bone present with that of others in the same age group, size and sex [31]. A trabecular bone score (TBS) is a tool which adds to predicting risk of fracture in persons who are in the osteopenia or normal range [32, 33]. Furthermore, this tool may be used to adjust FRAX (fracture risk assessment tool) probabilities of fracture [33]. Literature reports that novel application of artificial intelligence (AI) and machine learning (ML) may be useful for diagnosis of osteoporosis [34]. Chapter 25 presents a discussion of AI and ML in imaging.

Table 18.3 HU range of BMD

BMD	HU
Normal	>160
Osteopenia	>100 to <160
Osteoporosis	<100

Concurrent screening for osteoporosis and CRC at CTC adds to service delivery to patients. By using the region of interest (ROI) to measure trabecular bone mineral density (BMD) of L1 of 2D CT scans does not increase radiation dose to a patient [24, 28]; if there is a compressed fracture of LI the Hounsfield unit (HU) of L2 is measured. It is recommended that the HU measurements are included in CTC reports (see Table 21.2 in Chap. 21).

The use of ROI to measure BMD provides information to identify fracture risk of patients who undergo screening CTC for CRC [35]. This means that more patients can be assessed for osteoporosis. This is important as there has been underutilisation of preventive osteoporosis strategies [30]. CTC is a cost-effective study for screening of CRC [36]; hence, there are no additional costs in opportunistic screening. Table 18.3 shows Hounsfield unit (HU) range for BMD.

The ROI must only include the trabecular bone of a vertebra to obtain an accurate HU reading. Figure 18.5a (i, ii) shows incorrect ROI placement. It is important that ROI placement is correct to obtain the HU values of trabecular bone. Correct ROI placement is illustrated in Fig. 18.5b (i, ii). Figure 18.5c (i) shows osteoporosis at CTC on a female patient and Fig. 18.5c (ii) shows osteoporosis in a male patient. As evident in Fig. 18.5d, the HU value is <100 indicating osteoporosis.

Figure 18.5e shows a grade 3 fracture of lumbar vertebra. There is ≥40% loss of vertebral height according to the Genant classification which is based on vertebral shape, and loss of ver-

tebral height involving anterior, posterior, and/or middle vertebral body. Grade 0 = normal; grade 1 = mild fracture (20–25%) loss of height; grade 2 = moderate fracture (25–40% loss of height), and grade 3 = severe fracture (>40% loss of height). Figure 18.5f (i, ii) illustrates osteopenia, namely a HU reading of >100 to <160. Osteopenia can be a risk fracture in males and females.

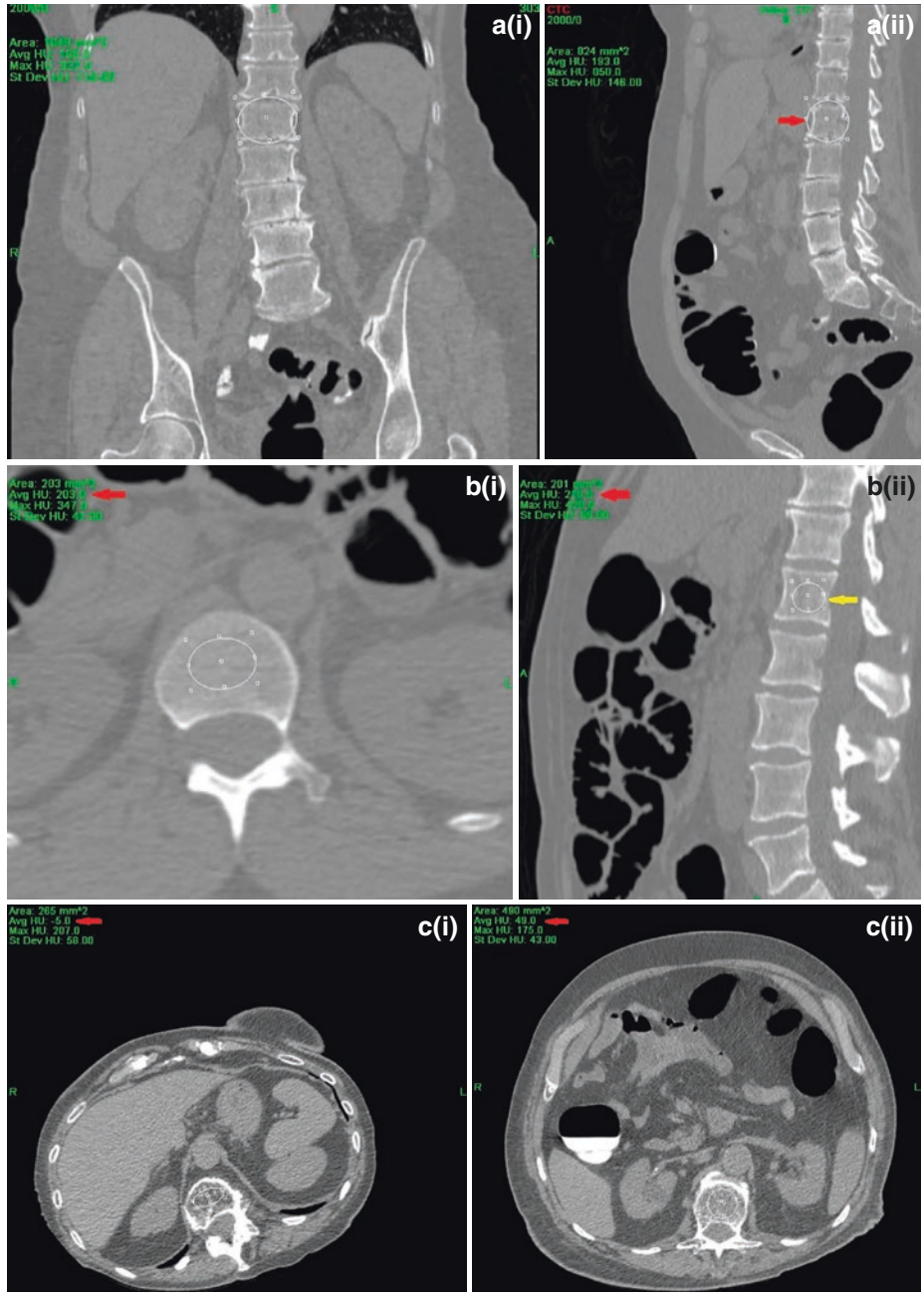

Fig. 18.5 (**a**) (**i**) Incorrect ROI placement on coronal 2D image at CTC as it extends beyond trabecular bone. (**ii**) Incorrect ROI placement on sagittal 2D image at CTC as it extends beyond trabecular bone. (**b**) (**i**) Correct ROI placement to measure BMD of lumbar vertebra at CTC. There is a vertebral venous plexus in the posterior portion of the vertebral body. To ensure correct placement the ROI should not touch cancellous bone. Red arrow shows average HU reading of 203. (**ii**) Correct ROI placement to measure BMD of L1 on sagittal 2D scan at CTC. Red arrow shows average HU reading of 210. (**c**) (**i**) HU -5 (red arrow) showing osteoporosis at CTC in a female patient. (**ii**) HU 49 (red arrow) showing osteoporosis in a male patient with a history of respiratory pathology and prolonged corticosteroid treatment.

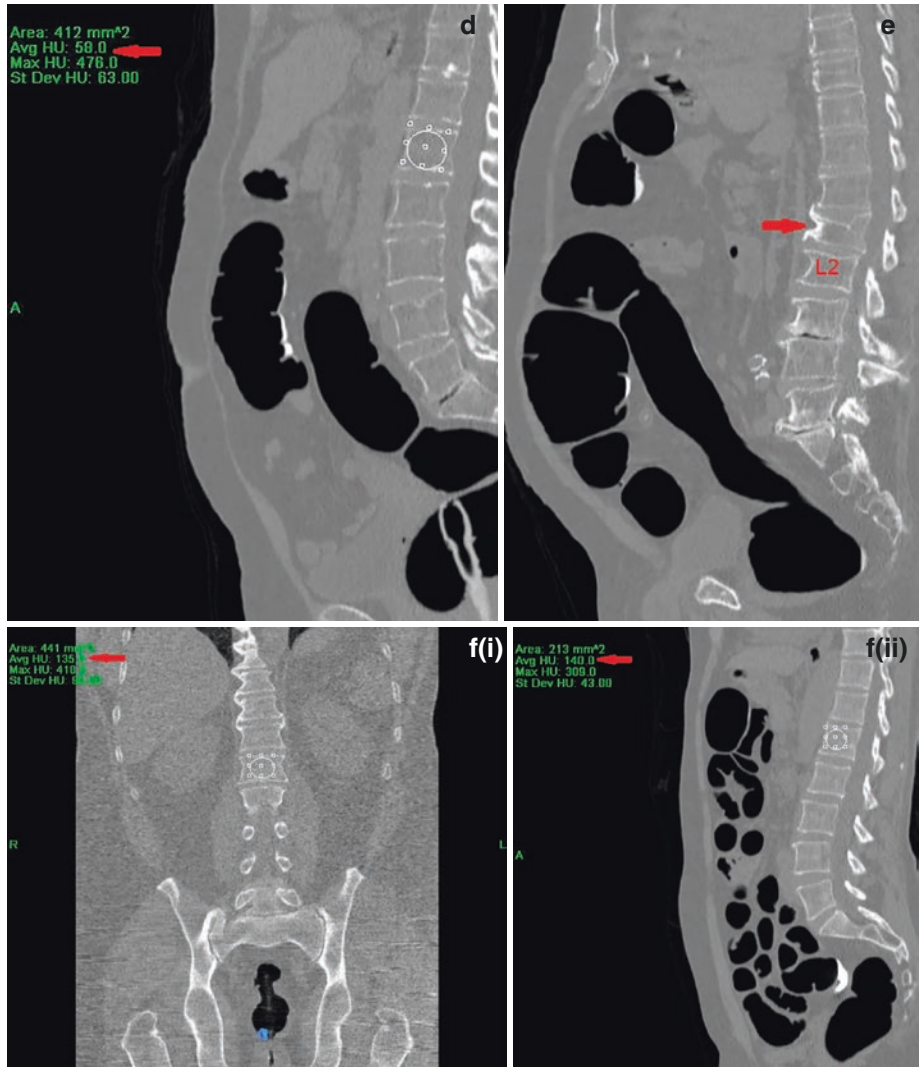

Fig. 18.5 (**d**) Average HU reading 58 (red arrow) of L1 on sagittal 2D scan at CTC showing osteoporosis. (**e**) 2D sagittal view of male patient in Fig. 18.5c (ii) showing grade 3 fracture of L1 (red arrow). (**f**) (**i**) 2D coronal view at CTC showing osteopenia in a male patient. HU 135 (red arrow) of L1. (**ii**) Sagittal view showing osteopenia in a female patient. HU 140 (red arrow)

18.7 Calcific Score: Abdominal Aortic Calcification

A recent prospective study over 14 years of bone mineral density screening and monitoring of elderly women focussed on abdominal aortic calcification (AAC) on lateral spine DXA scans [37]. The study measured the amount of calcium present in the wall of the aorta and scored the amount of calcium present as: low, moderate, and extensive. The findings were that those patients with moderate and extensive calcification had a higher incidence of dementia and hospitalisation compared to those with a low score [37]. This shows that extra-coronary vascular calcification in patients may be a marker for late-life dementia. The study only included lateral spine DXA scans. In terms of ECFs, the abdominal aorta is one of the sites where calcification is seen at CTC: AAC is common in both men and women. Late-life dementia (>80 years of age) may be related to vascular or nonvascular causes and is a major global health issue. Figure 18.6a–d shows normal abdominal aorta and abdominal aortic calcification at CTC.

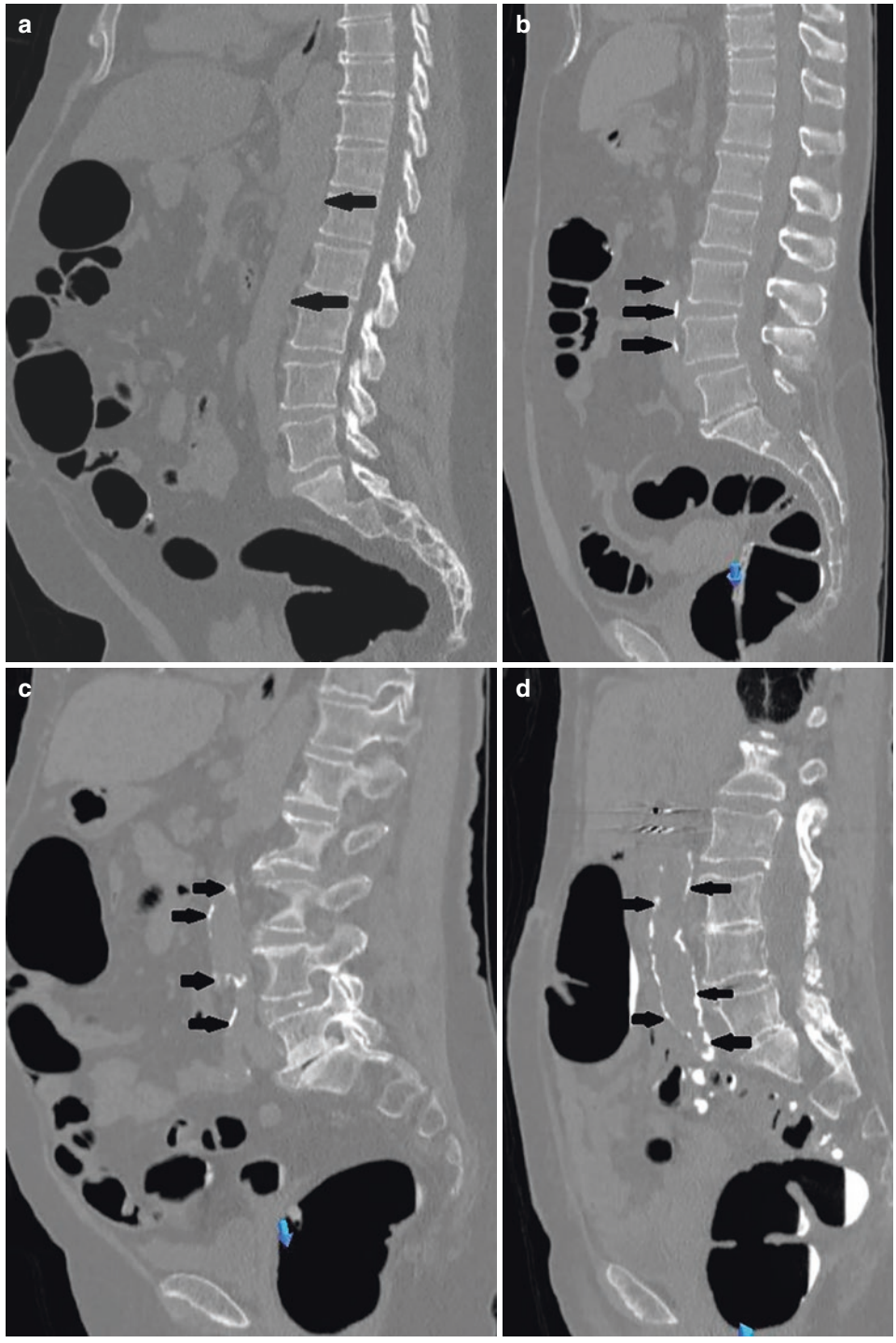

Fig. 18.6 (**a**) Sagittal view showing normal abdominal aorta (black arrows). (**b**) Sagittal view showing mild calcification in the abdominal aorta (black arrows). (**c**) Sagittal view showing moderate calcification in the abdominal aorta (black arrows). (**d**) Sagittal view showing extensive calcification in the abdominal aorta (black arrows)

18.8 Inguinal Hernias as Extracolonic Findings: An Overview, Types of Hernia, Complications, and Repair

Inguinal hernias are commonly present in males and rare in females. They often remain undiagnosed as many patients do not complain of symptoms or swelling in the groin region. Hernias at CTC are reported as ECFs. Abdominal herniation may be defined as the protrusion of part of its content from the abdominal cavity through a normal or abnormal aperture or from wall weakness [38]. Hernias may be reducible (i.e., can be safely pushed back into the abdominal cavity) or irreducible. The latter may then result in vascular compromise and possible ischaemia and ultimately gangrene [39]. A hernia may cause obstruction resulting in failure of intestinal content to pass through the obstructed area [39].

18.8.1 Types of Hernias

Hernias may be congenital or acquired. A congenital malformation occurs in new-borns whilst in adults a hernia is due to stress on the abdominal wall, or a weakness in the elderly [40]. Indirect inguinal hernias are the most common and protrude through the patent internal (deep) inguinal ring lateral to the inferior epigastric vessels. In men, the hernia may extend together with the spermatic cord into the scrotum. In women, the hernia may follow the course of the round ligament into the labia majora [41]. The peritoneal sac containing bowel loops may protrude through the inguinal canal and emerge at the external inguinal ring. Direct inguinal hernias behave differently: they extend through an acquired weakness in the posterior wall of the canal, known as the Hesselbach triangle, and pass medially to the inferior epigastric vessels. A femoral hernia on the other hand passes through the femoral canal, which is medial to the femoral vein and below the inguinal canal and lateral to the pelvic tubercle. Women have a wider bony pelvis compared to men thus femoral hernias are more common in women. Figure 18.7a (i, ii) shows a femoral hernia in a female. Figure 18.7b (i)–(vi) depicts small bowel bilateral inguinal hernia (E4 classification). Figure 18.7c (i, ii) shows a large bowel inguinal hernia (E4 classification).

18.8.2 Tips to Determine Whether Small or Large Bowel Is Trapped in an Inguinal Hernia

- If valvulae conniventes are seen within the trapped bowel, the diagnosis is small bowel as shown in Fig. 18.7d. If haustral markings are observed, then it is large bowel.
- The most accurate way of deciding whether it is small or large bowel is by looking at the colon-map, initially with small bowel included and then removing the small bowel which is usually an automatic process.
- If the contour of the large bowel remains intact, then no large bowel has herniated and the content is small bowel as shown in Fig. 18.7e (i, ii).
- When large bowel herniates, it is usually sigmoid colon. A colon-map will show displacement of sigmoid colon inferiorly, making it a left-sided hernia entering the scrotum in the male (Fig. 18.7e (iii)) and possibly in the labia of the female.
- Colon hernias are usually left-sided.

18.8.3 Frequency of Inguinal Hernias

Inguinal hernias are 20 times more common in men than women [42, 43]. Dabbas et al. [44] underscore that inguinal hernia repair was carried out almost 15 times more in men than women. They state that there has been a reduction in inguinal hernias over time accompanied by an increase in the proportion of midline abdominal wall hernia repairs. Inguinal hernias are a more common cause of groin pain, and their repair is the commonest one for hernias. Dabbas et al. [44] report that 96.8% of repair cases were in men and 3.2% in women. Figure 18.7f (i) is an ECF of small bowel in a right inguinal hernia and Fig. 18.7f (ii) is an ECF of bilateral inguinal hernias.

18.8.4 Complications

Complications of abdominal wall hernias include obstruction, incarceration and strangulation, and clinically include abdominal pain, vomiting, and distension. Adhesions are the leading cause of bowel obstruction, followed by abdominal her-

nias causing small bowel obstruction [39]. Obstruction of the colon by abdominal wall hernia is uncommon. Obstruction of small bowel is best diagnosed on multi-detector CT (MDCT) scans showing dilated bowel proximal to the hernia and normal or reduced calibre or collapsed bowel distal to the obstruction [39].

- Incarceration occurs when a hernia cannot be reduced or pushed back manually and diagnosis may be suggested if a hernia occurs through a small defect and the hernial sac has a narrow neck. Incarceration may predispose to obstruction, inflammation or ischaemia. The latter occurs due to a compromised blood supply [39].
- Strangulation may be caused by incarceration when there is free fluid within the hernia sac, bowel wall thickening is present or bowel is dilated. If the blood supply is compromised, then ischaemia or strangulation occurs. This happens when there is obstruction to the afferent and efferent loops by the hernia defect [39].

18.8.5 Surgical Repair Procedures

Surgical procedures for abdominal wall hernias repair vary from open repair to laparoscopic suture repair with or without the use of mesh. Figure 18.7 g shows repair of an inguinal hernia.

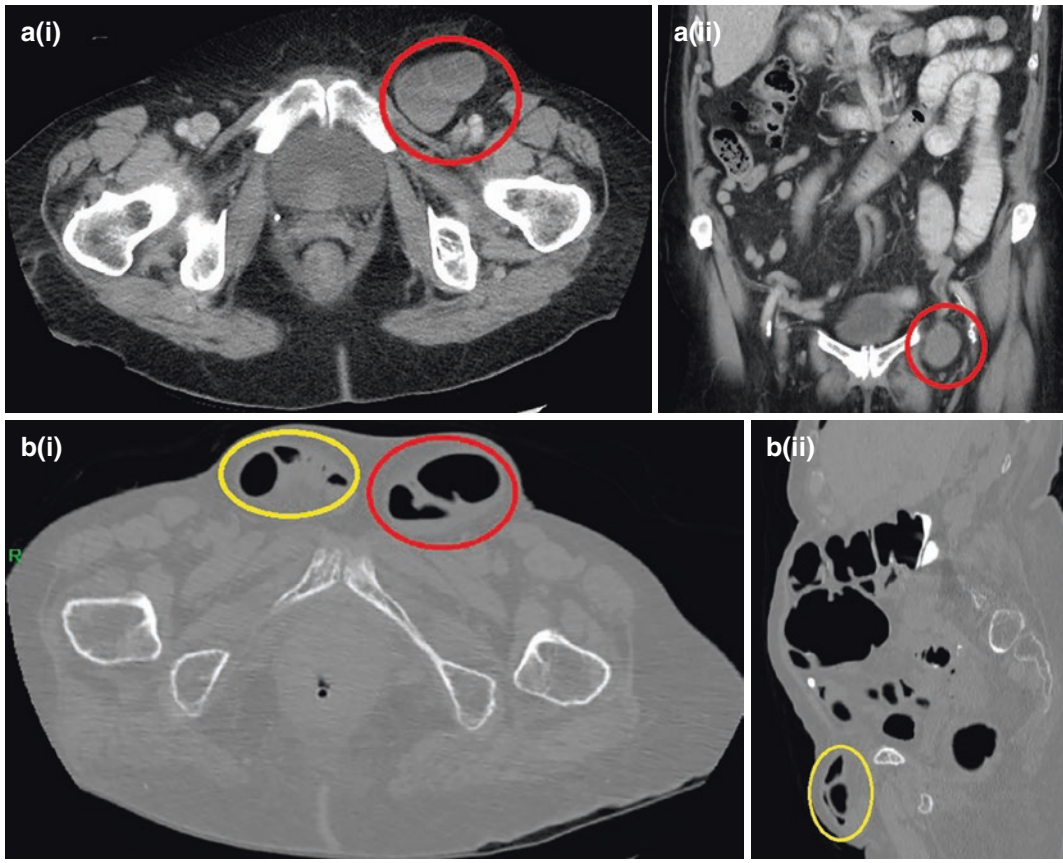

Fig. 18.7 (**a**) (**i**) 2D supine axial view showing left femoral hernia containing loops of small bowel (Courtesy of Prof D Kim, Wisconsin University). E4 classification: high clinical importance. (**ii**) 2D coronal supine view showing a loop of small bowel in a left femoral hernia. Mild proximal dilation of small bowel is present indicating partial obstruction (Courtesy of Prof D Kim, Wisconsin University). E4 classification. (**b**) (**i**) 2D axial view showing the presence of small bowel hernias in both inguinal canals (yellow and red circles). (**ii**) 2D right supine sagittal view showing small bowel hernia (yellow circle).

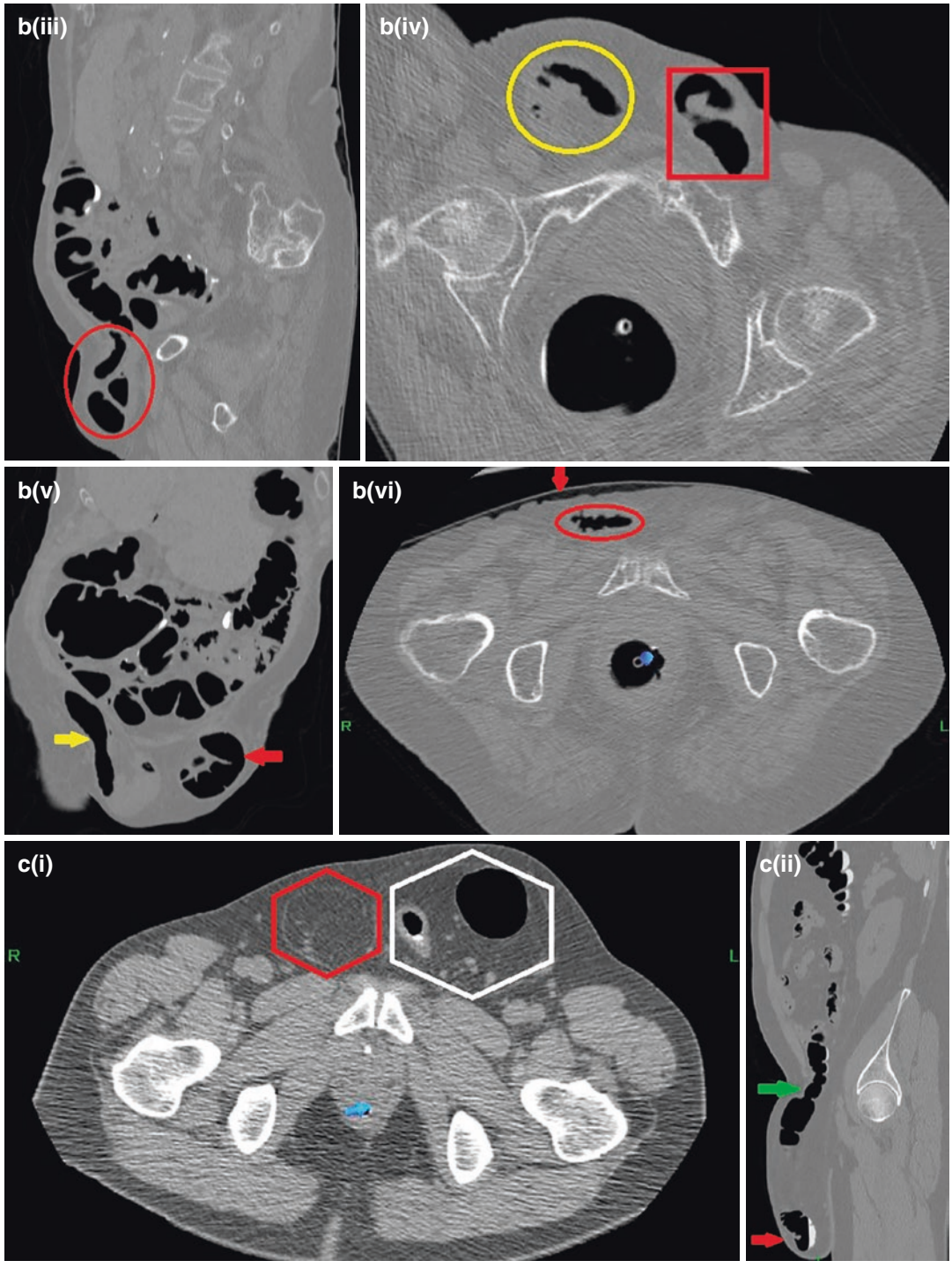

Fig. 18.7 (**b**)(**iii**) 2D left supine sagittal view showing small bowel hernia (red circle). (**iv**) 2D right decubitus view showing left hernia (red square) and right hernia (yellow circle). (**v**) 2D supine coronal view showing bilateral small bowel hernias (yellow and red arrows). (**c**) (**i**) 2D supine axial view showing bowel in left inguinal hernia (white hexagon) and fat in right inguinal hernia (red hexagon). (**ii**) 2D supine sagittal view showing bowel in the scrotum (red arrow) and small area of narrowing as it exits the inguinal canal (green arrow).

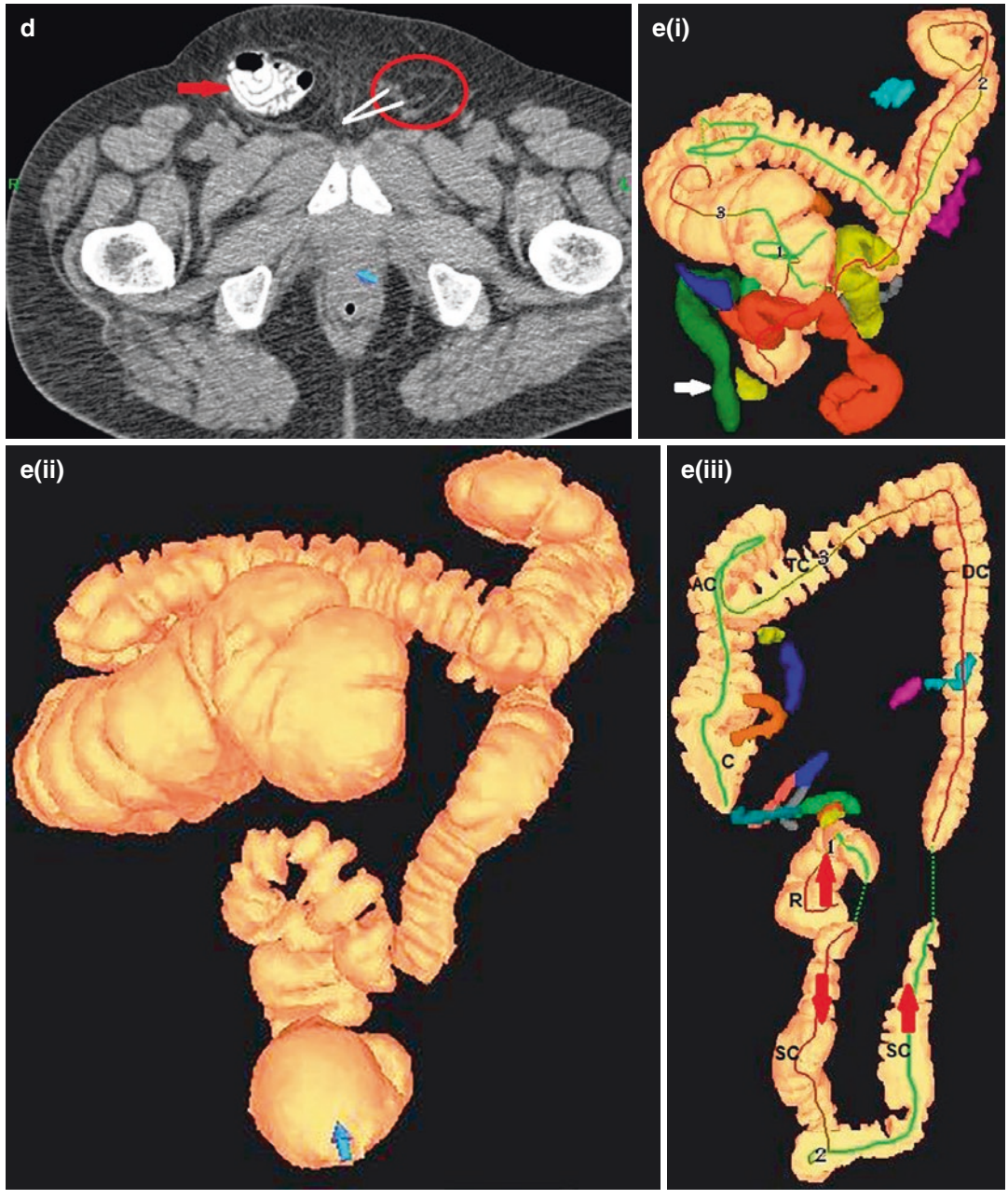

Fig. 18.7 (**d**) 2D axial scan of an abdominal CT study showing collapsed small bowel loops containing barium in a right direct inguinal hernia (red arrow). Left side shows a small direct inguinal hernia containing fat (red circle) with vessels displaced medially (white lines). (**e**) (**i**) Colon-map supine showing small bowel inguinal hernia (white arrow) on the right. (**ii**) Supine colon-map of large bowel with small bowel removed. (**iii**) Colon-map with small bowel removed showing herniation of sigmoid colon (S). R = rectum; DC = descending colon; TC = transverse colon; AC = ascending colon; C = caecum. Red arrows indicate direction of flow of CO_2 from rectum to sigmoid colon.

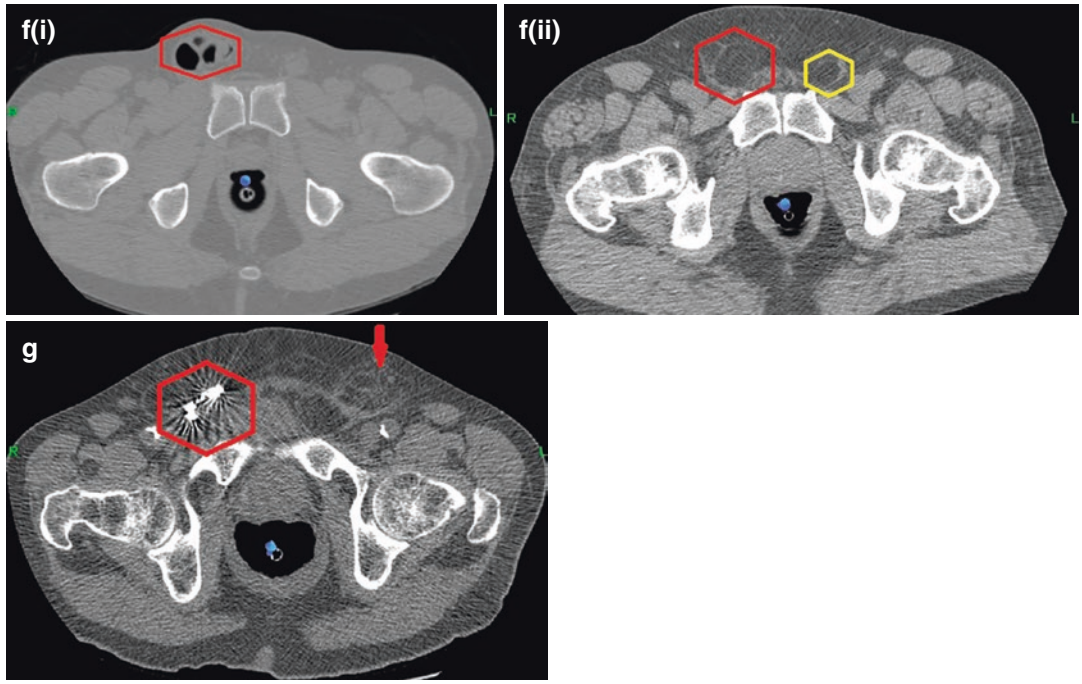

Fig. 18.7 (**f**) (**i**) 2D axial supine image showing small bowel in right inguinal hernia (red hexagon). E4 classification: high clinical importance. (**ii**) 2D axial supine view showing a right inguinal containing fat (red hexagon) and a small left inguinal hernia containing fat (yellow hexagon). E3 = moderate clinical importance. (**g**) 2D axial supine view showing repair of right inguinal hernia (red hexagon). Red arrow = left inguinal hernia

The most commonly used method is 'tension-free' mesh repair and is regarded as the standard surgical technique for the majority of cases. Complications of surgical repair may involve up to 50% of cases. Hernia recurrence is the most common one irrespective whether mesh is used or not. Fluid collection after surgery may occur as well as infection [39].

18.9 Air in Vagina

Vaginal air may be seen on 2D images; thus, it is important to carefully examine these images to exclude pathology causes as an ECF [45]. Table 18.4 lists normal causes of air in the vagina. Figure 18.8a (i, ii) shows no air in the vagina. Figure 18.8a (iii) shows air between vulva folds. Figure 18.8a (iv, v) shows air in the vagina due to yoga stretching.

Table 18.4 Normal causes of air in vagina[a]

Sexual intercourse
Insertion of objects into the vagina (e.g., pessaries or speculum)
Tampon insertion
Exercise or stretching (e.g., stretching in yoga)

[a]Adapted from Bortz [45]

It is important not to not mistake air between vulva folds as air in the vagina. If air is present it may be one or two bubbles that are rounded, horizontal, vertical, or curvilinear (Fig. 18.8b (i)–(v)). A cluster of bubbles may indicate an underlying infection or malignancy. Pathological conditions that show air in the vagina are presented in Table 18.5. Figure 18.8c (i)–(iii) shows a rectovaginal fistula at a CTC study.

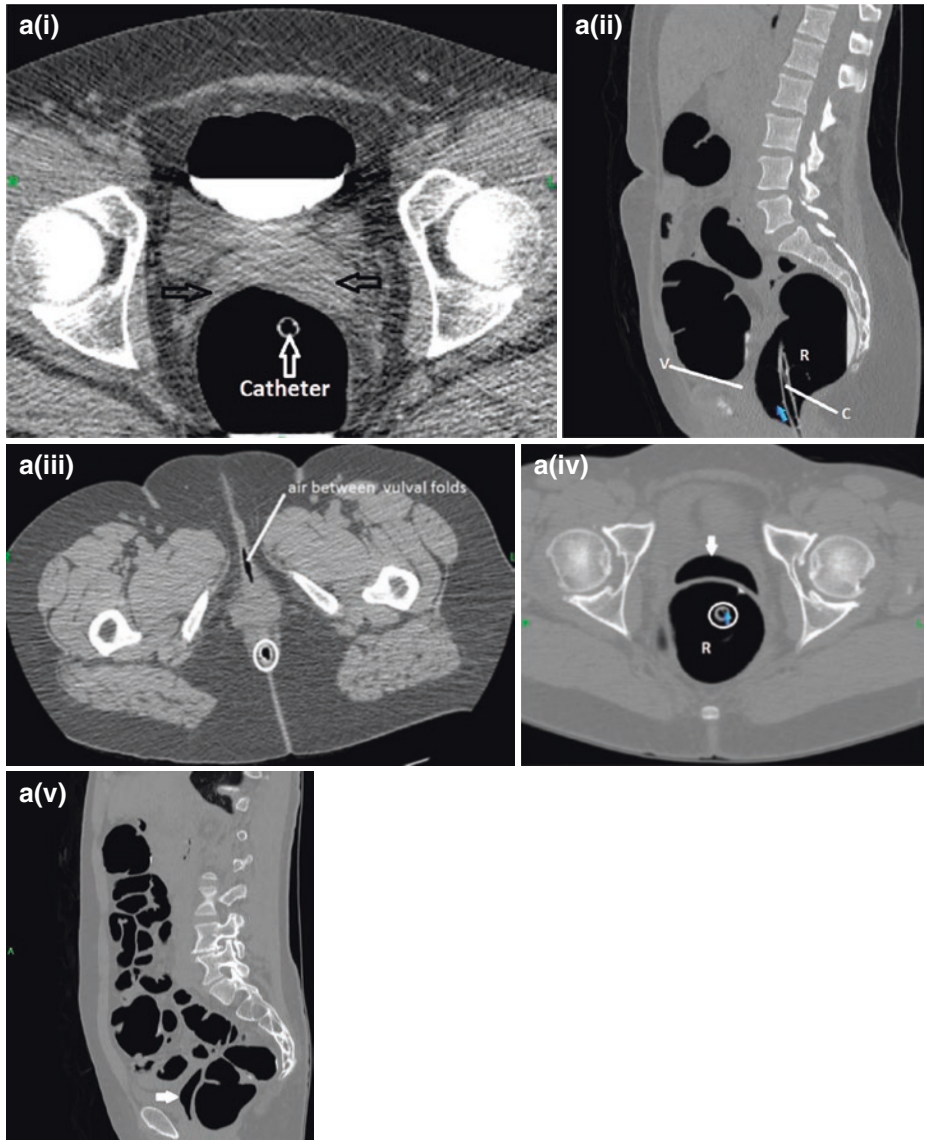

Fig. 18.8 (**a**) (**i**) 2D axial viewing showing normal vagina without air (open black arrows) and rectal catheter. (**ii**) Sagittal view showing no air in the vagina (V). Rectal catheter (C). Rectum (R). (**iii**) Axial supine view showing air between vulval folds. White circle = rectal catheter. (**iv**) 2D axial view showing a large amount of air in the vagina (white arrow). R = rectum; circle = catheter. This air was caused by yoga exercises. (**v**) Sagittal view showing a large amount of air in the vagina (white arrow) post yoga exercises

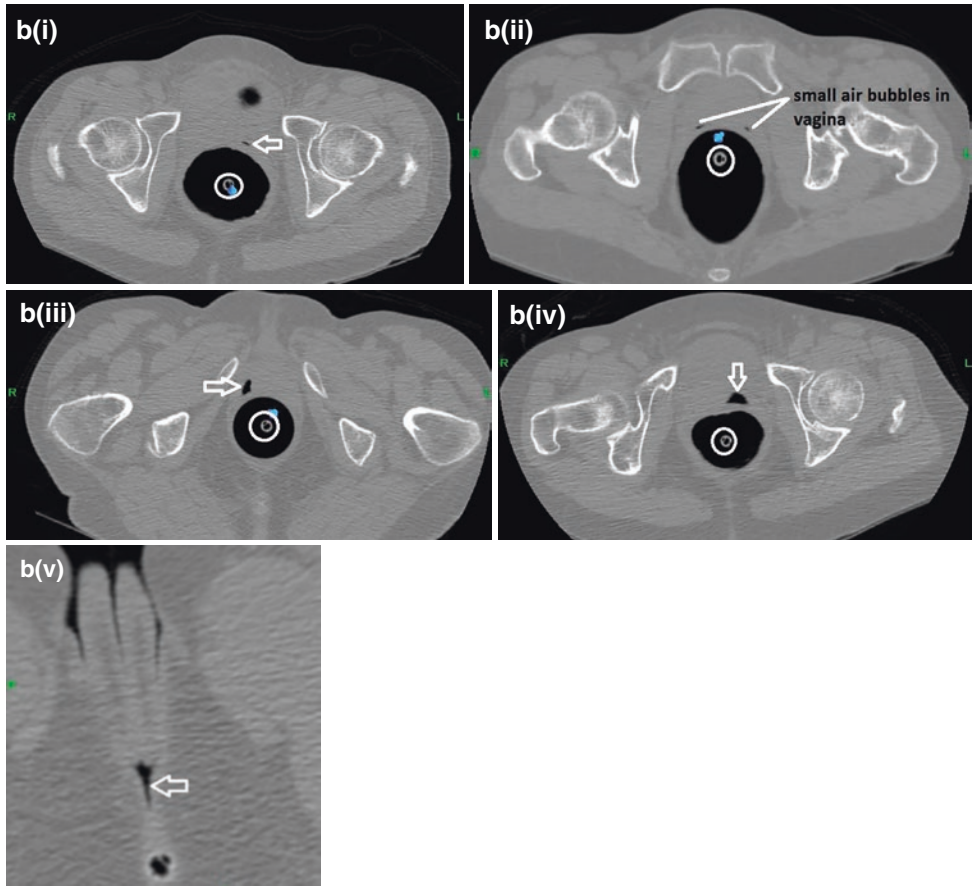

Fig. 18.8 **(b) (i)** 2D Axial showing solitary air bubble in the vagina (open white arrow). Circle = rectal catheter. (**ii**) 2D axial view showing two small air bubbles in the vagina. Circle = rectal catheter. (**iii**) 2D axial view showing curvilinear air in vagina (open white arrow). Circle = rectal catheter. (**iv**) 2D axial showing a triangular shape air bubble air (open white arrow). Circle = rectal catheter. (**v**) 2D view showing air in the vagina (open white arrow)

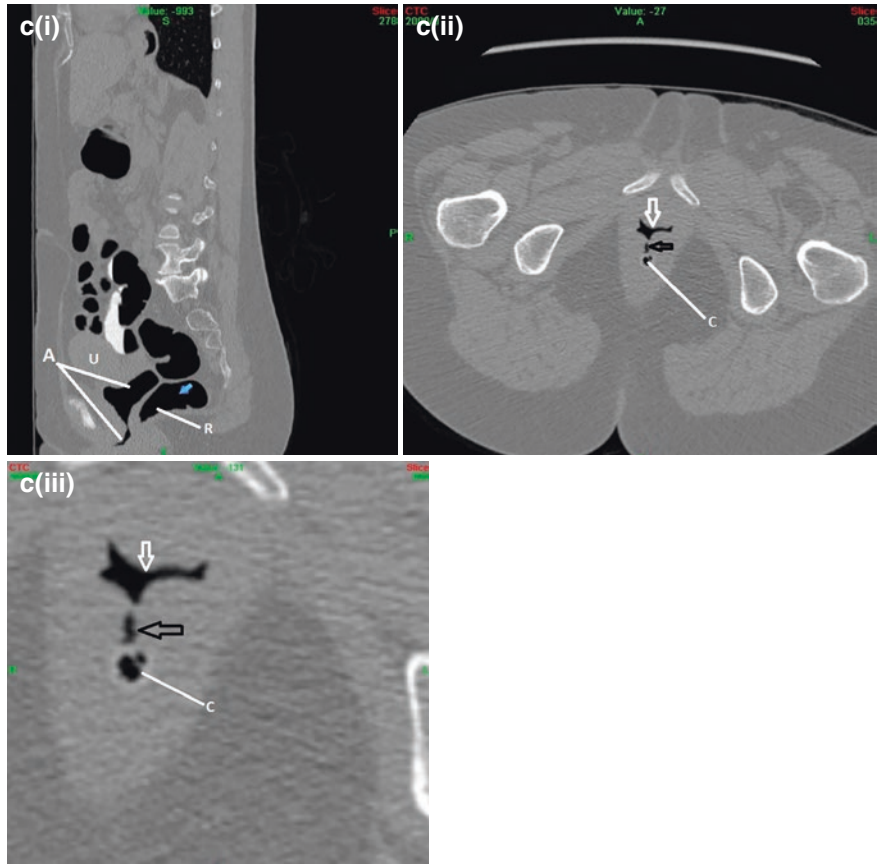

Fig. 18.8 (**c**) (**i**) Sagittal view showing air in the vagina (A). Rectovaginal fistula = bottom white line. Rectum (R); Uterus (U). (**ii**) 2D prone axial demonstrates a fistulous tract (open black arrow) between the rectum (C = rectal catheter) and the vagina (open white arrow).(**iii**) 2D close-up view showing the rectovaginal fistula. Open black arrow = fistulous tract; open white arrow = air in the vagina; C = rectal catheter

Table 18.5 Air in the vagina due to pathology

Inflammatory bowel disease, especially Crohn's disease[a]. CTC is not performed on patients with inflammatory bowel disease[b]
Pelvic malignancies arising from the cervix or uterus; vaginal secondaries from breast cancer or melanoma[c]
Radiotherapy to the pelvis[a]
Recto or colo-vaginal fistula[a]
Pelvic floor dysfunction or prolapse following childbirth, enterocoele, rectocoele, or vaginal prolapse[d]

[a] Das and Snyder [46]
[b] Bortz [47]
[c] Bortz [45]
[d] Krissi et al. [48]

18.10 Comparison of ECFs and Clinical Outcomes at Screening and Diagnostic CTC

A recent comparative study was done to determine the distribution of ECFs and clinical outcomes in 388 patients who underwent screening and diagnostic CTC studies [49]. The majority (262/68%) had screening CTC studies compared to the diagnostic CTC cohort (126/32%). The majority (84.%) had E1 and E2 ECFs as shown in Table 18.6. The distribution of ECFs distribution and clinical outcomes showed there was no statistically significant difference between the screening and diagnostic CTC population (4.4%/4.0%) [49].

Table 18.6 Total ECFs [a]

E classification	Percentage of $n = 388$
E1 and E2	88.4% ($n = 347$)
E3	4.4% ($n = 17$)
E4	7.2% ($n = 28$)

[a] Adapted from the text of Taya et al. [49]

Key Messages

- Extracolonic findings are an integral part of a CTC examination and must be reported on even if the examination is considered non-diagnostic.

- Although the number of ECFs are high, only a small percentage are of significant clinical importance.
- A low-dose technique without intravenous contrast is used.
- The most common findings include abdominal aortic aneurysm, renal carcinoma, lymphadenopathy, and ovarian tumours.
- Opportunistic screening for bone mineral density should be included in a CTC study.
- When a hernia containing bowel is visualised, it is important to determine whether it is reducible or whether obstruction, incarceration, or strangulation has occurred and which bowel (large or small) is involved.
- A cluster of bubbles in a vagina may indicate an underlying infection or malignancy.

18.11 Summary

Detection of ECFs is an unavoidable responsibility of the radiologist or radiographer who interprets the CTC images. Most ECFs are determined to be clinically inconsequential on CTC and most patients do not have further testing. A disclaimer should be in CTC reports, namely that the lack of intravenous contrast material and low-dose technique limit the evaluation of CT findings outside the colon. It is essential to report ECFs in poor quality non-diagnostic CTC studies to ensure that if the abnormalities are deemed to be clinically important this will result in further diagnostic studies or medical/surgical follow-up.

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References

1. British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiologists. Guidance on the use of CT colonography for suspected cancer (Ref No.: BF CR [14]9), 2014. [Cited 2022 October 7]. www.rcr.ac.uk.
2. Jensch S, van Gelder E, Florie J, et al. Performance of radiographers in the evaluation of CT colonographic images. AJR Am J Roentgenol. 2007;188:W249–55.
3. Lauridsen C, Lefere P, Gerke O, et al. Comparison of the diagnostic performance of CT colonography interpreted by radiologists and radiographers. Insights Imaging. 2013;4:491–7. https://doi.org/10.1007/s13244-013-0260-x.
4. Yee J, Kumar NN, Godara S, et al. Extracolonic abnormalities discovered incidentally at CT colonography in a male population. Radiology. 2005;236:519–26.
5. Plumb AA, Boone D, Fitzke H, et al. Detection of extracolonic pathologic findings with CT colonography: a discrete choice experiment of perceived benefits versus harms. Radiology. 2014;273(1):144–52.
6. Wernli KJ, Rutter CM, Dachman AH, Zafar HM. Suspected extracolonic neoplasms detected on CT Colonography: literature review and possible outcome. Acad Radiol. 2013;20(6):667–74.
7. Pickhardt PJ, Taylor AJ. Extracolonic findings identified in asymptomatic adults at screening CT colonography. AJR Am J Roentgenol. 2006;186:718–28.
8. Chin M, Mendelson R, Edwards J, et al. Computed tomographic colonography: prevalence, nature and clinical significance of extracolonic findings in a community screening program. Am J Gastroenterol. 2005;100(12):2771–6.
9. Pickhardt PJ, Choi JR, Hwang I, et al. Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. N Engl J Med. 2003;349(23):2191–200.
10. Hara AK, Johnson CD, MacCarty RL, et al. Incidental extracolonic findings at CT colonography. Radiology. 2000;215:353–7.
11. Gluecker TM, Johnson CD, Wilson LA, et al. Extracolonic findings at CT colonography: evaluation of prevalence and cost in a screening population. Gastroenterology. 2003;124(4):911–6.
12. Pickhardt PJ, Hanson ME, Vanness DJ, et al. Unsuspected extracolonic findings at screening CT colonography: clinical and economic impact. Radiology. 2008;249(1):151–9.
13. Yee J, Sadda S, Aslam R, et al. Extracolonic findings at CT colonography. Gastrointest Endoscopy Clin N Am. 2010;20:305–22.
14. Veerappan GR, Ally MR, Choi JR, et al. Extracolonic findings on CT colonography increases yield of colorectal cancer screening. AJR Am J Roentgenol. 2010;195(3):677–86. https://doi.org/10.2214/ajr.09.3779.
15. Macari M, Nevsky G, Bonavita J, et al. CT colonography in senior versus non senior patients: extracolonic findings, recommendations for additional imaging, and polyp prevalence. Radiology. 2011;259(3):767–74.
16. Tolan J, Armstrong EM, Chapman AH. Replacing barium enema with CT colonography in patients older than 70 years: the importance of detecting extracolonic abnormalities. AJR Am J Roentgenol. 2007;189:1104–11.
17. Boone D, Mallet S, Zhu S, et al. Patients' & healthcare professionals' values regarding true- & false-positive diagnosis when colorectal cancer screening by CT colonography: discrete choice experiment. PLoS One. 2013;8(12):e80767.
18. Tsui K, Shvarts O, Smith R, et al. Renal cell carcinoma: prognostic significance of incidentally detected tumours. J Urol. 2000;163(2):426–30.

19. Pickhardt PJ, Kim D, Meiners RJ, et al. Colorectal and extracolonic cancers detected at screening CT colonography in 10,286 asymptomatic adults. Radiology. 2010;255(1):83–8.
20. Halligan S, Woolradge K, Dadswell E, et al. Identification of extracolonic pathologies by computed tomographic colonography in colorectal cancer symptomatic patients. Gastroenterology. 2015;149(1):89–101.e5.
21. Zalis ME, Barish MA, Choi JR, et al. CT colonography reporting and data system: a consensus proposal. Radiology. 2005;236(1):3–9. https://doi.org/10.1148/radiol.2361041926.
22. Siddiki H, Fletcher JG, McFarland B, et al. Incidental finding in CT colonography. Literature review and survey of current research practice. J Law Med Ethics. 2008;36(2):320–31, 213. https://doi.org/10.1111/j.1748-720X.2008.00276.x.
23. Pooler BD, Kim DH, Pickhardt PJ. Potentially important extracolonic findings at screening CT colonography: incidence and outcome of data from a clinical screening program. AJR Am J Roentgenol. 2016;206:313–8. [cited 2022 October 7]. https://www.ajronline.org/doi/full/10.2214/AJR15.15193.
24. Pickhardt PJ. Value-added opportunistic CT screening: state of the art. Radiology. 2022;303(2):241–54. https://doi.org/10.1148/radiol.211561.
25. Law M. "Opportunistic" screening. J Med Screen. 1995;1:208.
26. Boutin RD, Lenchik L. Value-added opportunistic CT: insights into osteoporosis and sarcopenia. AJR Am J Roentgenol. 2020;215(3):582–94. https://doi.org/10.2214/AJR.20.22874.
27. Ziemlewicz TJ, Binkley N, Pickhardt PJ. Opportunistic osteoporosis screening: addition of quantitative CT bone mineral density evaluation to CT colonography. J Am Coll Radiol. 2015;12(10):1036–41. https://doi.org/10.1016/j.jacr.2015.04.018.
28. Summers RM, Baecher N, Yao J, Liu J, et al. Feasibility of simultaneous CT colonography and fully automated bone mineral densitometry in a single examination. J Comput Assist Tomogr. 2011;35(2):212–6.
29. Pisani P, Renna MD, Conversano F, Casciaro E, Di Paola M, et al. Major osteoporotic fragility fractures: risk factor updates and societal impact. World J Orthop. 2016;7(3):171–81.
30. Willson T, Nelson SD, Newbold J, Nelson RE, LaFleur J. The clinical epidemiology of male osteoporosis: a review of recent literature. Clin Epidemiol. 2015;7:65–76.
31. Kanis JA. Diagnosis of osteoporosis and assessment of fracture risk. Lancet. 2002;359:1929–36.
32. Bazzocchi A, Ponti F, Diano D, Amadoni M, Albisinni U, Battishta G, Guglielmi G. Trabecular bone score in healthy aging. Br J Radiol. 2015;88:20140865. https://doi.org/10.1259/bjr.20140865.
33. Rajan R, Chenan KE, Kapoor N, Pauli V. Trabecular bone score—an emerging tool in the management of osteoporosis. Indian J Endocrinol Metab. 2020;24:237–43. https://doi.org/10.4103/ijem.IJEM_147_20.
34. Smets J, Shevroja E, Hügle T, Leslie WD, Hans D. Machine learning solutions for osteoporosis—a review. J Bone Miner Res. 2021;36(5):833–51. https://doi.org/10.1002/jbmr.4292.
35. Pickhardt PJ, Lee LJ, del Rio AJ, Lauder T, Bruce RJ, et al. Simultaneously screening for osteoporosis at CT colonography: bone mineral density assessment using MDCT attenuation technique compared with the DXA reference standard. J Bone Miner Res. 2011;26(9):2194–203.
36. Obaro AE, Burling DN, Plumb AA. Colon cancer screening with CT colonography: logistics, cost-effectiveness, efficiency and progress. Br J Radiol. 2018;91:20180307. https://doi.org/10.1259/bjr.20180307.
37. Porter T, Sim M, Prince RL, Schousboe JT, Bondonno C, Lim WH et al. Abdominal aortic calcification on lateral spine images captured during bone density testing and late-life dementia risk in older women: a prospective cohort study. Lancet Regional Health Western Pacific.2022;26: 100502. doi:https://doi.org/10.1016/j.lanwpc.2022.100502.
38. Mathieu D, Luciani A. Internal abdominal herniations. AJR Am J Roentgenol. 2004;183:397–404.
39. Aguirre DA, Santosh AC, Cabola G, et al. Abdominal wall hernias: imaging features, complications, and diagnostic pitfalls at multi-detector row CT. Radiographics. 2005;25:1501–20.
40. Lassandro F, Iasiello F, Pizza NL, et al. Abdominal hernias: radiological features. World J Gastrointest Endosc. 2011;3(6):110–7.
41. Miller PA, Mezwa DG, Feezbo PJ, et al. Imaging of abdominal hernias. Radiographics. 1995;15:333–47.
42. Brooks DC, Hawn M. Classification, clinical features, and diagnosis of inguinal and femoral hernias in adults. [Cited 2022 October 7]. https://www.uptodate.com/contents/classification-clinical-features-and-diagnosis-of-inguinal-and-femoral-hernias-in-adults/print.
43. Sulaiman J, Sahayam SJ, Senthurpandian S, Anandan H. A study of incidence of different types of groin hernias in adults. Int J Sci Study. 2018;5(10):87–90.
44. Dabbas N, Adams K, Pearson K, Royle G. Frequency of abdominal wall hernias: is classical teaching out of date? JRSM Short Rep. 2011;2(1):5. https://doi.org/10.1258/shorts.2010.010071.
45. Bortz JH. A case study of air in the vagina at screening CT colonography including incidental visualisation of a rectrovaginal fistula. SAR. 2017;55(1):23–6.
46. Das B, Snyder M. Rectovaginal fistulae. Clin Colon Rectal Surg. 2016;26(1):50–6.
47. Bortz JH. CT colonography: an approach for a successful examination. S Afr J Rad. 2014;18(1):607, 11 pages. https://doi.org/10.4102/sajr.v18i1.607SAJR2014.
48. Krissi H, Medina C, Stanton SL. Vaginal wind—a new pelvic symptom. Int Urogynecol J. 2003;14:399. https://doi.org/10.1007/s00192-003-1086-8.
49. Taya M, McHargue C, Ricci ZJ, Flushberg M, Weinstein S, Yee J. Comparison of extracolonic findings and clinical outcomes in a screening and diagnostic CT colonography population. Abdom Radiol (NY). 2019;44(3):429–37.

19 Metabolic-Associated Fatty Liver Disease: Opportunistic Screening at CT Colonography

Joel H. Bortz

19.1 Introduction

In this chapter, the novel term metabolic-associated fatty liver disease (MAFLD) previously termed non-alcoholic fatty liver disease (NAFDL) [1, 2] is used. According to a group of experts, the term non-alcoholic fatty liver disease (NAFLD) does not reflect current knowledge associated with fatty liver disease in terms of associated metabolic dysfunction [3]. They suggest the use of metabolic-associated fatty liver disease (MAFLD) as an overarching term to cover specific metabolic conditions in terms of inclusion criteria compared to the exclusion criteria of NAFLD. This suggested term is supported by many international patients because the term NAFLD is not acceptable in terms of their religious, cultural, and spiritual beliefs [4]. The use of alcoholic in the term to describe their clinical condition leads to them being stigmatised; they therefore support the suggested use of MAFLD [4].

The global prevalence of metabolic-associated fatty liver disease (MAFLD) has increased by 25% [5, 6]. Such a prevalence could lead to a clinical and economic burden [7]. In radiology, opportunistic screening is the practice of maximum use of imaging data, unrelated to the clinical indication, for risk profiling and prevention of relevant disease [8]. According to Pickhardt [8], opportunistic screening allows for early detection of, for example, liver fat content on unenhanced scan. AI-based CT tools or manual region of interest (ROI) assessment can be used in opportunistic screening of the liver [8]. It is therefore important that the liver should be carefully assessed during screening CTC as it allows visualisation of the colon as well as extracolonic structures [9, 10]. The examination includes visualisation of the liver as an extracolonic organ; unenhanced images of the liver and spleen are obtained. A reader can compare these two organs' respective CT attenuation values (Hounsfield units/HU) [11]. This allows for differentiation and quantification of visceral and subcutaneous fat; liver fat (steatosis) can be accurately quantified [12]. Moderate steatosis is when unenhanced liver attenuation under 40 HU corresponds to 15% proton fat fraction calculated from MRI [8]. In the absence of multiple blood transfusions, or amiodarone therapy, if the attenuation of unenhanced liver exceeds 75 HU then iron overload must be considered [8].

Steatosis used to be considered a self-limiting and relatively benign condition, but is now recognised as a typical feature of MAFLD (formerly NAFLD), which may lead to non-alcoholic steatohepatitis (NASH/MASH), and even cirrhosis [13, 14]. Figure 19.1a and b are examples of a normal liver and hepatic steatosis. MAFLD is an extracolonic finding (ECF) which needs to be

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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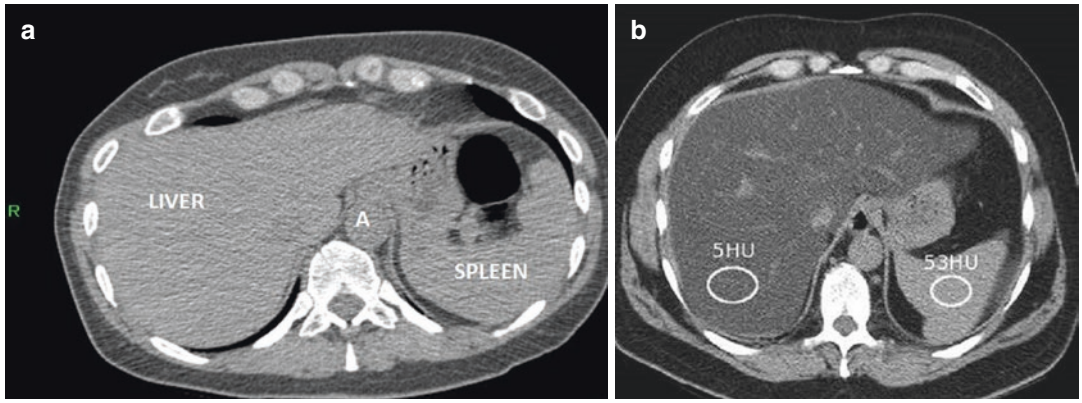

Fig. 19.1 (**a**) 2D axial view showing equal density between the liver and the spleen (normal liver HU is 65, spleen HU 55–65) [E1]. *A* aorta. (**b**) 2D axial view showing hepatic steatosis in keeping with severe fatty infiltration as liver attenuation is 5 Hounsfield units (HU) whereas the spleen reading is 53HU [E3] (Image courtesy of Prof P Pickhardt, Wisconsin University)

reported in terms of the E-classification [9, 15]. The reasons for this are discussed further in this chapter.

The incidence of MAFLD has risen considerably over the last few years. Its incidence has been linked to the rapid rise in the prevalence of obesity [16]. It is the most common disease affecting the liver in the United States of America (USA), and is the leading cause of abnormal liver functions [17]. The worldwide prevalence varies considerably between 20 and 31% in the general population, and up to 70% in patients with type 2 diabetes mellitus [18, 19]. It has a strong association with insulin resistance (IR) and hyperglycaemia and is thus closely linked to type 2 diabetes [20]. It begins initially with the intracellular accumulation of triglycerides resulting in a condition known as hepatic steatosis [21]. The latter occurs when the fat content exceeds 5% of liver volume; it is the first recognisable stage of MAFLD [20]. At this stage, a patient is asymptomatic. Furthermore, literature reports a high prevalence of MAFLD in the post-acute Covid syndrome [22].

MAFLD in asymptomatic patients is frequently seen as an incidental finding at cross-sectional imaging studies [11]. Within a CTC context, this would be an ECF. Literature however shows an inter-related common fat thread between metabolic syndrome, hepatic steatosis, visceral fat, MAFLD, and cardiovascular disease (CVD) [12]. Literature also reports there is an association between cardiovascular risk factors and colorectal cancer (CRC) [23]. MAFLD is the leading cause of hepatocellular carcinoma (HCC) [5, 24]. In other words, patients with MAFLD have an increased risk of HCC. According to Younossi et al. [24], NAFLD [MAFLD] in the USA is becoming a major cause of HCC and is associated with shorter survival time and more advanced tumour stage. From 2004 to 2009 there was a 9% annual increase of NAFLD [MAFLD] HCC [24]. Literature has reported on identified genes in HCC induced by NAFLD/MAFLD [25].

Hepatitis C virus (HCV) is also a common cause of chronic liver disease in North America [26]. It too leads to hepatic steatosis, which is present in ~50% of subjects with HCV. Hepatic steatosis, in most subjects, is related to the metabolic syndrome, often accompanied by MAFLD.

Important acronyms, abbreviations, and terms, used in the literature and in this paper are presented in Table 19.1. Other abbreviations used in this chapter are listed below.

- ECFs: extracolonic findings
- E2: low clinical importance
- E3: moderate clinical importance
- E4: significant importance
- MRS: MR spectroscopy
- US: ultrasound
- USA: United States of America
- WHO: World Health Organisation

Table 19.1 Important acronyms, abbreviations and terms

ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
CC	Cryptogenic cirrhosis: end stage of chronic liver disease
CTC	Computed tomographic colonography (a.k.a. virtual colonoscopy, CT pneumocolon)
CVD	Cardiovascular disease
GGT	Gamma-glutamyltransferase
Hepatic steatosis	Fat content exceeds 5% of liver volume
HCC	Hepatocellular carcinoma
HCV	Hepatitis C virus
HU	Hounsfield unit
IR	Insulin resistance
Metabolic syndrome	Risk factor that arises from IR together with abnormal adipose deposition and function
MAFLD	Overarching term for all fatty liver disease, metabolic dysfunction
NAFLD	Non-alcoholic fatty liver disease
NASH	Non-alcoholic steatohepatitis
ROI	Region of interest
Steatosis	Build-up of fat within the liver

19.2 Importance of Reporting MAFLD Seen at CTC: E-Classification

Zalis et al. [15] recommended reporting extracolonic findings (ECFs) in terms of their clinical importance, namely

- low importance: low clinical importance thus no immediate impact on patient management (E2)
- moderate importance: usually benign but may require further work-up (E3)
- significant importance/medically important (E4).

Table 19.2 shows E1 to E4 classification. Until recently, fatty liver was considered a common finding without a potential risk [13]. Some authors mention the importance of life style modification for fatty liver as an ECF [27, 28]. It is now considered to be of clinical importance [10]. Professor D Kim (personal communication, June 2017) stated that some radiologists may classify it as E2 (low clinical importance), and others as E3 (moderate clinical importance). A revised classification of ECFs is a work in progress and should be published within the next few months.

Table 19.2 E classification[a]

E1	***Not of clinical importance*** Normal examination or anatomic variant	No extracolonic abnormalities visible Anatomic variant, for example, retro-aortic left renal vein
E2	***Low clinical importance*** Clinically unimportant findings	No work-up indicated, for example • Liver, kidney: simple cysts • Non-obstructing renal stones • Non-obstructing gall stones • Gallbladder: cholelithiasis without cholecystitis • Vertebra: haemangioma • Arterial calcification • Calcified granuloma • Uncomplicated hernias (inguinal, hiatal, femoral, enterocoele) • Various skeletal abnormalities • Adrenal adenomas • Renal calculi • Lipoma • Uterine fibroids
E3	***Moderate clinical importance*** Likely unimportant finding and likely to be benign. Incompletely characterised NB: In nearly all cases of asymptomatic patients, these lesions prove to be benign	Further work-up may be indicated • Kidney: minimally complex or homogeneously hyper-attenuating cyst • Complicated renal cysts • Prominent adnexal lesions in women • Indeterminate pulmonary nodules • Indeterminate liver lesions • MAFLD (metabolic-associated fatty liver disease): formerly NAFLD (non-alcoholic fatty liver disease) • Pleural effusions • Cardiomegaly • Splenomegaly • Complicated hiatus hernia
E4	***High clinical importance*** Potentially important finding. Communicate to referring physician as per accepted practice guidelines NB: Appendicitis, diverticulitis, pancreatitis, irreducible inguinal hernia, pneumothorax, pneumoperitoneum must be communicated to the referring physician/ health practitioner	• Kidney: solid renal mass • Liver masses • Lymphadenopathy ≥10 mm • Vasculature: aortic aneurysms >50 mm • Lung: non-uniformly calcified pulmonary nodule ≥10 mm • Irreducible inguinal hernia containing large bowel

[a] Adapted from Zalis et al. [15]. See also Bortz [9, 10]

19.3 MAFLD and Non-alcoholic Steatohepatitis (NASH)

MAFLD is the most common cause of chronic liver disease in the general population. It occurs when >5% of hepatocytes are infiltrated by triglycerides in the absence of an alcohol history, as well as without any other causes of liver disease. It is a slowly progressive disease ranging from simple steatosis through to inflammation with hepatocyte ballooning and necrosis to variable degrees of fibrosis, ultimately leading to cirrhosis and an increased risk of HCC [29].

NASH (non-alcoholic steatohepatitis), which is based on exclusion criteria, is the more advanced form of the disease. The term NASH refers to advanced liver disease that histologically mimics alcoholic steatohepatitis in patients without a history of excessive alcohol consumption whereas metabolic-associated steatohepatitis (MASH) is based on inclusion criteria [1]. Hence, NASH/MASH is the combination of fat in the liver associated with inflammatory changes, which in turn cause a higher risk of cardiovascular disease (CVD) and mortality [30]. The next stage is when hepatic inflammation occurs and is defined as the presence of hepatic steatosis and inflammation with hepatocyte injury (ballooning) with or without fibrosis [18]. Its prevalence in the general population is estimated at 3–5%. Patients with NASH

[MASH] are at a much higher risk of developing significant and progressive liver fibrosis, cirrhosis, and hepatocellular carcinoma [31].

The prevalence of MAFLD is linked to IR and is closely associated with the rising incidence of obesity and type 2 diabetes. Up to 95% of obese patients, and 75% of diabetics, are likely to have MAFLD [32]. It is a marker of pathologic ectopic fat accumulation combined with a low-grade inflammatory state [33].

19.4 Metabolic Syndrome

A combination of signs and symptoms together represent a syndrome. Metabolic syndrome is a risk factor that arises from IR together with abnormal adipose deposition and function. It increases risk of heart disease, stroke, and diabetes [34]. The ATP III (American Treatment Panel) clinical definition of metabolic syndrome [18] requires three or more of the features in Table 19.3. Patients with this syndrome are four times more likely to have MAFLD than those who do not have the disease [19]. Those who have it have an approximate doubling of cardiovascular (CV) mortality risk [35]. Patients with MAFLD/NAFLD have been shown to be at increased risk of CVD, and it also contributes to accelerated atherogenesis [30]. It is estimated that 10% of patients with this fatty liver disease develop liver-related complications [5].

Table 19.3 Metabolic syndrome features

• Waist circumference: >102 cm (40.2 inch) in men or >88 cm (34.6 inch) in women
• Triglyceride level 150 mgm/dL (8.2 mmol/L) or greater
• High density lipoprotein (HDL): <40 mgm/dL (1.036 mmol/L) in men or <50 mgm/dL (1.295 mmol/L) in women
• Blood pressure: systolic 130 mmHg or greater or diastolic 85 mmHg or greater
• Fasting blood sugar level 110 mgm/dL (6.1 mmol/L) or greater

19.4.1 Clinical Outcomes of Metabolic Syndrome

CVD [36] is the primary clinical outcome of this syndrome. Most people with the syndrome have IR. This in turn results in an increased risk of type 2 diabetes. When a patient is diabetic, CVD risk rises sharply. In addition to CVD and type 2 diabetes, patients with the syndrome are susceptible to the following.

- Polycystic ovary syndrome in women
- Fatty liver
- Cholesterol gallstones
- Asthma
- Sleep disturbance

In addition to the ATP III guidelines in Table 19.3, other organisations include different and additional criteria. The World Health Organisation (WHO) [37] includes: (1) IR which is required for diagnosis, (2) risk factors from high blood pressure, and (3) raised triglycerides, low HDL, increased body mass index (BMI), and microalbuminuria (urinary albumin excretion rate 20 μg min^{-1} or albumin creatinine ratio 30 mg G^{-1}). The WHO underscores that early management of patients may have a significant impact on prevention of both diabetes and CVD. The syndrome can be present for up to 10 years before detection of glycaemic disorders.

19.5 Cryptogenic Cirrhosis

Cryptogenic cirrhosis (CC) has a 5% prevalence rate and is the end stage of a chronic liver disease; the cause of it remains unknown [38]. Common causes of cirrhosis of the liver include: hepatitis A, B, and C; autoimmune hepatitis; toxin exposure; vascular and biliary diseases; and chronic alcohol abuse. In recent years, the presence of MAFLD/NASH and its progression to fibrosis and cirrhosis has been added as a cause. Metabolic causes (e.g., metabolic syndrome, MAFLD and NASH, type 2 diabetes, and obe-

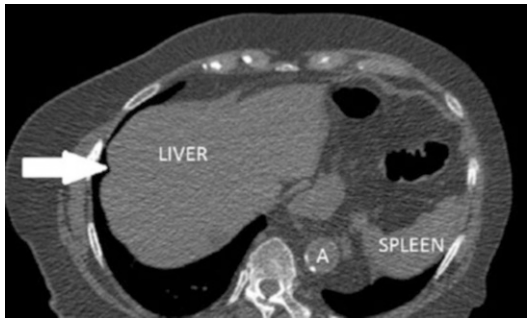

Fig. 19.2 2D axial view shows cirrhosis of liver [E3]. White arrow shows lobular margin of liver. A = aorta showing calcification

sity) have also become important. They have been increasingly identified with CC compared with other causes [39]. Figure 19.2 shows cirrhosis of the liver.

19.6 NAFLD in Terms of Alcohol Consumption

Diagnosis of NAFLD should only be made in people who consume no or only modest amounts of alcohol: exclusion criterion. Excessive alcohol consumption is ≥30 g per day for men and ≥20 g per day for women [5]. A history of alcoholism or alcohol abuse refers to a weekly intake of >21 drinks for males, and >14 drinks for females [21]. For the average person, without health problems, modest drinking will cause no harm. However, if there are health problems present, alcohol may aggravate these, even in small amounts. It is important to define what is meant by a 'standard drink'. It is 14 g of pure alcohol. Beer contains about 5% alcohol, but this may vary and reach up to 10%. One standard drink of beer is 12 oz. (340 mL). On average, there is about 7% alcohol in table wine, but may exceed 17%: a standard drink is 5 oz. (147 mL), and there are five standard drinks in a 25 oz. (735 mL) bottle. A standard drink of 80-proof spirits (40% alcohol) is 1.5 oz. (44 mL) [40]. The bottom line is that one 12 oz. (340 mL) beer has as much alcohol as 1.5 oz. (44 mL) shot of whisky or 5 oz. (147 mL) glass of wine (see Table 19.4) [41].

Table 19.4 Amount of beer, spirits, and wine in terms of same alcohol content

Type of drink	Amount
Beer or wine cooler (about 5% alcohol)	12 oz. (340 mL)
Table wine (about 7% alcohol)	5 oz. (147 mL)
Distilled spirits (about 40% alcohol); for example, a shot of whisky, brandy.	1.5 oz. (44 mL)

19.7 Diagnosis of MAFLD

The diagnosis of MAFLD is made by imaging studies, as well as biochemical testing, and finally by liver biopsy, which is regarded as the 'gold standard'. The latter is however not commonly performed because of its invasive nature with a risk of bleeding and tearing of the liver parenchyma. Of the imaging studies, ultrasound (US) is the commonest screening test. It is cheap and non-invasive. Its disadvantages are being operator dependent and results are variable. It can only detect steatosis when >30% of the liver is affected. Figure 19.3a and b are examples of a normal liver and a fatty liver US scans. It is however recommended as the first-line investigation to confirm the presence of a fatty liver [42].

CT scanning is frequently employed in gastroenterology practice for a variety of symptoms and signs. Diagnosis of MAFLD is easily made on CT screening, and screening CTC examinations, by noticing fat within the liver parenchyma. The liver density is 'darker' than normal, and its overall density is less than the spleen (Figure 19.4a–e).

At CT and CTC, measurement of the HU reading of the liver is an accurate method and

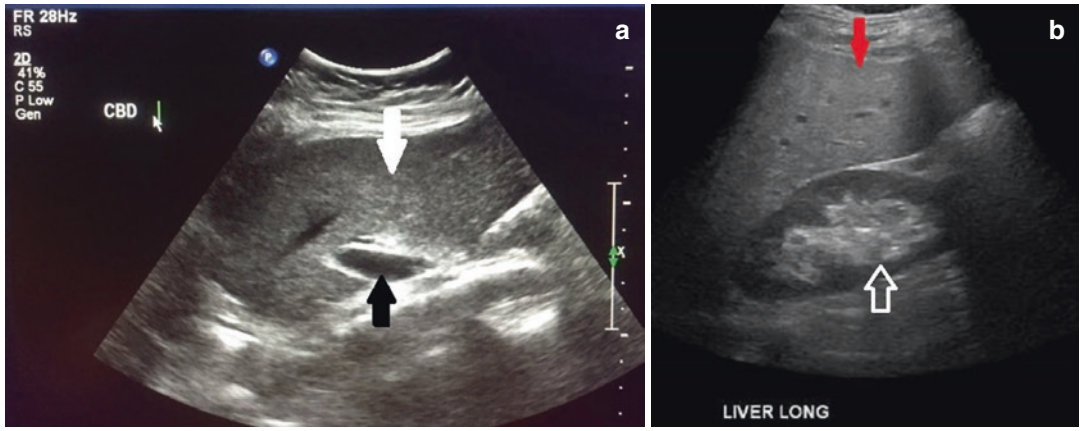

Fig. 19.3 (**a**) Normal liver (white arrow) ultrasound scan showing common bile duct (black arrow). (**b**) Bright echo pattern (red arrow) in keeping with fatty infiltration of the liver. White open arrow = RK. (Courtesy of Prof P Pickhardt, Wisconsin University)

highly specific for assessing fatty liver infiltration. The HU reading of a healthy liver is between 60 and 65. When fatty infiltration occurs, the liver becomes 'darker' on the scan; the HU value then drops to approximately 45. It is this infiltration that increases in extent when the HU value drops from 45 and often reaches 20–30 HU or less. Figure 19.5a–g show a range of HU values of the liver. This indicates moderate-to-severe hepatic steatosis: at least 30% of the liver has been replaced by fat. Pickhardt et al. [43]. proved in their study that the use of unenhanced liver CT attenuation measurements were accurate and precise for quantification of steatosis. An attenuation value of 45 HU or less was 100% specific for the biopsy proven moderate-to-severe steatosis [21]. Moderate steatosis, as stated in 19.1, is when unenhanced liver attenuation under 40HU corresponds to 15% proton fat fraction calculated from MRI [8]. In the absence of multiple blood transfusions, or amiodarone therapy, if the attenuation of unenhanced liver exceeds 75HU then iron overload must be considered [8].

19.7.1 Measuring Attenuation Values: Liver and Spleen

It is useful to compare the ROI (region of interest) of the spleen when measuring the HU of the liver to assess for fatty filtration. Normal reading of the spleen is usually between 55 and 65 HU, which is very similar to a normal liver reading. With fatty infiltration of the liver, the HU decreases but the splenic HU remains the same (Figure 19.6a and b).

Using the ROI tool, a HU reading is obtained of the right lobe of the liver, which is far lower than the splenic HU reading. HU reading of 45 or less is diagnostic of fatty liver infiltration of the liver. The lower the reading, the more severe the fatty infiltration. MR spectroscopy (MRS) has excellent sensitivity in detecting and accurately quantifying hepatic steatosis. Inflammation and/or NASH can be detected by CT or MRS. Biochemical testing has drawbacks. Up to 70% of MAFLD patients may have normal liver enzymes [44].

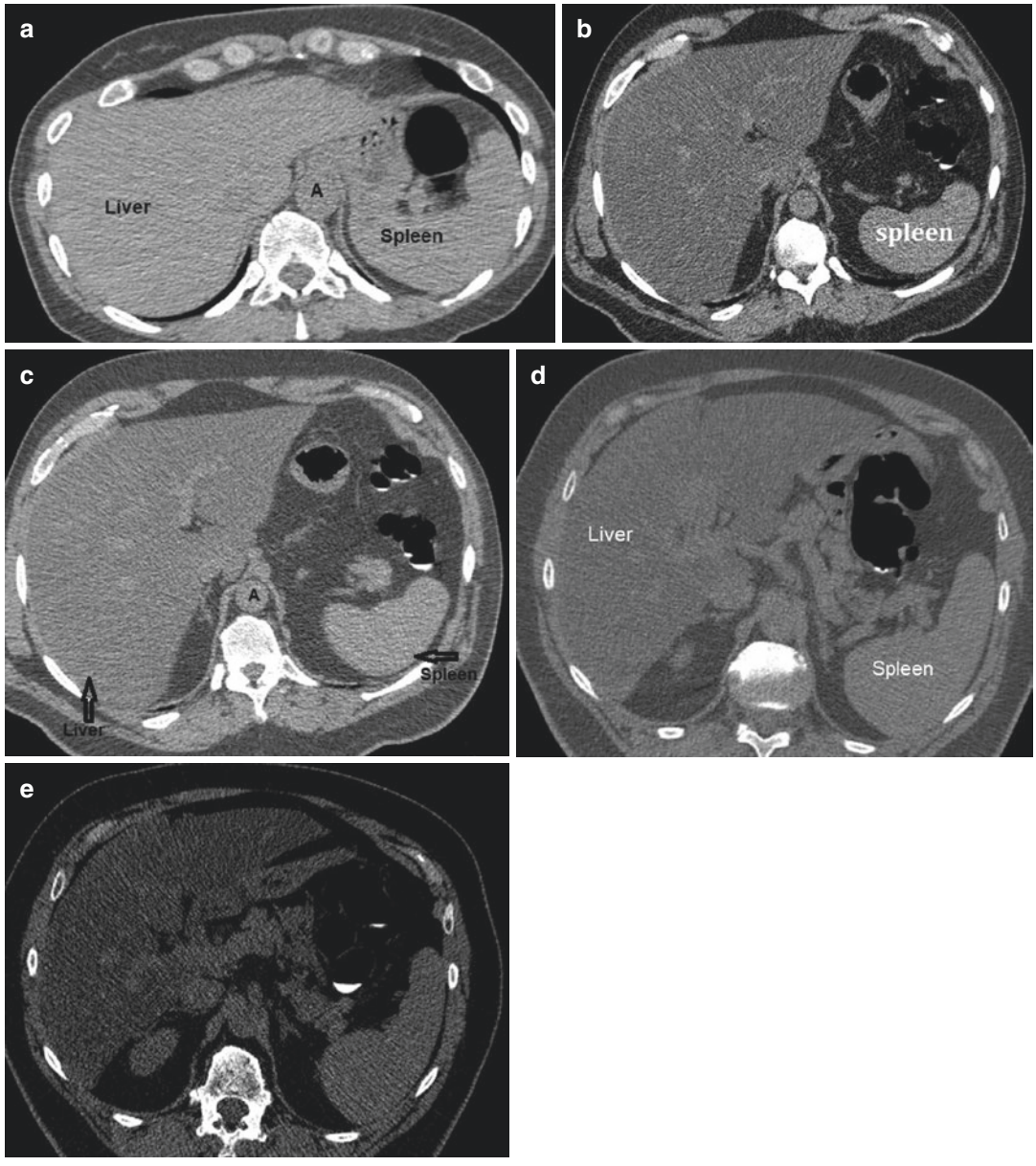

Fig. 19.4 (**a**) 2D axial view showing equal density between the liver and the spleen (normal liver HU is 65, spleen HU 55–65). A = aorta [E1]. (**b**) 2D axial view shows liver is darker then the spleen [E3]. (**c**) 2D axial view shows liver is darker than the spleen [E3]. A = aorta. (**d**) 2D axial view shows liver darker than spleen [E3]. (**e**) 2D axial view of the patient in Fig. 19.4d using liver setting [E3]

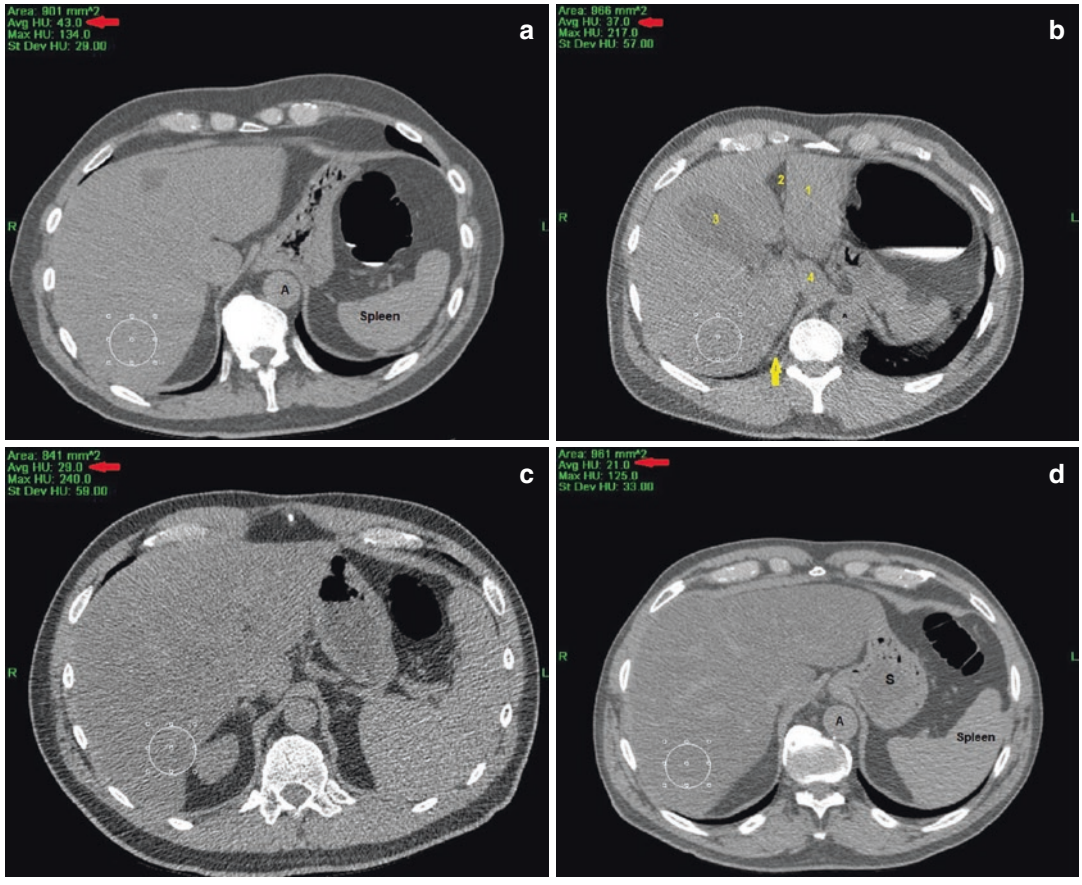

Fig. 19.5 (**a**) 2D axial view showing HU 43 in ROI right lower lobe (RLL) of liver. A = aorta [E3]. (**b**) 2D axial view showing HU 37 in ROI RLL of liver. 1 = left lobe of liver (LLL); 2 = falciform ligament; 3 = gallbladder; 4 = inferior vena cava (IVC); Yellow arrow = crus of right diaphragm; A = aorta [E3]. (**c**) 2D axial view showing HU 29 in ROI RLL of liver [E3]. (**d**) 2D axial view showing HU 21 in ROI. Note vessel prominence in liver. Compared to the spleen the liver is 'darker'. A = aorta; S = stomach [E3].

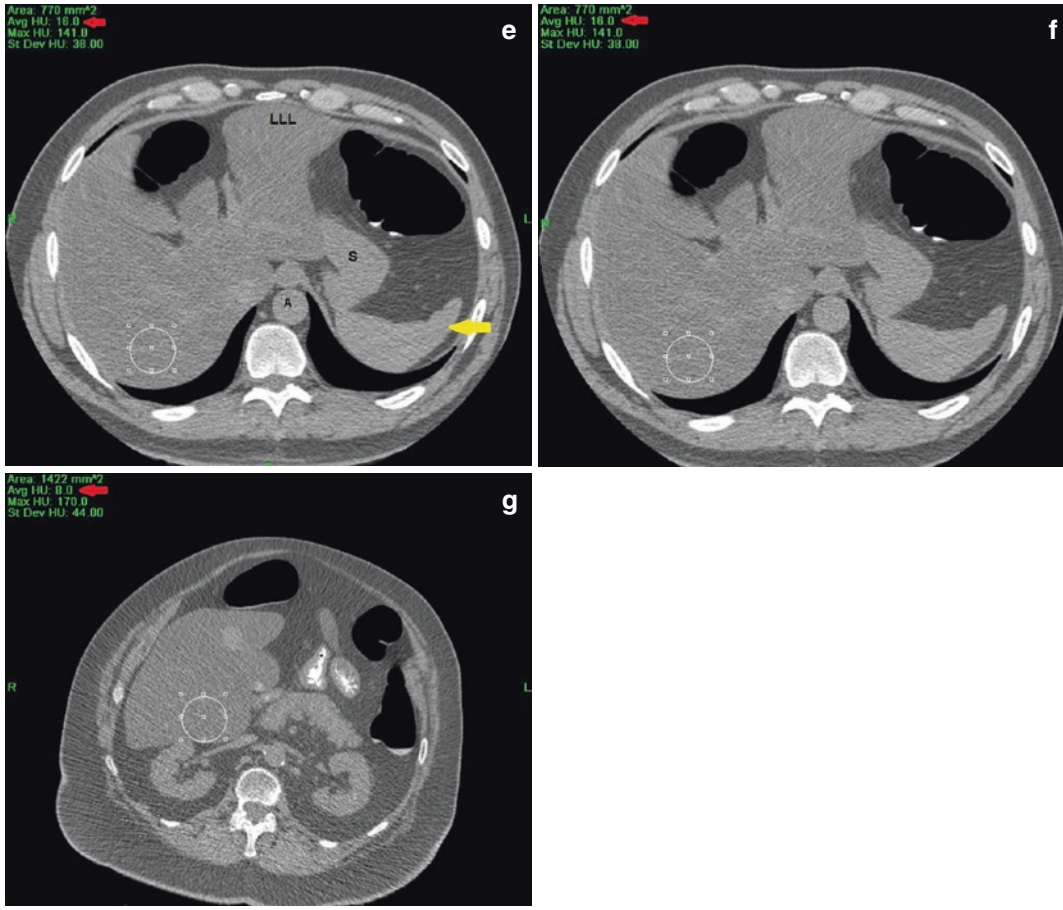

Fig. 19.5 (**e**) 2D axial view showing HU 18 in ROI. Liver is darker compared to the spleen (yellow arrow). A = aorta; LLL = left lobe of liver; S = stomach [E3]. (**f**) 2D axial view showing HU 16 in ROI [E3]. (**g**) 2D axial view showing HU 8 in ROI [E3]

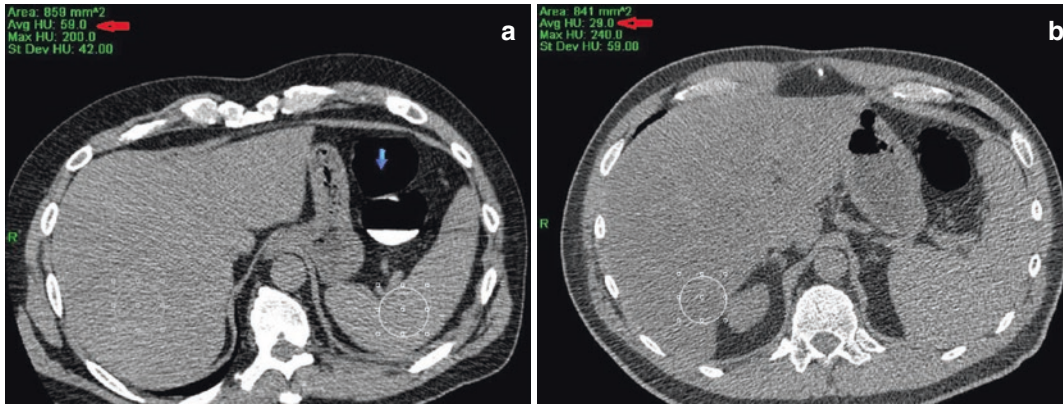

Fig. 19.6 (**a**) ROI reading HU 59 for both the liver and the spleen [E1]. (**b**) ROI reading liver is 29 HU [E3]

19.8 Serum Liver Enzyme Tests

ALT (alanine transaminase) and AST (aspartate transaminase) are the two performed tests for liver enzymes to assess fatty infiltration. In the early stages of MAFLD, only mildly abnormal liver enzymes are the clue pointing to the disease. ALT is the best single test to correlate with hepatic steatosis. It can however not distinguish between varying stages of NASH. It can be normal in chronic liver disease [45, 46]. When AST levels are elevated, this is more in favour of an alcohol aetiology.

Gamma-glutamyl transferase (GGT) is a blood test, which is also used to determine if there is disease in the liver or bile-ducts. It is usually performed in conjunction with other tests (e.g., AST, ALT, and bilirubin). An elevated GGT level suggests there is damage to the liver from a variety of conditions: cardiovascular disease, hypertension, or certain types of drugs, for example. It is especially useful when alcohol may be a factor in causes of liver disease because it is usually elevated. It is elevated in 75% of patients who are chronic drinkers. It can be used to monitor patients who are in rehabilitation. There is a significant association between increased GGT and cardiovascular (CV) mortality in a 12 -year follow-up period [47].

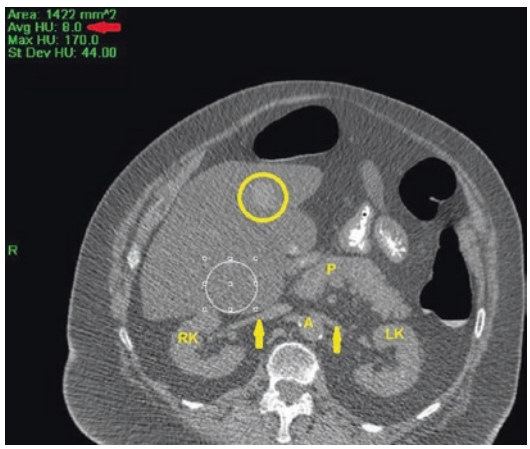

Fig. 19.7 2D axial view. Yellow circle = an area that is 'brighter' than the rest of the liver. This is focal fatty sparing as the HU was 16. ROI shows HU of 8. RK = right kidney; LK = left kidney; Yellow arrows = right and left renal veins; P = pancreas; A = aorta [E3]

19.9 Fatty Sparing in the Liver

A fatty liver as an ECF may in some patients show parts of the organ that have an absence of increased intracellular hepatic fat. It is important to take HU readings if this is noted. Figure 19.7 shows fatty sparing. Literature underscores that nodular fatty sparing may, in error, be interpreted as a mass [48–50]. On an US examination, fatty sparing is hypoechoic or isoechoic [50].

19.10 How to Distinguish MAFLD from Alcoholic Liver Disease

In MAFLD, the usual biochemical pattern is that of an increased level of transaminases. Up to 3% of the general population may have elevated ALT [51]. ALT levels are higher than that of AST. When alcohol is the cause of fatty infiltration of the liver, the AST rises higher than ALT, resulting in a ratio of AST: ALT >1.5. Alcohol may also increase the HDL cholesterol as well as the triglycerides.

19.11 Main Points of MAFLD Diagnosis and Patient Management

MAFLD is now considered a potential risk which could require patient management. As evident in Table 19.5 there are several recommendations for management of MAFLD.

19.11.1 Who Should Inform Patients with MAFLD of Its Potential Risks?

Plumb et al. [52] recommend in their comparative study of patients' experiences of CTC and colonoscopy that patients should be informed of their CTC results, and whether additional tests may be needed. Studies on patients' perceptions and experiences of CTC examinations underscore the need to provide them with feedback

Table 19.5 MAFLD[a]

Diagnosis	Detection of liver steatosis (histology, non-invasive biomarkers) In addition, at least one of three criteria: obesity, type 2 diabetes mellitus, clinical evident of metabolic dysfunction (e.g. ↑ waist circumference and abnormal lipid or glycaemic profile) Imaging study (e.g. US, CT) with evidence of fatty content
Management	The following are recommended • Change in lifestyle and exercise, reduce dietary fat intake • Metabolic risk management (e.g. hypertension and dyslipidaemia) • Pioglitazone, vitamin E

[a] Adapted from text of Eslam et al. [1]

[52, 53]. The author personally informs patients with MAFLD seen at screening CTC of its potential risks so that they can then discuss future management with their physicians [10]. Literature underscores that colonic findings and ECFs must be reported on [10, 28, 50]; hence, the reporting template in Chap. 21 includes MAFLD.

Key Messages

- 70% of patients with MAFLD may have normal liver enzymes.
- Ultrasound can only detect steatosis when >30% of the liver is affected.
- Liver attenuation in steatosis is always lower than the HU of spleen.
- Magnetic resonance spectroscopy (MRS) has excellent sensitivity in both detecting and accurately quantifying hepatic steatosis.
- Liver biopsy remains the gold standard for diagnosing MAFLD, staging the degree of MASH, and assessing histological fibrosis.
- Increased incidence of adverse CV events in patients with MAFLD compared to the general population.
- MAFLD is characterised by an atherogenic lipid profile, namely
  - High triglyceride (TG) levels.
  - Low high-density lipoprotein (HDL) levels.
  - An increased level of low-density lipoprotein (LDL).
  - Increased very low-density lipoprotein (VLDL) particles.
  - Increase levels of lipoprotein B100 concentration.
- MAFLD diagnosis includes elevated serum liver enzymes (ALT, AST, GGT)
- Cryptogenic cirrhosis is the end stage of a chronic liver disease.
- MAFDL may induce HCC.
- Fatty sparing may be present.

19.12 Summary

In recent years, the presence of MAFLD in asymptomatic individuals has increased significantly, especially in those who are obese or have type 2 diabetes. While most will remain asymptomatic in the presence of MAFLD, a small percentage will progress to non-alcoholic steatohepatitis (NASH), and, with inflammatory and necrotic changes will then progress to cirrhosis, and finally hepatocellular carcinoma.

The diagnosis of MAFLD at CTC is easily made on unenhanced abdominal CT scans. The ROI tool is placed over the right lobe of the liver to measure the HU readings. The liver normally has a HU value of approximately 60. MAFLD is diagnosed when the value drops below 45 HU; lower readings mean more fatty infiltration in the liver. MAFLD liver is an ECF of moderate clinical importance (E3), but some radiologists classify it as E2 (low clinical importance).

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References

1. Eslam M, Sarin SK, Wong V, Fan J-G, Kawaguchi T, et al. The Asian Pacific Association for the study of the liver clinical practice guidelines for the diagnosis and management of metabolic associated fatty liver disease. Hepatol Int. 2020;14:889–919. https://doi.org/10.1007/s12072-020-10094-2.

2. Demirtas CO, Yilmaz Y. Metabolic-associated fatty liver disease: time to integrate ground-breaking new terminology to our clinical practice? Hepatol Forum. 2020;3:79–81.
3. Eslam M, Sanyal AJ, George J, International Consensus Panel. MAFLD: a consensus-driven proposed nomenclature for metabolic associated fatty liver disease. Gastroenterology. 2020;158(7):1999–2014.e1. https://doi.org/10.1053/j.gastro.2019.11.312.
4. Shiha G, Korenjak M, Eskridge W, Casanovas T, Velez-Moller P, Högström S, et al. Redefining fatty liver disease: an international patient perspective. Lancet Gastroenterol Hepatol. 2021;6(1):73–9. https://doi.org/10.1016/S2468-1253(20)30294-6.
5. Powell E, Wong V, Rinella M. Non-alcoholic fatty liver disease. Lancet. 2021;397(10290):2212–24. https://doi.org/10.1016/S0140-6736(20)32511-3.
6. Guerra-Ruiz AR, Casals G, Ituzubieta P, Lalana M, et al. Biochemical assessment of metabolic-associated fatty liver disease. Adv Lab Med. 2021;2(2):199–208.
7. Younossi ZM, Koenig AB, Abdelatif D, Fazel Y, Henry L, Wymer M. Global epidemiology of nonalcoholic fatty liver disease-meta-analytic assessment of prevalence, incidence, and outcomes. Hepatology. 2016;64(1):73–84.
8. Pickhardt PJ. Value-added opportunistic CT screening: state of the art. Radiology. 2022;303(2):241–54. https://doi.org/10.1148/radiol.211561.
9. Bortz JH. Extracolonic findings. In: Bortz JH, Ramlaul A, Munro L, editors. CT colonography for radiographers. A guide to performance and image interpretation. Basel: Springer. 2016. pp. 239–242.
10. Bortz JH. Is non-alcoholic fatty liver disease (NAFLD) seen at CT colonography an important extracolonic finding? SAR. 2017;55(2):7–12.
11. Boyce CJ, Pickhardt PJ, Kim DH, et al. Hepatic steatosis (fatty liver disease) in asymptomatic adults identified by unenhanced low-dose CT. AJR. 2010;194:623–8.
12. Graffy PM, Pickhardt PJ. Quantification of hepatic and visceral fat by CT and MR imaging: relevance to the obesity epidemic. Metabolic syndrome and NAFLD. Br J Radiol. 2016;89:20151024.
13. Qayyum A. MR spectroscopy of the liver: principles and clinical applications. Radiographics. 2009;29:1653–64.
14. Estes C, Razavi H, Loomba R, Younossi Z, Sanyal AJ. Modeling the epidemic of nonalcoholic fatty liver disease demonstrates an exponential increase in burden of disease. Hepatology. 2018;67(1):123–33.
15. Zalis ME, Barish MA, Choi JR, et al. CT colonography reporting and data system: a consensus proposal. Radiology. 2005;236(1):3–9. https://doi.org/10.1148/radiol.2361041926.
16. Marchesini G, Moxatello S, Di Domingo S, et al. Obesity-associated liver disease. J Clin Endocrinal Metab. 2008;93(11 Suppl):S74–80.
17. Clark JM, Bronceti FL, Diehl AME. Non-alcoholic fatty liver disease: the most common cause of abnormal liver enzymes in the US population. Gastroenterology. 2011;120(5 Suppl 1):A65.
18. Chalasani N, Younossi Z, Lavine JE, et al. The diagnosis and management of non-alcoholic fatty liver disease: practice guidelines by the American Gastroenterological Association, American Association of the Study of Liver Diseases and American College of Gastroenterology. Gastroenterology. 2012;142:1592–609.
19. Browning JD, Szczepaniak LS, Dobbins R, et al. Prevalence of hepatic steatosis in an urban population in the United States: impact of ethnicity. Hepatology. 2004;40:1387–95.
20. Sattar N, Forrest E, Preiss D. Non-alcoholic fatty liver disease. Clinical review. BMJ. 2014;349:g4596. https://doi.org/10.1136/bmj.g4596. [cited 2022 September 23]. www.bmj.com/content/349/bmj.g4596/rapid-responses.
21. Pickhardt PJ, Hahn L, del Pio AM, et al. Natural history of hepatic steatosis: observed outcomes for subsequent liver and cardiovascular complications. AJR. 2014;202:752–8.
22. Milic J, Barbieri S, Gozzi L, Brigo A, Beghé B, Verduri A, Bacca E, Iadisernia V, Cuomo G, Dolci G, Yaacoub D, Aprile E, Belli M, Venuta M, Meschiari M, Sebastiani G, Clini E, Mussini C, Lonardo A, Guaraldi G, Raggi P. Metabolic-associated fatty liver disease is highly prevalent in the post acute COVID syndrome. Open Forum Infect Dis. 2022;9(3):ofac003. https://doi.org/10.1093/ofid/ofac003.
23. Zhang C, Cheng Y, Luo D, Wang J, Liu J, Luo Y, Zhou W, Zhuo Z, Guo K, Zeng R, Yang J, Sha W, Chen H. Association between cardiovascular risk factors and colorectal cancer: a systematic review and meta-analysis of prospective cohort studies. EClinicalMedicine. 2021;34:100794. https://doi.org/10.1016/j.eclinm.2021.100794.
24. Younossi ZM, Otgonsuren M, Henry L, Venkatesan C, Mishra A, Erario M, et al. Association of nonalcoholic fatty liver disease (NAFLD) with hepatocellular carcinoma (HCC) in the United States from 2004 to 2009. Hepatology. 2015;62:1723–30.
25. Cai C, Song X, Yu C. Identification of genes in hepatocellular carcinoma induced by non-alcoholic fatty liver disease. Cancer Biomark. 2020;29:68–78.
26. Ramesh S, Sanyal AJ. Hepatitis C and non-alcoholic fatty liver disease. Semin Liver Dis. 2004;24(4):399–413.
27. Alanazi M, Ali NA. Incidental extra-colonic findings in CT colonography at Riyadh region. Int J Radiol Imaging Technol. 2020;6(2):067. https://doi.org/10.23937/2572-3235.1510067.
28. Lambe G, Hughes P, Rice L, McDonnell C, Murphy M, Judge C, Guiney M. The bowel and beyond: extracolonic findings from CT colonography. Ir J Med Sci. 2022;191(2):909–14. https://doi.org/10.1007/s11845-021-02595-2.

29. Tiniakos OG, Vos MB, Brunt EM. Non-alcoholic fatty liver disease: pathology and pathogenesis. Annu Rev Pathol. 2010;5:145–71.
30. Targher G, Arcaro G. Non-alcoholic fatty liver disease and increased risk of cardio-vascular disease. Atherosclerosis. 2007;191:235–40.
31. Vernon G, Baranova A, Younessi ZM. Systematic review: the epidemiology and natural history of non-alcoholic fatty liver disease and non-alcoholic steatohepatitis in adults. Aliment Pharmocol Ther. 2011;34:274–85.
32. Byrne CD, Olufadi KD, Cagampang FR. Metabolic disturbance in non-alcoholic fatty liver disease. Clin Sci (Lond). 2009;116:539–64.
33. Bhatia LS, Curzen NP, Calder PC, et al. Non-alcoholic fatty liver disease: a new and important cardiovascular risk factor? Eur Heart J. 2012;33:1190–200.
34. Mayo Clinic. Metabolic syndrome.[cited 2022 September 20]. http://www.mayoclinic.org/diseases-conditions/metabolic-syndrome/home/ovc-20197517.
35. Mortillo S, Filion KB, Genest J, et al. The metabolic syndrome and cardiovascular risk: a systematic review and meta-analysis. Am Coll Cardiol. 2010;56:1113–32.
36. Belby J. Definition of metabolic syndrome: report of the National Heart, Lung and Blood Institute/American Heart Association conference on scientific issues related to definition. Circulation. 2004;109:433–8.
37. World Health Organisation. Definition, diagnosis and classification of diabetes mellitus and its complications. Geneva: WHO; 1999. p. 32–4.
38. Mercado-Irizarry A, Torres EA. Cryptogenic cirrhosis: current knowledge and future directions. Clin Liver Dis. 2016;7(4):69–72.
39. Poonawala A, Nair SP, Thulivath PJ, et al. Prevalence of obesity and diabetes in patients with cryptogenic cirrhosis: a case study. Hepatology. 2000;32:689–92.
40. National Institute on Alcohol Abuse and Alcoholism (NIAAA). [cited 2022 September 26]. https://www.niaaa.nih.gov/.
41. How it all adds up. [cited 2022 September 26]. www.nconet.org/alcohol.
42. Ratziu V, Bellentani S, Cortez-Pinto H, et al. A position statement on NAFLD/NASH based on the EASL special conference. J Hepatol. 2010;53:372–84.
43. Pickhardt PJ, Park SH, Hahn L, et al. Specificity of unenhanced CT for non-invasive diagnosis of hepatic steatosis: implications for the investigation of the natural history of incidental steatosis. Eur Radiol. 2012;22:1075–85.
44. Szczepaniak LS, Nurenberg P, Leonard D, et al. Magnetic resonance spectroscopy to measure hepatic triglyceride content: prevalence of hepatic steatosis in the general population. Am J Physiol Endocrinol Metab. 2005;288(2):E462–8.
45. Kotronen A, Westerbacka J, Bergholm R, et al. Liver fat in the metabolic syndrome. J Clin Endocrinol Metab. 2007;92:3490–7.
46. Mofrad P, Contos MJ, Haque M, et al. Clinical and histologic spectrum of non-alcoholic fatty liver disease associated with normal ALT values. Hepatology. 2003;37:1286–92.
47. Wannanethee G, Ebrahim S, Shaper AG. Gamma-glutamyltransferase determinants and association with mortality from ischemic heart disease and all causes. Am J Epidemiol. 1995;142:699–708.
48. Tom WW, Yeh BM, Cheng JC, et al. Hepatic pseudotumor due to nodular fatty sparing: the diagnostic role of opposed-phase MRI. AJR. 2004;183(3):721–4.
49. Hamer OW, Aguirre DA, Casola G, Lavine JE, Woenckhaus M, Sirlin CB. Fatty liver: imaging patterns and pitfalls. Radiographics. 2006;26(6):1637–53.
50. Décarie PO, Lepanto L, Billiard JS, Olivié D, Murphy-Lavallée J, Kauffmann C, Tang A. Fatty liver deposition and sparing: a pictorial review. Insights Imaging. 2011;2(5):533–8.
51. Ruhl CE, Everhart JE. Determinants of the association of overweight with elevated serum alanine aminotransferase activity in the United States. Gastroenterology. 2003;124(1):71–9.
52. Plumb AA, Ghanouni A, Rees CJ, et al. PWE-033 comparison of patient experience of colonoscopy and CT colonography in the English Bowel Cancer Screening Programme. Gut. 2014;63:A136–7. https://doi.org/10.1136/gutjnl-2014-307263.293.
53. von Wagner C, Knight K, Halligan S, et al. Patient experiences of colonoscopy, barium enema and CT colonography: a qualitative study. BJR. 2009;82(973):13–9.

CTC for Incomplete and Failed Colonoscopy Cases

20

Joel H. Bortz

20.1 Introduction

Colorectal cancer (CRC) is a leading cause of death worldwide [1]. Over the past few years, colon cancer has been diagnosed in younger adults [2–7]. The American Cancer Society [6], as well as the US Preventive Services Task Force [7], recommend CRC screening should commence at age 45 years and not at age 50 years. Screening begins at age 40 years if there is a family history of CRC. Both computed tomography colonoscopy (CTC) and optical colonoscopy (OC) are used in screening of patients; OC is used for therapeutic and diagnostic procedures. There are a range of reasons for an incomplete or failed OC [8, 9]. The 2020 guideline update of the European Society of Gastrointestinal Endoscopy (ESGE) and the European Society of Gastrointestinal and Abdominal Radiology (ESGAR) includes CTC and colon capsule endoscopy (CCE) as alternative imaging procedures in incomplete or failed OC [10]. Double contrast barium enema (DCBE) is not listed in current literature [9, 10] thus will not be discussed in this chapter (see also Chap. 1). The focus of this chapter is the role of CTC and its advantages compared to CCE. Reasons for incomplete or failed OC are provided. CTC images are presented to illustrate some of these reasons.

The following abbreviations are used in this chapter.

- CCE: colon capsule endoscopy
- CRC: colorectal cancer
- DCBE: double contrast barium enema
- ECFs: extracolonic findings
- ESGAR: European Society of Gastrointestinal and Abdominal Radiology
- ESGE: European Society of Gastrointestinal Endoscopy
- 3D: three-dimensional
- 2D: two-dimensional
- OC: optical colonoscopy

20.2 Colon Capsule Endoscopy (CCE)

Spada et al. [11] compared CCE and CTC in patients with incomplete colonoscopy (IC). They concluded that the two tools were of comparable efficacy in terms of colon evaluation. Patients who had undergone an OC and a CCE study indicated they preferred the latter [12]. A disadvantage of CCE is its battery life; video compression could be a possible solution [13]. It is not feasible to visualise organs and structures outside of the colon in a CCE procedure. In terms of the respective average costs of CCE and CTC, the latter is almost half that of CCE [14].

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

J. H. Bortz et al. (eds.), *CT Colonography for Radiographers*,
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20.3 Reasons for Incomplete and Failed Optical Colonoscopy

Reasons for incomplete or failed OC: operator factors (e.g., endoscopists' experience, caecal intubation rate); patient factors (e.g., inadequate bowel preparation, low body mass index); technical factors (e.g., diverticular disease, previous surgery, previous radiotherapy in the pelvis region) [9]; and anatomic factors. The latter include tortuous or exceedingly long colon, looping of the colon especially in the sigmoid colon, acute flexure angle, and fixation of colon loops [9]. According to CTC literature, predictive factors on incomplete OC include total colon length, number of flexures, and advanced diverticular disease [15, 16].

20.4 Advantages of CTC

CTC is a fast, safe, socially distanced, minimally invasive, low-dose examination which does not require sedation [10, 17–21]. A CT scanner with special software produces a reconstruction of the carbon dioxide (CO_2) filled colon. The software produces two-dimensional (2D) images and three-dimensional (3D) endoluminal views [18, 20, 21]. The software allows video viewing of a 3D virtual fly-through of the colon from the rectum to the caecum (retrograde navigation) and back to the rectum (antegrade navigation). This process takes approximately 2 min to perform; one is able to stop the fly-through at any stage for careful scrutiny of any part of the colon that may have a lesion [22]. In a routine supine and prone CTC examination, a virtual fly-through is performed four times.

The software also has a tool to produce a 3D surface-rendered image (colon-map) of the entire colon as shown in Fig. 20.1a–c. The software generates an automated centreline for endoluminal navigation. The automated centreline may be used for in vivo length measurements. Figure 20.1d, e shows an automated green line.

Redundancy of colon segments is a reason for incomplete or failed OC [9, 15, 23]. Examples of redundant segments of the colon at CTC are presented in Fig. 20.1f, g. Figure 20.1h shows redundancy and an acute flexural fold. Examples of colon pathologies seen at CTC are presented in Fig. 20.1i–n.

Another advantage of a CTC is that a scan covers the entire abdomen from the lung bases to below the pelvis allowing for visualisation of extracolonic organs and structures [24–28]. It is not feasible to visualise organs and structures outside of the colon in CCE and OC. Examples of extracolonic findings (ECFs) at CTC are presented in Fig. 20.2a–f.

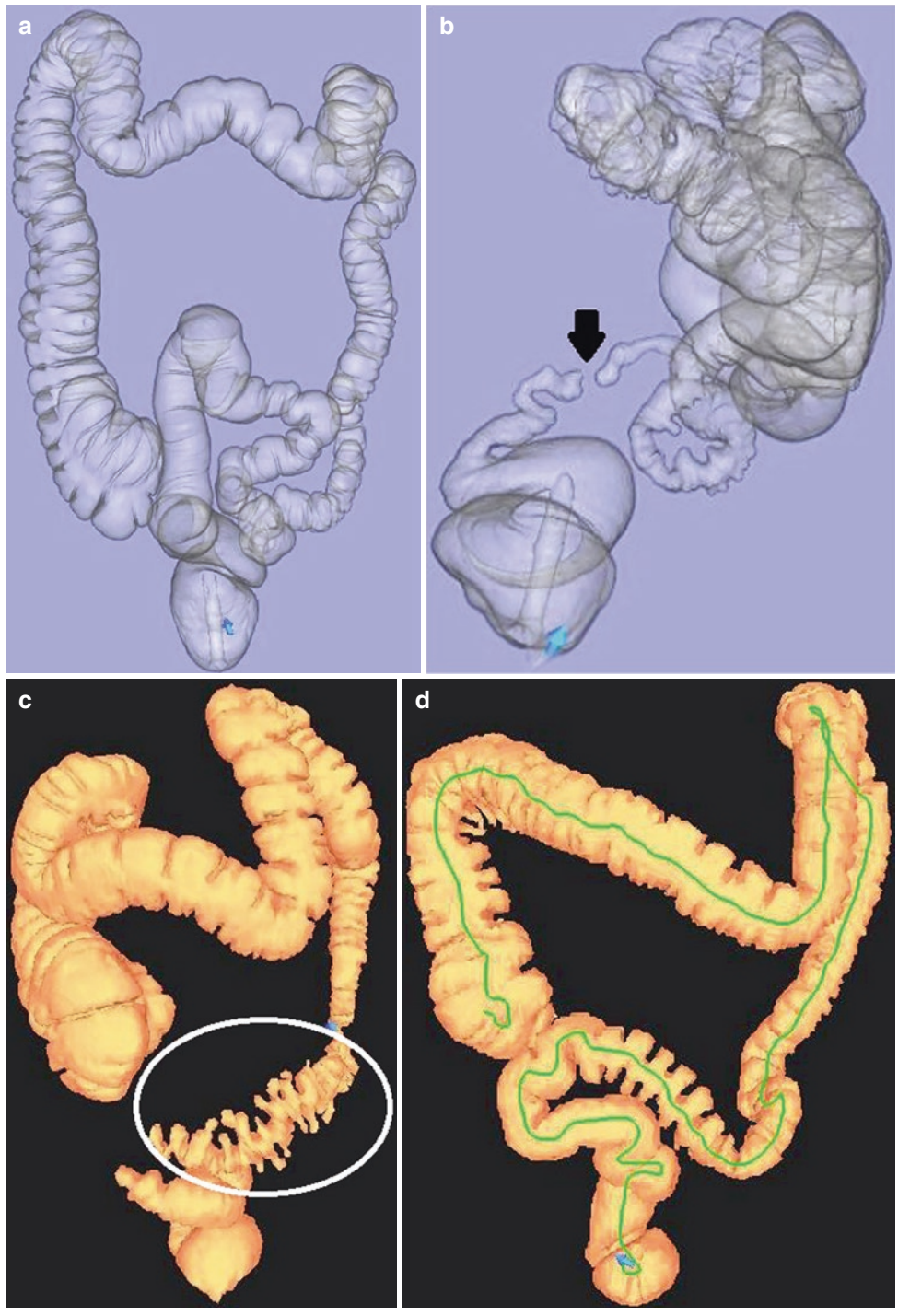

Fig. 20.1 (**a**) 3D surface-rendered image (colon-map) showing sigmoid in a normal appearing colon. (**b**) An oblique colon-map showing an ischaemic stricture (black arrow). (**c**) Colon-map showing extensive diverticular disease involving the sigmoid and distal descending colon (white circle). The rest of the colon is normal. (**d**) Normal colon-map with automated centreline (green line) which allows for measurement of length of the colon.

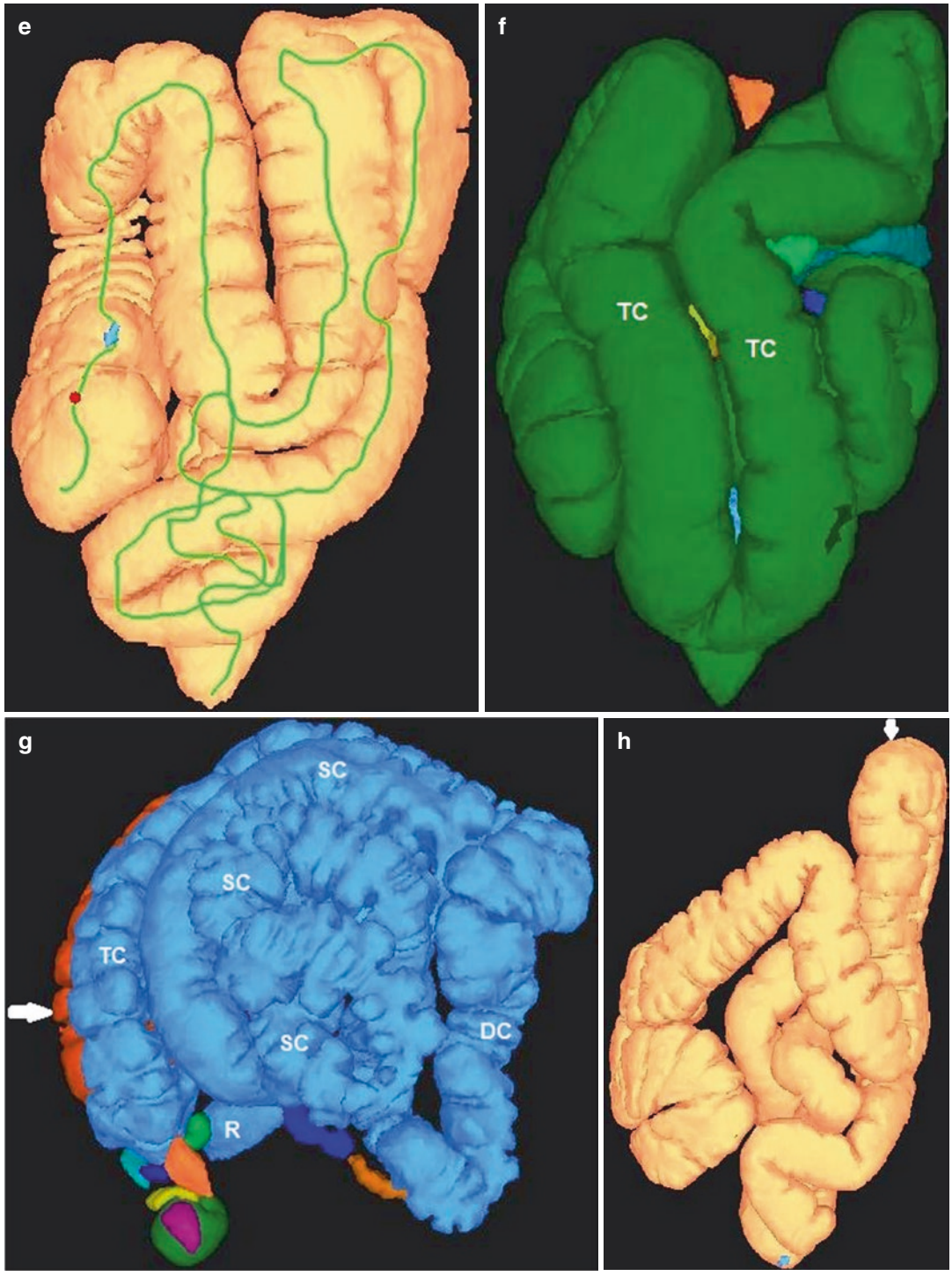

Fig. 20.1 (**e**) Colon-map with green centreline. Red dot in the caecum indicates the site of a lesion observed in the CTC fly-through. (**f**) Grossly redundant transverse colon (TC) with loops lying low in the pelvis. (**g**) Colon-map showing a grossly redundant sigmoid colon (SC), and normal descending colon (DC), transverse colon (TC), and ascending colon (white arrow). R rectum. (**h**) Colon-map showing an acute flexural fold (white arrow) and redundancy.

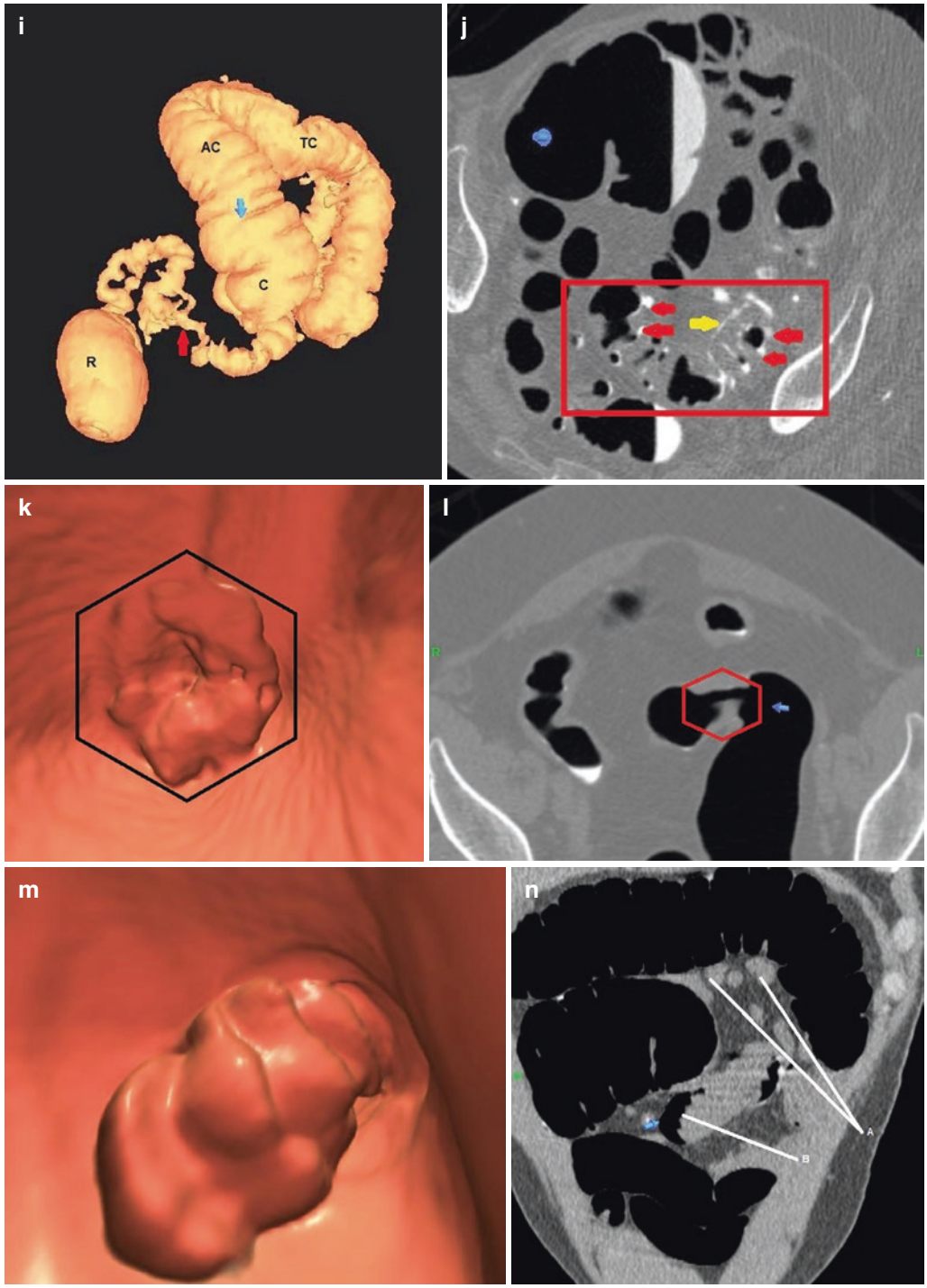

Fig. 20.1 (**i**) Colon-map of left lateral decubitus with the patient slightly oblique. Red arrow indicates stricture in sigmoid colon due to previous attacks of diverticulitis. R rectum, TC transverse colon, AC ascending colon, C caecum. (**j**) 2D left lateral decubitus view of patient in (i). Sigmoid colon (red square). Thickening of colon with multiple diverticula throughout the sigmoid colon (red arrows). Yellow arrow = presence of an intramural sinus tract which indicates a linear collection of fluid within the thickened wall. (**k**) 3D of annular carcinoma in the sigmoid colon. (**l**) 2D axial view of patient in (**k**). Red hexagon = 'apple-core' appearance of underlying cancer. (**m**) 3D showing mass at CTC. (**n**) 2D coronal view of patient in (**m**). A = enlarged mesenteric nodes. B = mass in jejunum

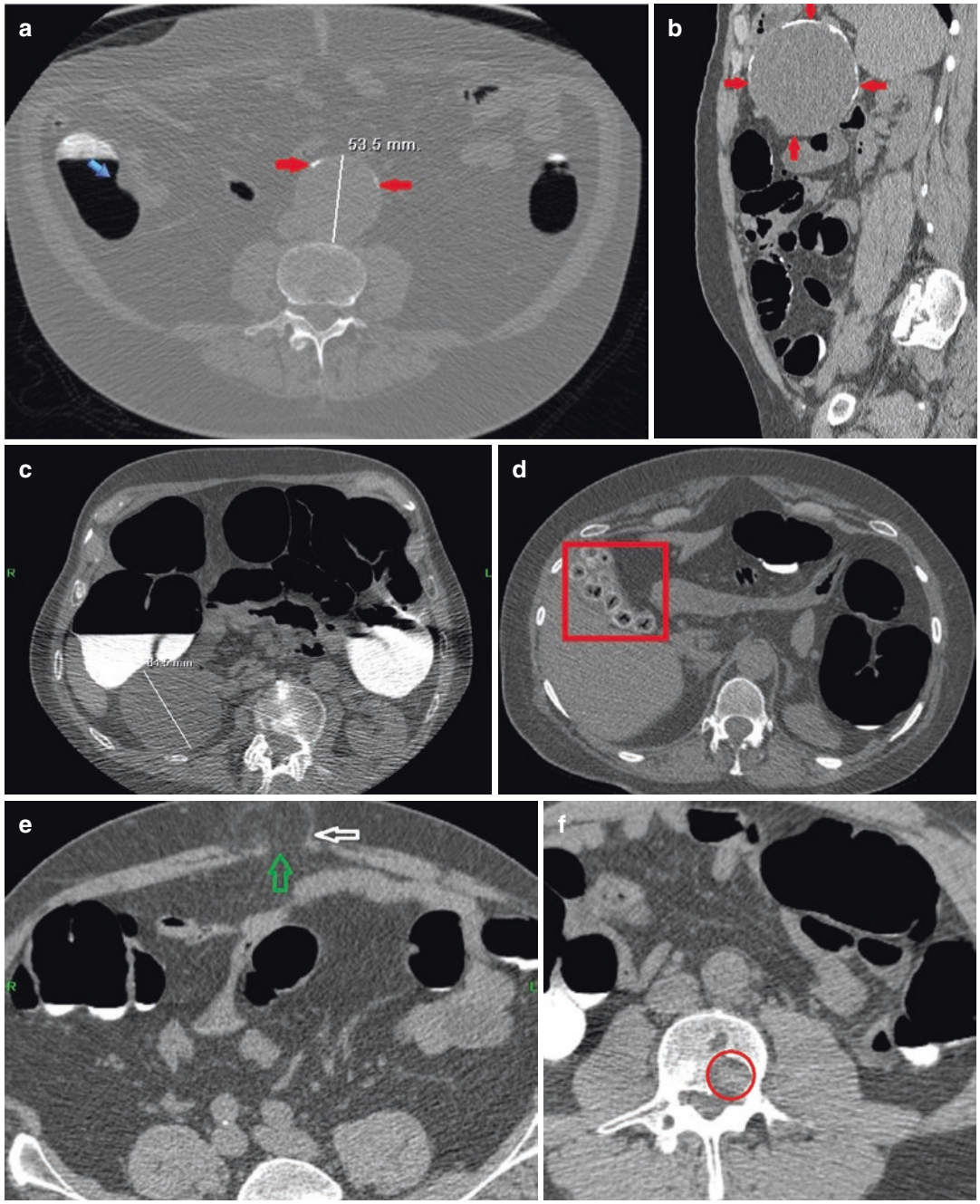

Fig. 20.2 (**a**) Axial 2D view showing 5.3 cm abdominal aortic aneurysm. Scattered calcification in wall of aorta (red arrows). The aneurysm constitutes an urgent referral for a stenting procedure. (**b**) 2D sagittal view showing large mass (red arrows) anterior to spleen and left kidney with partial calcification of wall. Adenocarcinoma of the pancreas proven on biopsy. (**c**) 2D axial view showing cyst lower pole of right kidney. An incidental finding of no clinical importance. (**d**) 2D axial view showing multiple gallstones containing air (red square). There is no evidence of cholecystitis. (**e**) 2D axial view showing umbilical hernia (green and white arrows) filled with fat. An incidental finding. (**f**) 2D axial view showing destruction of posterior margin of the vertebral body (red circle). An important finding indicating metastasis

20.5 Incomplete Optical Colonoscopy: Role of Radiology Imaging

Literature underscores that CTC should be performed on patients with incomplete OC [9, 29–33]. The percentage of incomplete OC studies is reported to range from 0.4 to 15% [34, 35]. The ESGE and ESGAR 2020 guideline includes CTC in incomplete OC; DCBE as an imaging alternative to colonoscopy is not included [10]. The guideline does not list DCBE as an imaging alternative to colonoscopy. The diagnostic performance of CTC in symptomatic and asymptomatic patients for the detection of CRC and large polyps is similar to OC and superior to barium enema thus the latter examination should be discouraged [3].

ESGE and ESGAR [10] recommend a same day or next day CTC for incomplete OC. A same day CTC requires tagging of any residual stool and fluid. A patient is given 250 mL of 2% barium and 50 mL of non-ionic iohexol (Omnipaque) to drink when fully recovered after incomplete OC. On average, it takes 3–4 h for the tagging agents to reach the colon. Before insufflation of CO_2 commences a pre-procedure low-dose CT scan is performed to exclude the possibility of an OC caused colonic perforation [10]. Examples of colonic perforation in a patient referred for CTC following an incomplete OC are shown in Fig. 20.3a, b.

If free air is visualised, a CTC is not performed: the referring gastroenterologist is informed of this complication. If a CTC is to be performed the next day, then the patient is kept on fluids only overnight and the tagging agents are taken orally that night. If free air has been excluded on the pre-procedure CT scan, a CTC examination is performed the next day.

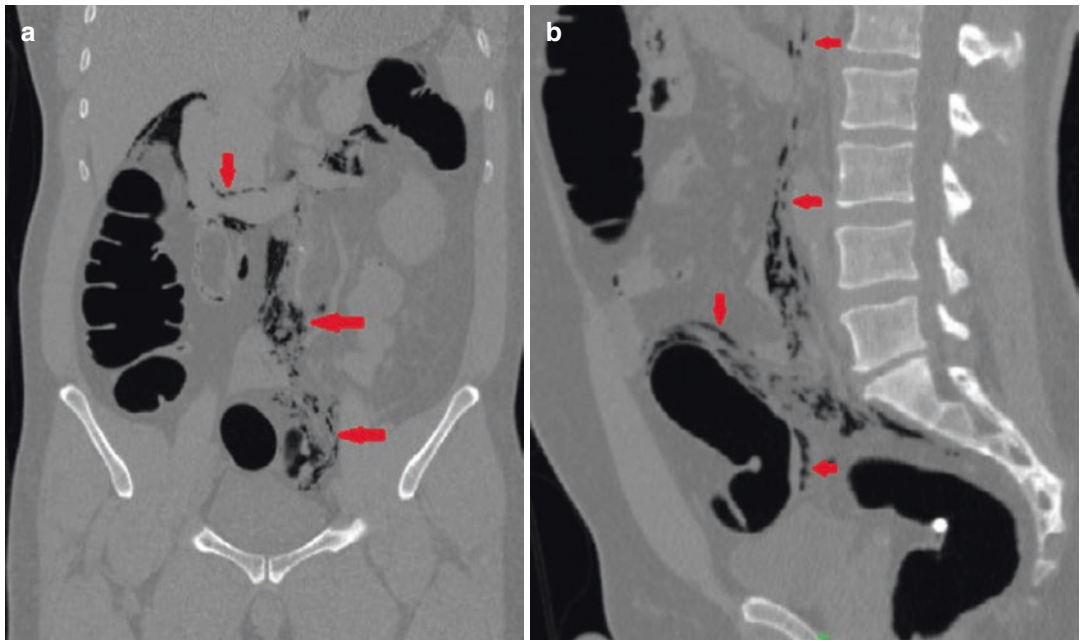

Fig. 20.3 (**a**) 2D CTC coronal image shows extensive gas (red arrows) extending along the sigmoid mesentery and superiorly along the retroperitoneal fascial planes. Incomplete optical colonoscopy earlier on the same day was difficult and included sigmoid polypectomy. (**b**) 2D sagittal view of patient in (**a**). Red arrows show extraluminal gas extending along the sigmoid mesentery and superiorly along the retroperitoneal fascial planes

Key Messages

- All cases of incomplete or failed OC must be completed by CTC or CCE.
- CCE is more expensive than CTC.
- CCE has a difficult and prolonged bowel cleansing procedure.
- CCE cannot visualise extracolonic pathology.
- Reasons for failed or incomplete OC include diverticular disease, long bowel loops, acute flexure angle.
- Essential to exclude OC caused perforation referred for CTC following an incomplete or failed OC.

20.6 Summary

CTC is recommended in the literature as the imaging alternative in patients with incomplete and failed OC. Collaboration between radiologists and gastroenterologists is therefore important for optimal management and imaging of incomplete colonoscopy patients.

References

1. World Health Organisation. Cancer. 2021.[cited 2022 September 27]. https://www.who.int/news-room/fact-sheets/detail/cancer.
2. Cavestro GM, Zuppardo RA, Mannucci A. Early-onset of colorectal cancer: trends and challenges. Lancet Gastroenterol Hepatol. 2019;4(7):F491–2. https://doi.org/10.1016/S2468-1253(19)30146-3.
3. Exarchakou A, Donaldson LJ, Girardi F, Coleman MP. Colorectal cancer incidence among young adults in England: trends by anatomical sub-site and deprivation. PLoS One. 2019;14(12):e0225547. https://doi.org/10.1371/journal.pone.022554.
4. Kim J, Dobson B, Ng Liet Hing C, Cooper M, Lu CT, Nolan G, Von Papen M. Increasing rate of colorectal cancer in younger patients: a review of colonoscopy findings in patients under 50 at a tertiary institution. ANZ J Surg. 2020;90:2484–9. https://doi.org/10.1111/ans.16060.
5. Rajagopalan A, Antoniou E, Rajagopalan E, Arachchi A, Chouhan H, Nguyen TC, Teoh W. Is colorectal cancer associated with altered bowel habits in young patients? ANZ J Surg. 2021;91:943–6.
6. American Cancer Society. Guidelines for colorectal cancer screening. [cited 2022 September 27]. https://www.cancer.org/cancer/colon-rectal-cancer/detection.
7. Davidson KW. Screening for colorectal cancer US Preventive Services Task Force recommendation statement. JAMA. 2021;325(19):1965–77.
8. Sakata S, Kheir AO, Hewett DG. Optical diagnosis of colorectal neoplasia: a Western perspective. Dig Endosc. 2016;28:281–8.
9. Franco DL, Leighton JA, Gurudu SR. Approach to incomplete colonoscopy: new techniques and technologies. Gastroenterol Hepatol. 2017;13(8):476–83.
10. Spada C, Hassan C, Bellini D, Burling D, Cappello G, Carretero C, et al. Imaging alternatives to colonoscopy: CT colonography and colon capsule. European Society of Gastrointestinal Endoscopy (ESGE) and the European Society of Gastrointestinal and Abdominal Radiology (ESGAR) guideline—update 2020. Endoscopy. 2020;52:1127–41. https://doi.org/10.1055/a-1258-4819.
11. Spada C, Hassan C, Barbaro B, et al. Colon capsule versus CT colonography in patients with incomplete colonoscopy. A prospective, comparative trial. Gut. 2015;64(2):272–81.
12. Ismail MS, Murphy G, Semenor S, McNamara D. Comparing colon capsule endoscopy to colonoscopy; a symptomatic patient's perspective. BMC Gastroenterol. 2002;2(1):31. https://doi.org/10.1186/s12876-021-02081-0.
13. Kwack WG, Lim YJ. Current status and research into overcoming limitations of colon capsule endoscopy. Clin Endosc. 2016;49:8–15.
14. Tabone T, Koulaouzidis A, Ellul P. Scoring systems for clinical colon capsule endoscopy—all you need to know. J Clin Med. 2021;10(11):2372. https://doi.org/10.3390/jcm10112372.
15. Hanson ME, Pickhardt PJ, Kim DH, Pfau PR. Anatomic factors predictive of incomplete colonoscopy based on findings at CT colonoscopy. AJR. 2007;198:774–9.
16. Sachdeva R, Tsai SD, El Zein MH, Tieu AA, Abdelgelil A, Besharati S, Khashab MA, Kalloo AN, Kumbhari V. Predictors of incomplete optical colonoscopy using computed tomographic colonography. Saudi J Gastroenterol. 2016;22(1):43–9. https://doi.org/10.4103/1319-3767.173758.
17. Macari M, Bini EJ. CT colonography: where have we been and where are we going? Radiology. 2005;237:819–33. https://doi.org/10.1148/radiol.22373041717.
18. Pickhardt PJ. Screening CT colonography: how I do it. AJR. 2007;184(2):290–8.
19. de Haan MC, Halligan S, Stoker J. Does CT colonography have a role for population-based colorectal screening? Eur Radiol. 2012;22(7):1495–503. https://doi.org/10.1007/s00330-012-2449-7.
20. Bortz JH. An approach for performing a successful CT colonography examination. S Afr J Rad. 2014;18(1):607, 11 pages. https://doi.org/10.4102/sajr.v18i1.607.
21. Pickhardt PJ, Yee J, Johnson CD. CT colonography: over two decades from discovery to practice. Abdom Radiol. 2018;43:517–22.

22. Bortz JH. CT colonography in the visualisation of lymphangioma: a rare benign submucosal lesion. SAR. 2021;59(1):33–40.
23. Copel L, Sosna J, Kruskal JB, Raptopoulos V, Fareell RJ, Morrin MM. CT colonography in 546 patients with incomplete colonoscopy. Radiology. 2007;244(2):471–8.
24. Gluecker TM, Johnson CD, Wilson LA, Maccarty RL, Welch TJ, Vanness DJ, Ahlquist DA. Extracolonic findings at CT colonography: evaluation of prevalence and cost in screening population. Gastroenterology. 2003;124(4):911–6. https://doi.org/10.1053/gast.2003.50158.
25. Pickhardt PJ, Hanson ME, Vanness DJ, Lo JY, Kim DH, Taylor AJ, Winter TC, Hinshaw JL. Unsuspected extracolonic findings at screening CT colonography: clinical and economic impact. Radiology. 2008;49(1):151–9.
26. Yee Y, Weinstein S, Morgan T, Alore P, Aslam R. Advances in CT colonography for colorectal cancer screening and diagnosis. J Cancer. 2013;4(3):200–9.
27. Pooler BD, Kim DH, Pickhardt PJ. Potentially important extracolonic findings at CT colonography: incidence and outcomes of data from a clinical screening program. AJR. 2016;206:313–8.
28. Pooler BD, Kim DH, Pickhardt PJ. Extracolonic findings at screening CT colonography: prevalence, benefits, challenges, and opportunities. AJR. 2017;209:94–102.
29. Pullens HJ, van Leeuwen MS, Laheij RJ, Vleggaar FP, Siersema PD. CT-colonography after incomplete colonoscopy: what is the diagnostic yield? Dis Colon Rectum. 2013;56:593–9.
30. Laghi A. Computed tomography colonography in 2014: an update on technique and indications. World J Gastroenterol. 2014;20(45):16858–67.
31. Maggialetti N, Capasso R, Pinto D, Carbone M, Laporta A, Schipani S, Piccolo CL, Zappia M, Reginelli A, D'Innocenzo M, Brunese L. Diagnostic value of computed tomography colonography (CTC) after incomplete optical colonoscopy. Int J Surg. 2016;33:536–44.
32. De Lázaro y de Molina S, Marco-Doménech SF, Casanovas-Feliu E, Gaona-Morales J. Usefulness of colonography by tomography or virtual colonoscopy. Anal Radiol. 2016;15(3):177–93.
33. Villa NA, Pannala R, Pasha SF, Leighton JA. Alternatives to incomplete colonoscopy. Curr Gastroenterol Rep. 2015;17(11):43. https://doi.org/10.1007/s11894-015-0468-7.
34. Rex DK, Adler SN, Aisenberg J, Burch WC, Carretero C, Chowers Y, et al. Accuracy of capsule colonoscopy in detecting colorectal polyps in a screening population. Gastroenterology. 2015;148(5):948–57.
35. Spada C, Hassan C, Munoz-Navos M, Neuhaus H, Deviere J, Fockens P, et al. Second generation colon capsule endoscopy compared with colonoscopy. Gastrointest Endosc. 2011;74:581–9.

Good Practice Reporting in CTC

21

Joel H. Bortz

21.1 Introduction

A reader should check both intracolonic and extracolonic structures when reporting on a CT colonography (CTC) study. A successful CTC examination means that the colon was well prepared and adequately distended for full visualisation of the six segments of the colon. Two views are usually required, but additional views may be necessary. The report must cover all aspects of the study. The use of a template ensures all required information is reported. CTC interpretation uses a combination of a 3D-2D approach in which 3D is the most important. A screening CTC examination does not require administration of intravenous (IV) contrast. It is indicated when there is a known colonic or extracolonic malignancy; non-ionic agents should be used. As discussed in Chap. 8 some centres may administer an antispasmolytic, hyoscine-N-butylbromide (Buscopan), for example, provided there are no contraindications for its use. Glucagon is not used because it is expensive, not effective, and it has side-effects.

If a study is non-diagnostic due to poor quality, it is essential to report on extracolonic findings (ECFs). Figure 21.1(i–iii) shows examples of a non-diagnostic study due to excessive stool in the colon. There were multiple areas of large amounts of residual stool because the patient did not follow the bowel preparation steps correctly. The CTC was rescheduled. However, it is essential to report on any ECFs even if a patient is rescheduled for a repeat CTC. The following abbreviations are used in this chapter.

- AI: artificial intelligence
- CAD: computer-aided diagnosis
- IVC: ileocaecal valve
- ECFs: extracolonic findings
- FOV: field of view
- HU: Hounsfield unit

J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

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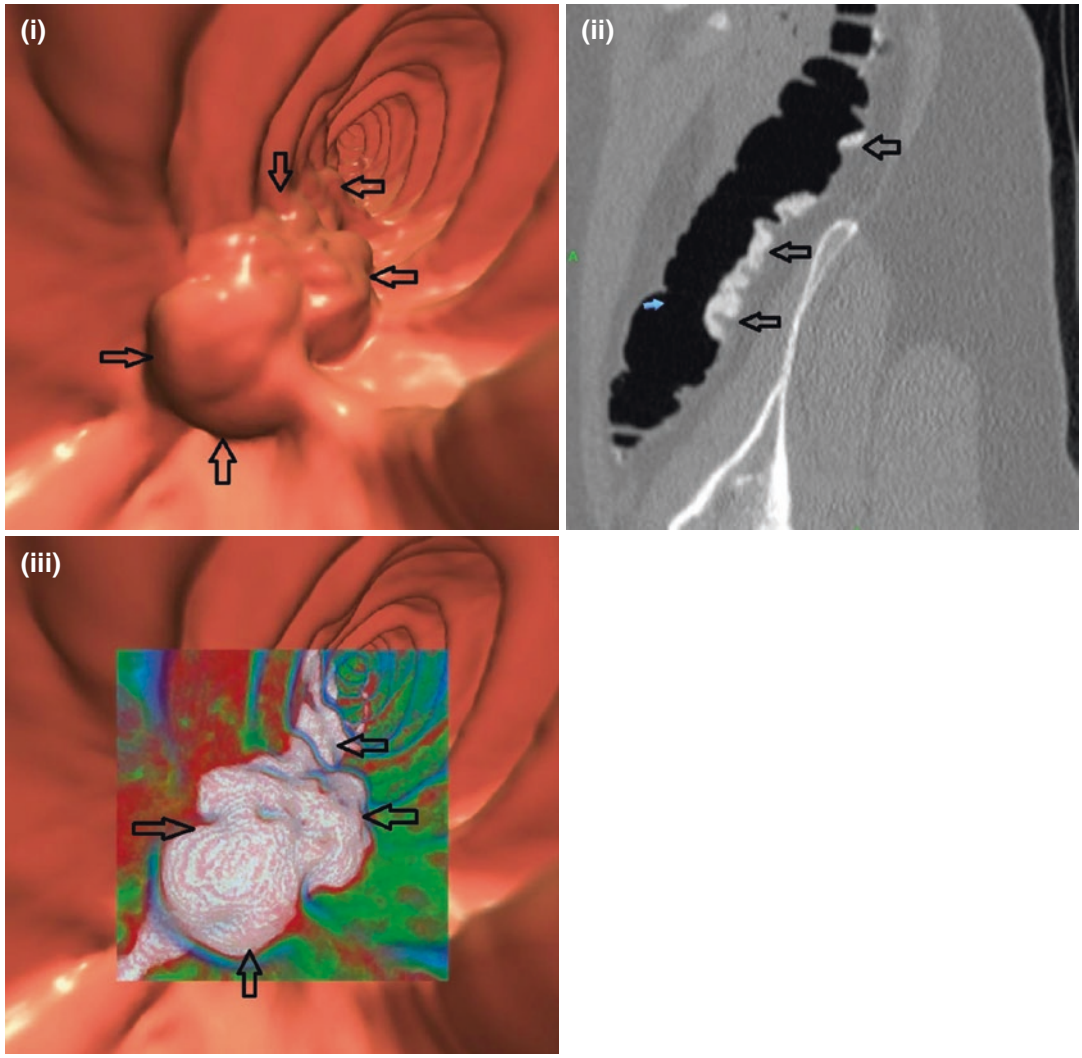

Fig. 21.1 (**i**) 3D view showing stool (arrows). (**ii**) 2D view showing stool (arrows). (**iii**) TD view showing stool (arrows)

21.2 Reading and Interpretation Requirements

Accurate reading and interpretation of CTC studies should be done by a radiologist, or an appropriately trained radiographer. Readers of CTC studies should be familiar with normal colon anatomy and variants, such as the different appearances of the ileocaecal valve (ICV). Figure 21.2a–e depicts variations of ICVs (see Chap. 11 for more examples).

It is important to be able to distinguish residual stool from polyps. Potential pitfalls should be recognised (see Chap. 12). Reading and interpretation requires knowledge of the various pathologies that occur within the colon wall, as well as ECFs (see Chaps. 18, 19, and 20). How to measure polyps is discussed in Chap. 14, as are the different sizes of polyps, and polyp subsets.

In 2005, the C-Rads-CT colonography reporting and data system was introduced for reporting both asymptomatic screening studies and diagnostic studies. Suggested feature descriptors for polyps and masses are presented in Table 21.1 [1]. In terms of Table 21.1, the following is important.

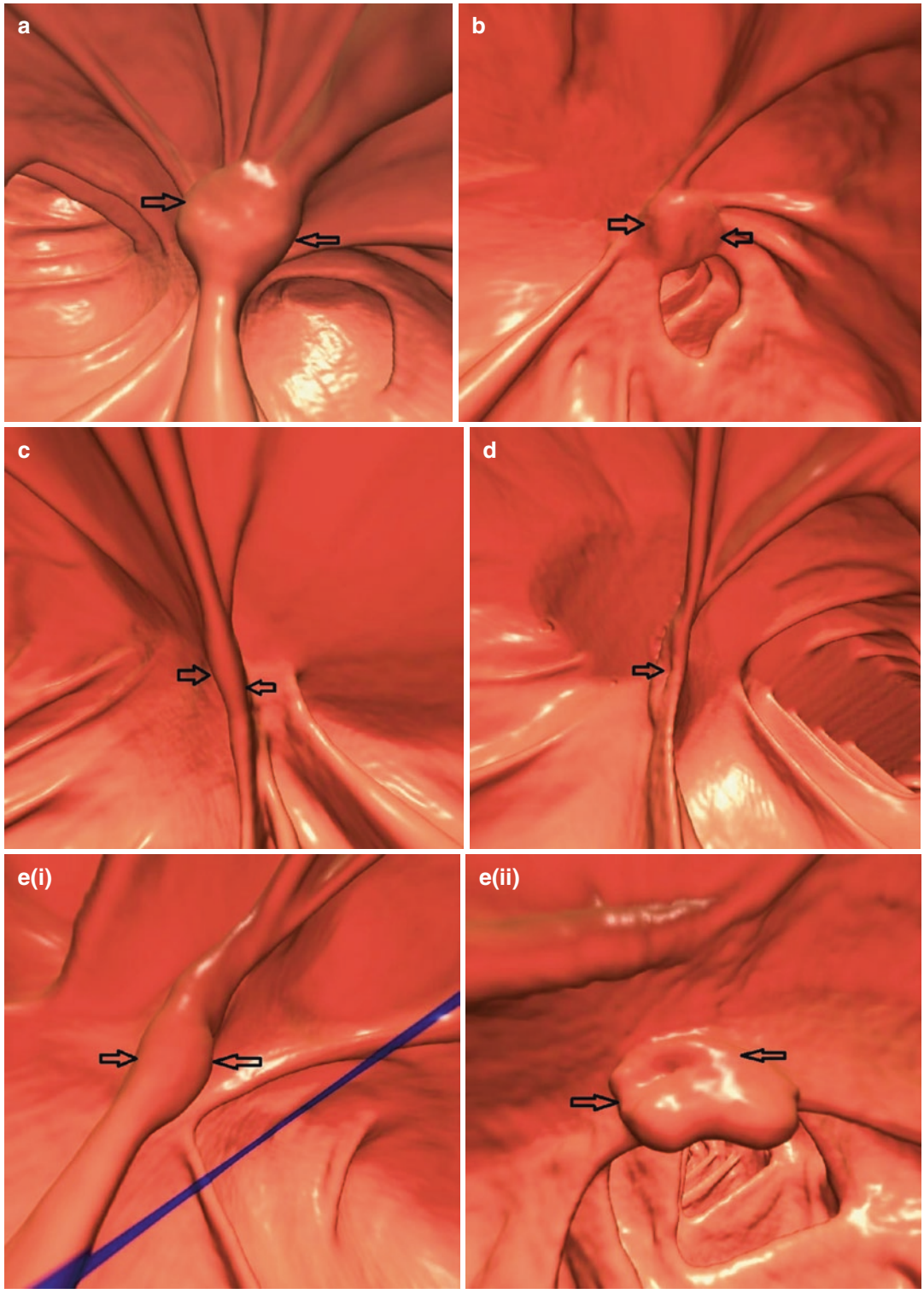

Fig. 21.2 (**a**) Bulbous ICV (arrows). (**b**) Bulbous (polypoidal) ICV (arrows). (**c**) Vulval type ICV (arrows). (**d**) Partially patent ICV (arrow). (**e**) (**i**) 3D endoluminal supine view showing ICV (arrows). (**ii**) 3D endoluminal prone view of the same patient shows change of shape of the ICV (arrows)

Table 21.1 Suggested feature descriptors for polyps and masses[a]

Size (mm)	Always measure the largest diameter in the correct plane, i.e. axial, sagittal or coronal plane
Morphology (form/shape)	Refers to the type of polyp present, namely, sessile, pedunculated, flat or carpet lesion
Location	Polyps may be present in any part of the colon and may be single or multiple. The colon is divided into six segments for CTC as discussed in Chap. 11: rectum, sigmoid colon, descending colon, transverse colon, ascending colon, and caecum
Attenuation	Refers to the density of the lesion being investigated

[a] Adapted from [1]. Zalis et al. CT colonography reporting and data system: a consensus proposal. Radiology 2005; 236 (1):3–9. [https://doi.org/10.1148/radiol.2361041926]

- Measurement of polyps
- An extremely accurate measurement of a polyp is required. For example, a variation of 1–2 mm may convert a normal CTC study into an optical colonoscopy (OC) rather than a 3-year surveillance programme if, for example, a 9 mm polyp is measured incorrectly.
- Size of polyps
  - Polyps may be divided into: diminutive polyps ≤5 mm; small polyps ≥6–9 mm; large polyps ≥10 mm (advanced adenoma).
  - A study is considered to be positive when a polyp size is ≥6 mm.
  - All polyps ≥10 mm are removed via optical colonoscopy.
- Morphology: the type of polyp found
  - Sessile: A broad base of attachment to the colonic mucosa.
  - Pedunculated: It consists of a head and stalk; only the head of the polyp is measured and not the length of the stalk.
  - Flat polyp: A flat lesion usually raised about 3 mm above the colonic mucosa; it is often identified on CTC by having a barium coating on the surface as a result of tagging.
  - Carpet lesion: A laterally spreading superficial tumour occurring mainly in the caecum and rectum.
- Location
  - A polyp may occur in any segment of the colon and may be multiple.
- Attenuation: Polyps and tumours measured in Hounsfield units (HU) to indicate the density of a lesion
  - HUs vary between polyps, tumours, air, water, and bone and show an increase in value following iv contrast enhancement [2, 3]. As an example, the HU value of air is −1000, water is 0 HU, dense bone is +2000 HU, and metal is +3000 HU.
  - Polyp HU values will change from pre-enhancement value to post-enhancement value [3]; unenhanced polyp 30 ± 15 HU and post-enhancement 90 ± 18 HU [3].
  - Colorectal cancers: Pre-enhancement 43 ± 15 HU and post-enhancement 124 ± 18 HU [3].
  - Solid faecal residue: 43 ± 15 HU [3].

The reporting and data system created a common language for CTC studies. It is similar to BI-RADS (breast imaging reporting and data system) that has been successfully used for mammography reporting. The C-Rads system provides consistency of reports between individuals and institutions. An advantage of the system is that it allows valid comparisons of CTC data in clinical and research settings. Knowledge of definitions of polyps and colonic masses, for example, is necessary to use the C-Rads system. Chapter 14 presents a detailed discussion of polyps including definitions.

21.3 Interpretation Tools for CTC

A combination of a 3D-2D approach is used for CTC interpretation; 3D is the most important. Software is required to transition easily between 3D and 2D viewing for detection and measurement of polyps, other polypoidal pathology, and internal haemorrhoids. CAD (computer-aided diagnosis) may also be used [4, 5]. Artificial intelligence (AI) can also be used for polyp diagnosis [6] (see Chap. 25).

The author has used V3D Viatronix (Stony Brook, New York) since 2000. It is currently the only CTC software in the USA with FDA approval. Viatronix tools allow the following.

- Segmentation and creation of 3D model
- Bookmarking
- Tracking 3D mucosal coverage
- Translucency rendering (i.e., a semi-transparent view in different colours beneath the surface): stool and polyp
- Measurement
- Volume measurement
- Electronic cleansing

These tools allow a user to segment out the colorectum to create the 3D model and fly-through. An automated centre-line allows a reader to focus on polyp detection without having to manually produce such a line. Even if there is a break in the colonic outline, the centre-line is present in the next section. The current software now allows for a field of view (FOV) of 120° which gives more coverage; a single fly-through from rectum to caecum may cover up to 90% of the colon lumen. A 90° FOV required four fly-throughs. The 120° FOV only requires two fly-throughs due to increased visualisation.

As described in Chap. 10 when the supine and prone scanned images have been obtained they are then checked. The scanned images are sent to PACS as well as to the Viatronix workstation (Fig. 21.3a). It is at this stage that a 3D model for the fly-through has to be created. A full air column outlining the colon may be obtained in a substantial number of scans. This requires accessing all the scanned supine and prone data. Some cases may present with discontinuity in the colon. Figure 21.3b(i–vi) shows breaks in the colon. Breaks in colon distension may be the result of (i) incomplete distension of a segment of colon or (ii) a column of fluid in a portion of the colon, which does not allow the CO_2 to pass through. These breaks usually occur in the hepatic flexure region as well as the sigmoid colon as demonstrated in Chap. 10.

In a small percentage of patients, reflux of CO_2 into the terminal ileum may occur, and in some patients it may track all the way up to the stomach (see Fig. 21.3c(i)). These areas are excluded from the colon-map view in the automatic centre-line creation; this results in a 3D map view of the colon only as shown in Fig. 21.3c(ii).

When a polyp is detected manual navigation is possible by holding down the left button on the mouse in order to navigate fully around the polyp. The Viatronix software includes a bookmarking tool. When a polyp is detected, its position may be bookmarked on the colon-map with a red dot as evident in Fig. 21.3d. This allows for a quick review of the scan. It is best to describe a polyp's location according to the six segments of the colon (rectum; sigmoid colon; descending colon; transverse colon; ascending colon; caecum). Although the centre-line measurement from the anorectal region to the caecum is accurate, it seldom corresponds to colonoscopic measurements. This is because at optical colonoscopy the bowel is pushed and pulled to advance the colonoscope forward, whereas at CTC no interference with the bowel occurs. Measurement of polyps is covered in detail in Chap. 14. It is essential to address ECFs in the report as underscored in Chap. 18.

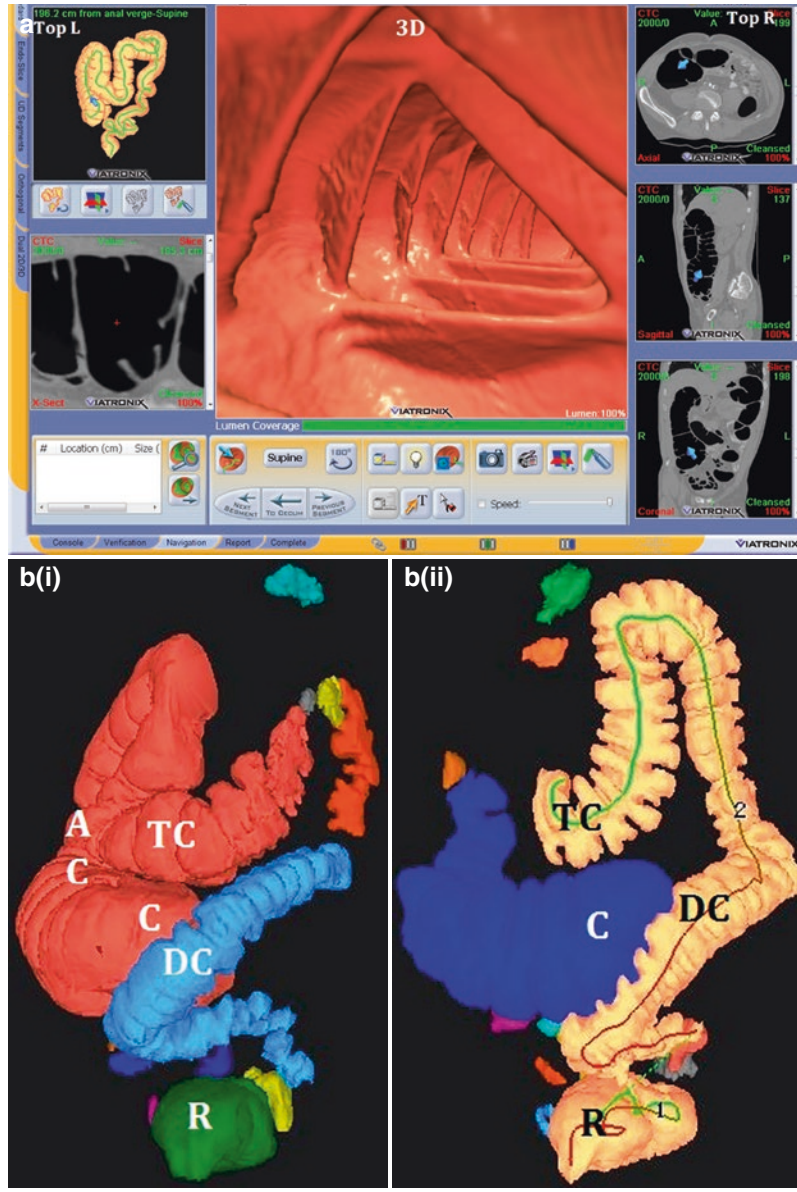

Fig. 21.3 (**a**) Viatronix V3D workstation showing images of a patient and icons. A 3D image must always be in the centre when we commence viewing. Right side shows 2D views (axial at the top; sagittal in the middle; and coronal at the bottom). Each 2D view can be viewed separately clicking the icon. Top left image shows a colon-map with automated green centreline. Below it is a 2D perpendicular view of the 3D image in the centre. The icons at the centre of the screen below the 3D images are used, for example, for direction of flow and speed. (Image courtesy of Viatronix, Stony Brook, New York). (**b**) (**i**) Supine with four breaks. *R* rectum; *DC* descending colon; *TC* transverse colon; *AC* ascending colon; *C* caecum. (**ii**) Prone view shows a break in proximal TC and gap in bowel. This is fully covered in the supine in (**i**); therefore, the study is complete.

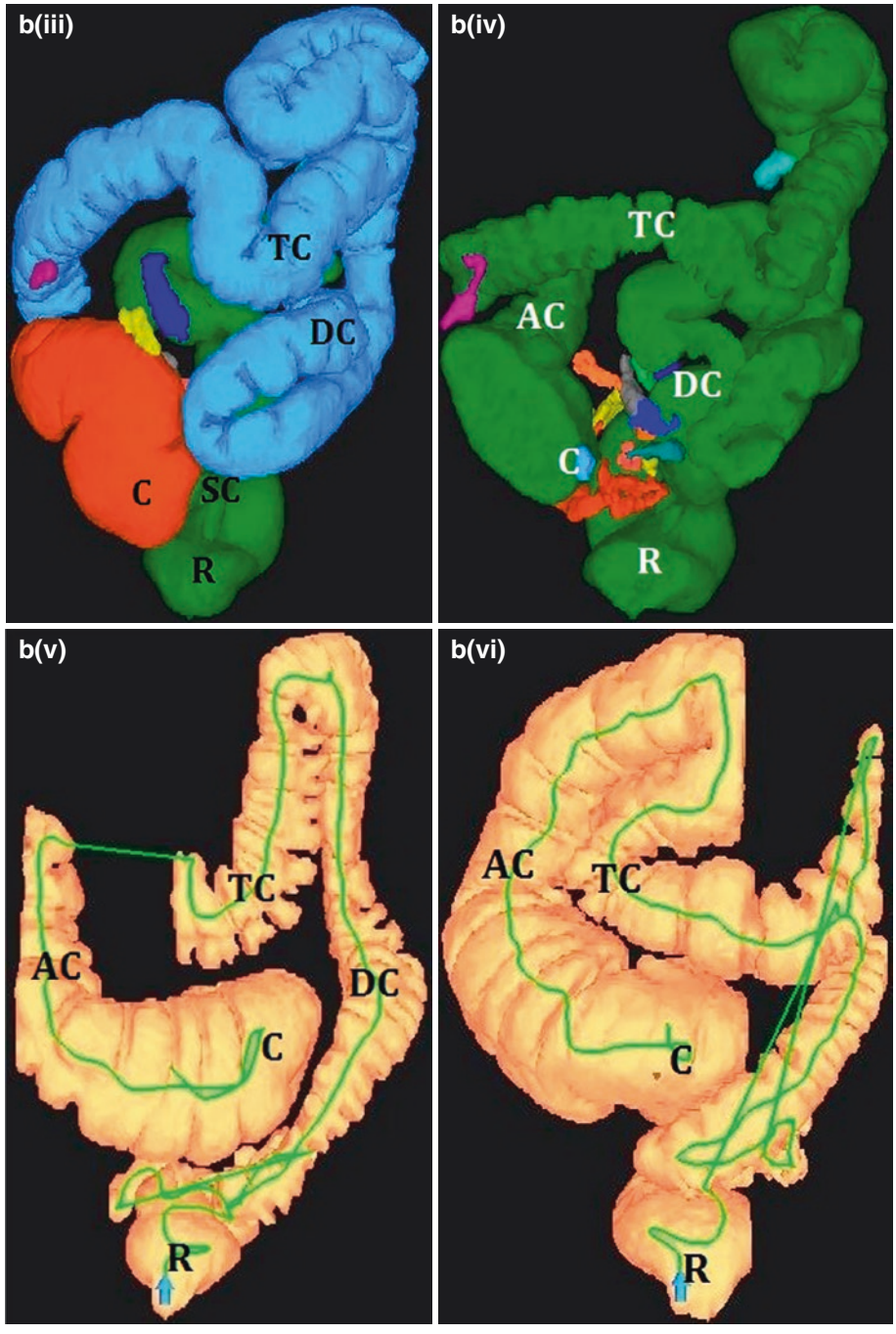

Fig. 21.3 (**iii**) Supine two breaks. *R* rectum; *SC* sigmoid colon; *DC* descending colon; *TC* transverse colon; *C* caecum. (**iv**) Prone showing entire colon distended. *R* rectum; DC descending colon; TC transverse colon; *AC* ascending colon; *C* caecum. (**v**) Gap proximal transverse colon in LLD view. C caecum; *AC* ascending colon; TC transverse colon; *DC* descending colon; *R* rectum. (**vi**) Gap proximal transverse colon covered in RLD view thus study complete. *C* caecum; *AC* ascending colon; *TC* transverse colon; *R* rectum.

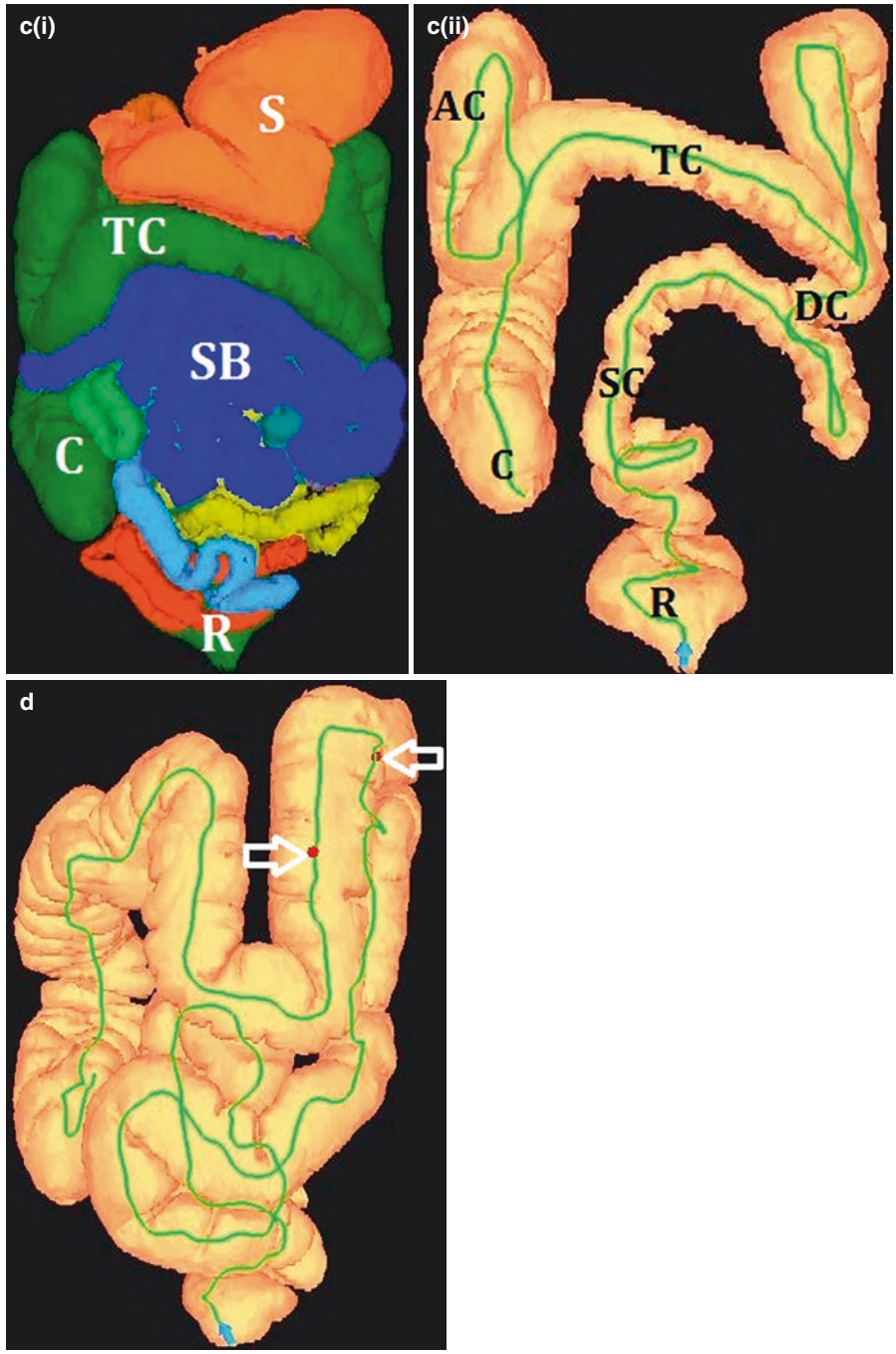

Fig. 21.3 (**c**) (**i**) Reflux of CO_2 into the stomach (S). *TC* transverse colon; *SB* small bowel; *C* caecum; R rectum. (**ii**) Complete colon-map after automatic removal of stomach and small bowel by Viatronix software. *R* rectum; *SC* sigmoid colon; *DC* descending colon; *TC* transverse colon; *AC* ascending colon; *C* caecum. (**d**) Colon-map showing two red dots indicating the site of lesions (open white arrows)

21.4 Role of Artificial Intelligence in CTC

A limitation of CTC is that a reader is not able to differentiate benign and malignant lesions. Over the past few years, the role of AI in imaging has been underscored. Literature reports on the role of AI (machine learning/deep learning) in CTC for polyp detection (e.g., sessile, pedunculated, and serrated polyps), differentiation (benign and premalignant), and size of polyps [6–12]. A detailed discussion of AI and machine learning in imaging is presented in Chap. 25.

21.5 Dictation Template

A dictation template (proforma report) should be used to ensure that all aspects of the CTC study are recorded and reported. Medical terminology and patient-centred concepts must be used in all CTC and extracolonic findings reports. Table 21.2

Table 21.2 Dictation template

Patient's name: **Date:** **Name of referring physician:**	
Indications	• Routine CRC screening • Diagnostic study, for example, bleeding or change in bowel habit • Study following incomplete OC
Technique	For example, the day before the examination the patient undergoes bowel preparation consisting of oral magnesium citrate, 2% barium sulphate, and iohexol. A 16-slice GE scanner is used; automated CO_2 insufflation via the rectum is performed; low-dose supine and prone CT images are obtained without iv contrast. Images are sent to the Viatronix V3D workstation for combined 2D-3D evaluation of the colon and rectum for polyps
Contrast media	If applicable state type and amount administered. • Adverse reactions must be reported
Antispasmolytic	If applicable state type and amount administered. • Adverse reactions must be reported
Ionising radiation dosage	**Dosage** For example: two sequences—typical CTDIvol = 2 mGy; total exam DLP = 215.70 mGy-cm. Note: In some countries, it is mandatory to provide patient dose report. Recommend always include in the CTC report
Findings	**Colon** (a) Comment on quality of bowel preparation (e.g., presence of stool) (b) Comment on degree of distension (c) Comment on presence or absence of diverticular disease (d) Comment on presence of small polyps (6–9 mm) and large polyps (≥ 10 mm). Provide accurate measurements (e) Describe location of polyp (f) Describe morphology of polyp (sessile, flat, pedunculated). *Add disclaimer*: Note that CTC is not intended for detection of diminutive polyps (≤ 5 mm), the presence of absence of which will not change the clinical management of the patient. **Extracolonic** Tabulate the most significant findings; comment on any additional workup needed. *MAFLD*[a]: Comment if noted and recommend that the patient should be informed of options to minimise potential risks. *Add disclaimer*: Note that extracolonic evaluation is limited by the low-dose CT technique and lack of IV contrast **Opportunistic BMD screening**[b] State HU values of lumbar vertebra. Include HU ranges for normal BMD, osteopenia, and osteoporosis

[a] See Chap. 19
[b] See Chap. 18

is a recommended dictation/pro forma reporting template.

21.6 Clinical Audit

The focus of a CTC report is quality of patient care in terms of management and treatment. The importance of structured imaging reporting is underscored in the literature [13–16]. The Royal College of Radiologists provides recommended standards of reporting of imaging studies [17]. The data in a CTC report should be subjected to regular clinical audits in terms of preselected standards in order to improve patient care quality, experience, and outcomes and to implement change based on the results of an audit. The 2021 joint guidance for CTC standards of practice of the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiology includes accuracy of reporting polyps and other pathology in terms of recommended minimum standards and aspirational targets [18]. The principles of clinical audit are presented in Chap. 27.

Key Messages

- A CTC report must include both intracolonic and extracolonic findings (ECFs).
- A CTC report should include a dose report.
- A CTC report must include two disclaimers in terms of detection of diminutive polyps, and evaluation of ECFs, respectively.
- CTC interpretation uses a combination of a 3D-2D approach.
- If applicable, a CTC report must include use of intravenous contrast.
- If applicable, a CTC report must include use of antispasmolytic.
- If applicable a CTC report must include metabolic-associated fatty liver disease.
- A CTC report should include opportunistic screening HU values.
- A CTC report should provide information in terms of best practice and standards in terms of auditable outcomes.
- The language of a CTC report should include patient-centred concepts.

21.7 Summary

The size, morphology (form/shape), and location of lesions in the colon must be reported. Extracolonic findings (ECFs) must be included in the report, with a disclaimer that evaluation of ECFs is limited by the low-dose CT technique and lack of intravenous contrast. The report must include a disclaimer that CTC is not intended for detection of diminutive polyps (≤5 mm), the presence or absence of which will not change the clinical management of the patient. The report should include opportunistic screening HU values.

Acknowledgements Viatronix V3D workstation image courtesy of Viatronix, Stony Brook, New York.

References

1. Zalis ME, Barish MA, Choi JR, et al. CT colonography reporting and data system: a consensus proposal. Radiology. 2005;236:3–9.
2. Oto A, Gelebek V, Oguz BS, Sivri B, Deger A, Akhan O, Besim A. CT attenuation of colorectal polypoid lesions: evaluation of contrast enhancement in CT colonography. Eur Radiol. 2003;13(7):1657–63. https://doi.org/10.1007/s00330-002-1770-y.
3. Neri E, Vagli P, Picchietti S, Vannozzi F, Linsalata S, Bardine A, Bartolozzi C. CT colonography: contrast enhancement of benign and malignant colorectal lesions versus fecal residuals. Abdom Imaging. 2005;30(6):694–7. https://doi.org/10.1007/s00261-005-0340-6.
4. Lawrence EM, Pickhardt PJ, Kim DH, Robbins JB. Colorectal polyps: stand-alone performance of computer-aided detection in a large asymptomatic screening population. Radiology. 2010;256(3):791–8. https://doi.org/10.1148/radiol.10092292.
5. Halligan S, Mallett S, Altman DG, et al. Incremental benefit of computer-aided detection when used as a second and concurrent reader of CT colonographic data: multiobserver study. Radiology. 2011;258(2):469–76. https://doi.org/10.1148/radiol.10100354.
6. Rasouli P, Moghadam AD, Eslami P, et al. The role of artificial intelligence in colon polyps detection. Gastroenterol Hepatol Bed Bench. 2020;13(3):191–9.
7. Grosu S, Wesp P, Graser A, Maurus S, Schulz C, et al. Machine learning–based differentiation of benign and premalignant colorectal polyps detected with CT colonography in an asymptomatic screening population: a proof-of-concept study. Radiology. 2021;299:326–35. https://doi.org/10.1148/radiol.2021202363.

8. Wesp P, Grosu S, Graser A, Maurus S, Schulz C, Knösel T, et al. Deep learning in CT colonography: differentiating premalignant from benign colorectal polyps. Eur Radiol. 2022;32:4749–59. https://doi.org/10.1007/s00330-021-08532-2.
9. Näppi JJ, Pickhardt PJ, Kim DH, Yoshida H. Uncertainty quantification in 3D deep learning for detecting serrated polyps in CT colonography. Proceedings Volume 12037, Medical Imaging 2022: Imaging Informatics for Healthcare, Research, and Applications. 2022;120370T. https://doi.org/10.1117/12.2612637
10. Kotecha S, Vasudevan A, Kashyap Holla VMK, Kumar S, Pruthviraja D. Latte MV.3D visualization cloud based model to detect and classify the polyps according to their sizes for CT colonography. J King Saud Univ. 2022;34(8):4943–55. https://doi.org/10.1016/j.jksuci.2020.12.006.
11. Hegde N, Shishir M, Shashank S, Dayananda P, Latte MV. A survey on machine learning and deep learning-based computer-aided methods for detection of polyps in CT colonography. Curr Med Imaging. 2021;17(1):3–15. https://doi.org/10.2174/1573405616666200415141427.
12. Tan J, Gao Y, Liang Z, Cao W, Pomeroy MJ, Huo Y, Li L, Barish MA, Abbasi AF, Pickhardt PJ. 3D-GLCM CNN: a 3-dimensional gray-level co-occurrence matrix-based CNN model for polyp classification via CT colonography. IEEE Trans Med Imaging. 2020;39(6):2013–24. https://doi.org/10.1109/TMI.2019.2963177.
13. Taylor F, Mangat N, Swift IR, Brown G. Proforma-based reporting in rectal cancer. Cancer Imaging. 2010;10:S142–50. https://doi.org/10.1102/1470-7330.2010.9092.
14. Mityul MI, Gilcrease-Garcia B, Mangano MD, Demertzis JL, Gunn AJ. Radiology reporting: current practices and an introduction to patient-centered opportunities for improvement. AJR Am J Roentgenol. 2018;210(2):376–85. https://doi.org/10.2214/AJR.17.18721.
15. Patel A, Rockall A, Guthrie A, Gleeson F, Worthy S, Grubnic S, Burling D, Allen C, Padhani A, Carey B, Cavanagh P, Peake MD, Brown G. Can the completeness of radiological cancer staging reports be improved using proforma reporting? A prospective multicentre non-blinded interventional study across 21 centres in the UK. BMJ Open. 2018;8(10):e018499. https://doi.org/10.1136/bmjopen-2017-018499.
16. Weber TF, Spurny M, Hasse FC, Sedlaczek O, Haag GM, Springfeld C, Mokry T, Jäger D, Kauczor HU, Berger AK. Improving radiologic communication in oncology: a single-centre experience with structured reporting for cancer patients. Insights Imaging. 2020;11(1):106. https://doi.org/10.1186/s13244-020-00907-1.
17. Standards for interpretation and reporting of imaging investigations 2nd edition. The Royal College of Radiologists, 2018. https://www.rcr.ac.uk/system/files/publication/field_publication_files/bfcr181_standards_for_interpretation_reporting.pdf.
18. The joint guidance for CTC standards of practice of the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiology. 2021. https://www.rcr.ac.uk/system/files/publication/field_publication_files/bfcr201-standards-of-practice-for-computed-tomography-colonography-ctc.pdf.

22 The Role of Ultrasound and Magnetic Resonance Imaging in the Evaluation of Colon Cancer

Kalpesh Mody

22.1 Introduction

Imaging has a crucial role in all aspects of the management of colorectal neoplasms; namely screening, diagnosis, staging, and surveillance. Accurate and reproducible imaging is essential to determine the appropriate course of clinical management. Current staging of colorectal cancer (CRC) utilises the tumour, nodes, metastases (TNM) staging system which analyses tumour extension into the bowel wall and surrounding tissue (T-stage), nodal involvement (N-stage), and the presence of distant metastases (M-stage) (see Chap. 15). CT colonography (CTC) has replaced barium enema as the first line alternative imaging modality to colonoscopy [1, 2]. In this chapter, the role of ultrasound and MRI is discussed as alternative imaging techniques for screening, diagnosis, and staging of CRC. New fields of research which may further refine the accuracy and importance of the imaging modalities are also discussed; particularly with the advent of artificial intelligence (AI) and the potential impact thereof.

The following abbreviations are used in this chapter.

- 2D: two-dimensional
- 3D: three-dimensional
- AI: artificial intelligence
- BLMRC: bright lumen MR colonography
- CEUS: contrast-enhanced ultrasonography
- CRC: colorectal cancer
- CTC: computed tomography colonography (aka virtual colonoscopy)
- EUS: endoscopic ultrasonography
- DL: deep learning
- DLMRC: dark lumen MR colonography
- FOV: field of view
- MRC: MR colonography
- MRE: MR elastography
- MRF: mesorectal fascia
- MRS: MR spectroscopy
- TNM: tumour, nodes, metastases
- TRUS: transrectal ultrasound
- USE: ultrasound elastography

22.2 Ultrasound

Two categories of ultrasound imaging are available for the management of CRC: transabdominal, and endoscopic ultrasonography (EUS). The former is not used for direct evaluation of colorectal neoplasms due to artefact from bowel gas shadowing and limited depth of imaging. It is, however, of

K. Mody (✉)
Inkosi Albert Luthuli Central Hospital, Durban, South Africa

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value in the detection of visceral lesions, abdomino-pelvic fluid, and lymphadenopathy which are markers for metastatic disease.

EUS involves the introduction of an ultrasound probe into a hollow organ such as the gastro-intestinal tract. This allows for direct visualisation of the lesions, as well for assessment of the depth of invasion. Transrectal ultrasound (TRUS), as a form of EUS, provides an alternative modality in imaging of rectal tumours. It utilises a high frequency (6–16 MHz) radial endoscopic ultrasound probe which provides a 360° field of view (FOV) with a 2–5 cm focal length [3]. TRUS provides high-resolution detail of tumour infiltration of the rectal wall, making it the best imaging modality for staging of early rectal carcinoma, particularly if confined to the rectal wall [1, 3–7]. When using TRUS for assessment of the depth of tumour infiltration through the layers of the rectal wall, studies have shown accuracies of between 70 and 95% [6].

TRUS also allows for assessment for local nodal involvement by evaluating the morphology of the adjacent nodes [1, 2]. This however has proven less reliable with accuracies of 70–75% [6]. As with all imaging modalities, there are advantages and disadvantages.

Advantages [4]

- Lack of ionising radiation.
- Less expensive.
- Shorter examination time.
- Allows for simultaneous imaging and biopsy.

Disadvantages

- Highly operator dependent.
- Stenotic lesions may limit passage of the probe and inhibit accurate imaging (use of micro probes may alleviate this) [3].
- Limited accuracy in evaluation of upper rectal lesions.
- Does not evaluate the remainder of the colon or for metastatic or distant nodal involvement [4].
- May overestimate tumour infiltration in the presence of concomitant inflammation [3, 4] and may not be able to depict involvement of the mesorectal fascia (MRF) [2, 6].

More recent advancements in EUS include the development of a forward-viewing radial echoendoscope which allows for ultrasonographic evaluation of the entire colon [6]. The role of contrast-enhanced ultrasonography (CEUS), ultrasound elastography (USE) as well as three-dimensional (3D) EUS is still being evaluated, with initial data showing promise particularly in the distinction between adenomas and adenocarcinoma. USE may be able to distinguish between benign and malignant neoplasms as well as lymphadenopathy based on tissue stiffness [6, 8].

CEUS utilises perfusion quantification to indirectly demonstrate important tumour biologic features including tumour grading and microvessel density. Due to the complexity, variability, and limited reproducibility of the measurements as well as no standard technical approach being established, CEUS is not currently recommended for routine clinical practice [8].

22.3 Magnetic Resonance Imaging, MR Colonography, and MRI Rectum

Magnetic resonance imaging (MRI) of the colon can be broadly divided into MR colonography (MRC) and dedicated rectal MRI. As an alternative imaging technique for screening, diagnosis, and staging of CRC, MRI has several advantages and disadvantages.

- Advantages.
  - Lack of ionising radiation.
  - Greater anatomical detail with clearer delineation of tumour infiltration into the layers of the bowel wall and beyond.
- Disadvantages of MRI.
  - Cost factor, particularly as a screening tool.
  - Limited availability.
  - Time required for imaging far greater than CT.

Table 22.1 MRI request checklist

Patient information. Please indicate Yes or No	Yes	No
Does the patient have a cardiac pacemaker?		
Does the patient have a neurostimulator?		
Does the patient have a hearing aid?		
Does the patient have any metallic orthopaedic hardware?		
Does the patient have any prosthesis (e.g. breast, eye)?		
Does the patient have false teeth, crowns, or other dental work?		
Does the patient have impaired renal function?		
Does the patient have any allergies? If YES, please list		
Has the patient had previous neurosurgery or cardiac surgery? If YES, give details		
Has the patient had previous MRI scan/s?		
Is the patient pregnant?		
Is the patient claustrophobic?		

- Imaging artefacts, particularly due to motion, breathing, etc., may significantly affect imaging quality.
- Impact of patient factors, such as claustrophobia and noise intolerance which may limit or prevent imaging.

In addition, patients for MRI also require extensive screening for metallic objects prior to entering the imaging room. Apart from the potential displacement of the object, of concern is the heat that will be generated by non-compatible metallic objects due to the magnetic field which will result in obvious patient discomfort and even severe burns. Also of concern is that metallic prostheses, even MRI compatible ones, create significant artefact which may obscure portions of the FOV. Table 22.1 is an example of a checklist for screening patients prior to MRI.

Whilst there has been significant progress in the development of higher field strength MRI scanners, studies have shown that there is no significant difference in image quality or detection of polyps greater than 6 mm in size between 1.5T and 3T machines [2, 6, 7]. Research into this aspect of MR imaging is however continuing with refinement of both software and hardware.

It is also important to remember that although many recently produced metallic prostheses are now considered MRI-safe, this compatibility may be dependent upon the field strength of the MRI scanner [9]. Objects which are deemed to be MRI-safe for imaging with a 1.5T scanner but may have questionable MRI-safety at 3T imaging include dental braces, cardiac metallic stents, sternal wires, aneurysm clips, etc. [9]. Compatibility of these prostheses and implants must be established with the manufacturer prior to imaging.

Table 22.2 Indications for MRC[a]

MRC: indications	• Incomplete colonoscopy • Colorectal cancer screening • Inflammatory bowel disease • Diverticulitis

[a] Adapted from [10]

22.3.1 MR Colonography

Table 22.2 presents the indications for MRC. Two different technical approaches are used in MRC based primarily on the endoluminal contrast agent administered: bright lumen MRC (BLMRC), and dark lumen MRC (DLMRC).

- BLMRC
- A gadolinium chelate-spiked enema is instilled into the colon with dual positioning also used. To assess the progress of colonic filling, a non-section-selective gradient echo (GRE) sequence is used which provides sequential images of the bowel [10].
- For diagnostic imaging, a 3D T1-weighted spoiled GRE sequence is used with imaging in both prone and supine positions [10].
- With BLMRC, polyps and neoplasms are depicted as filling defects against a hyperintense background. The extracolonic tissues are suppressed and therefore only the contrast-filled bowel loops stand out. Image acquisition is rapid, with the study taking

approximately 20 min. However, due to the hyperintense signal of the enema administered, intravenous (IV) contrast cannot be used to identify lesions as the enhancement would be masked. In addition, faecal material and air bubbles may also be mistaken for polyps as they also appear as filling defects [10].

- DLMRC

DLMRC requires administration of a negative agent such as water, air, or carbon dioxide via a rectal insufflation device. Air or carbon dioxide (CO_2) are more frequently used than water due to a better safety profile. Bowel distension is monitored using either half-Fourier acquisition single-shot turbo spin echo (HASTE) or true fast imaging with steady-state precession sequences [10]. DLMRC requires the administration of an IV contrast agent to distinguish polyps or neoplasms from adherent stool. Polyps and neoplasms should demonstrate post-contrast enhancement unlike adherent stool. In addition, the use of iv contrast also allows for assessment of the extracolonic structures and abdominal viscera, which are not suppressed as in BLMRC. Given the greater degree of information obtained via DLMRC in a single study as compared to BLMRC, the former has become the favoured imaging technique in recent times [10]. It is however important to remember that the use of iv contrast material in DLMRC incurs additional risks such as anaphylaxis and nephrogenic systemic fibrosis, a potentially fatal complication in the setting of renal failure.

As in CTC, optimal bowel preparation [10] is essential for MRC, particularly for detection of polyps and screening for early neoplasms. The protocols currently being used are similar to those of CTC (see Chap. 9). The suitability of stool tagging in MRC is still under investigation but appears promising. As in CTC, maximal bowel distension is essential to improve the diagnostic accuracy of MRC. Depending on the imaging technique used, contrast agent, gas or emulsions are introduced via a rectal catheter. In addition, dual positioning (supine and prone) is used to optimise distension and to displace residual faecal material. Antispasmodic agents, such as butylscopolamine (Buscopan) or glucagon, may be administered to alleviate discomfort and reduce motion artefact from bowel peristalsis. However, Buscopan is not available in certain countries such as the United States of America (USA), and the use of glucagon may induce reflux through the ileocecal valve which will affect colonic distension [10].

22.3.2 Rectal MRI

Rectal MRI involves limited imaging of the pelvis utilising multiplanar fine-slice imaging to depict the pelvic structures. In the primary (pretreatment) staging, rectal MRI is useful in the following circumstances.

- Identifying patients suitable for neoadjuvant chemoradiotherapy.
- Surgical planning.
- Identifying factors for prognostication.

In the work-up of patients with rectal carcinoma, there are five prognostic factors that must be identified [11].

1. Depth of tumour infiltration beyond the muscularis propria.
2. Nodal status.
3. Extramural vascular infiltration.
4. Involvement of the circumferential resection margin.
5. Presence of peritoneal perforation or involvement of the puborectalis sling in low rectal tumours.

MRI of the rectum provides accurate depiction of mural invasion by the tumour as well as possible extension beyond the muscularis layer up to the mesorectal fascia (T-staging). Studies have shown a significant increase in the rate of tumour recurrence in lesions with extension of

more than 5 mm into the mesorectal adipose tissue [11, 12]. Furthermore, tumour involvement of MRF is also an important prognostic factor in determining the correct course of therapy and for evaluating the risk of tumour recurrence [5, 11, 13]. Therefore, it is essential to ensure that the images produced are acquired in the appropriate plane to ensure the most accurate measurements possible [14]. In particular, the axial images must be obtained perpendicular to the long axis of the rectum to accurately depict tumour extension into the mesorectal adipose tissue and MRF involvement. In addition to the T-staging, MRI can also identify infiltration of the neurovascular bundles by the tumour, as well as possible nodal spread.

The standard MRI protocol, as recommended by the Magnetic Resonance Imaging and Rectal Cancer European Equivalence (MERCURY) group [15] includes the following.

- 2D FSE T2-weighted high-resolution sequences obtained in oblique axial (perpendicular to tumour), sagittal (longitudinal to tumour), and oblique coronal (parallel to the anal canal) planes with a small FOV and no fat suppression.
- FSE T2-weighted images without fat suppression in the axial plane of the pelvis with a wide FOV.

Localised high-resolution images of the tumour provide anatomic detail for local staging, and the wide-FOV images are used for nodal evaluation within the pelvis [15]. T1-weighted imaging with a wide FOV is not routinely performed but may be useful in assessment of bone changes as well as for evaluation of mucinous tumours.

The advantage of MRI of the pelvis, particularly in view of the lack of ionising radiation and contrast administration, is that studies can be repeated at short intervals to monitor patient progress on chemoradiotherapy as well as for tumour recurrence following resection. Figure 22.1a shows multiplanar MR images of the pelvis in a patient with rectal carcinoma. Figure 22.1b shows MR images of the liver in a patient with metastatic rectal carcinoma.

Apart from the basic sequences described above, there is no current agreement on the optimal imaging technique for rectal cancer staging particularly with regard to the use of surface phased array and endoluminal coils and endoluminal contrast agents. The newer pelvic multichannel surface coils provide higher spatial resolution and signal-to-noise ratio as well as a larger FOV [7]. Endorectal coils provide greater spatial resolution and detail of the rectal wall. However the limited FOV, need for a patent rectal lumen, and significant patient discomfort, means that phased array surface coils are preferred as they address the shortcomings of endorectal coils without significant loss of anatomical resolution [1, 2, 5].

Current consensus indicates that the administration of iv gadolinium-based contrast does not add significantly to the accuracy of primary tumour staging and therefore does not justify the added cost, imaging time and risk of NSF and contrast allergy [5, 13, 14]. Antispasmodic agents such as Buscopan may reduce motion artefact and improve image quality [15]. However, the use of such agents is not currently considered as routine practice.

Endorectal filling with either positive or negative contrast is also not routinely performed as the alteration of the rectal anatomy may distort the accuracy of tumour staging [15]. Diffusion-weighted imaging has also shown promise in identification of the primary tumour as well as possible nodal involvement [5, 7, 14]. In addition, some studies have highlighted the possibility of determining tumour response using the apparent diffusion coefficient (ADC) value [7, 8]. Further research is however required to refine the technique and improve reliability.

MRI is also useful in the evaluation of tumour response and potential local recurrence. Rectal MRI is able to do the following in terms of assessing tumour response.

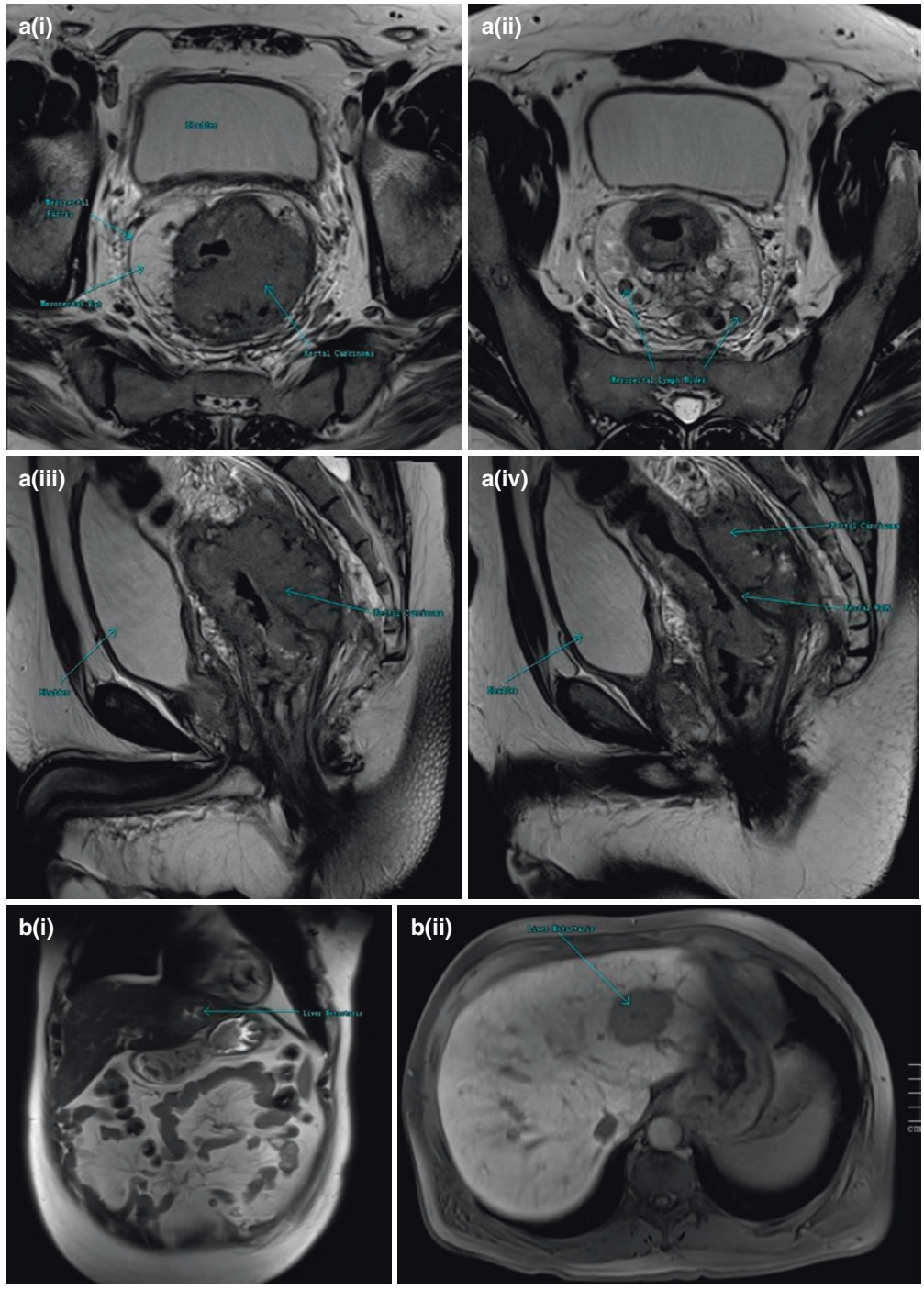

Fig. 22.1 (**a**) (**i**) Axial T2-weighted image demonstrating tumour extension to the mesorectal fascia. (**ii**) Axial T2-weighted image depicting mesorectal adenopathy. (**iii**) Sagittal T2-weighted image demonstrating tumour extension into the mesorectal tissue posteriorly. (**iv**) Sagittal T2-weighted image demonstrating tumour extension beyond the rectal wall. (**b**) (**i**) Coronal T2 HASTE image demonstrating a metastatic deposit in the left lobe of the liver. (**ii**) Axial T1 VIBE image obtained 20 min following administration of Primovist IV contrast. The metastatic deposit in the left lobe of the liver is further delineated

- Evaluate tumour regression.
- Assess mucin response in mucinous carcinomas.
- Detect complete clinical response.
- Tailor surgical planning.
- Where the non-surgical approach has been taken, rectal MRI is essential for monitoring.

In restaging MRI, it is crucial to try to distinguish between fibrosis and residual tumour. Whereas tumour should demonstrate intermediate signal intensity, fibrotic change should demonstrate low signal intensity on all sequences [15]. Diffusion-weighted imaging has shown value in differentiating between the two entities, with tumour and fibrosis showing high and low signal intensity, respectively, on high b-value sequences. However, in the presence of scarring and significant fibrosis, this distinction is not always easily appreciated [7]. In assessing for local recurrence, contrast-enhanced MRI has shown value for distinction between tumour and post-treatment change [15]. The below are features of concern.

- Increase in size
- Intense and heterogeneous enhancement
- Invasive behaviour
- Asymmetric appearance

22.4 Comparison of the Accuracy of Imaging Modalities in TNM Staging of Colon Cancer

Table 22.3 shows the comparative accuracy in percentages of TRUS, MRI, CT, and CTC in TNM staging.

Table 22.3 Comparative accuracy of TRUS, CT, CTC, and MRI[a]

Modality	T-stage	N-stage
TRUS [3]	80–95%	70–75%
CT, MRI [3]	75–85%	55–65%
CTC [10]	73–83%	59–71%

[a] Adapted from [3, 13]

22.5 Advancements in MR Imaging of CRC

MR elastography (MRE) is predominantly used in the characterisation of hepatic lesions rather than for primary tumour evaluation [8]. Virtual colonoscopy (CTC) utilising MRC provides two-dimensional (2D) and 3D imaging of the colon following bowel distension [8]. Use of MRC has generally been limited in clinical practice, with CTC being preferred. CTC is also limited due to poor sensitivity for lesions that are flat or less than 5 mm in size [8].

MR volumetry is useful in the calculation of tumour burden and monitoring of response. Studies have shown that tumour volume reduction is a superior predictor of pathologic response than tumour size according to response evaluation criteria in solid tumours (RECIST) [8]. However, distinction between residual tumour and fibrotic change on the T2-weighted images used for volumetry is difficult, therefore limiting the accuracy of the volumetric assessment [8].

Magnetisation transfer MR imaging is an evolving field of MRI. It looks at the difference in magnetisation interaction of free water and molecularly bound protons [8]. Theoretically, magnetisation transfer would be higher in fibrotic tissue which should allow for distinction between residual tumour and fibrosis. Magnetisation transfer assessment may also be of value in distinguishing between good and poor responders following oncologic therapy [8].

MR spectroscopy (MRS) provides information of the metabolic composition of lesions, with tumours demonstrating choline and lipid peaks which, respectively, are indicators of high cellularity and tumour necrosis. Currently, MRS is limited in clinical use particularly due to the difficulty in obtaining diagnostic images as a result of peristalsis, spectral contamination, limited spatial resolution, magnetic field distortion, etc. [8].

Tumours, in particular malignant lesions, demonstrate significant heterogeneity which is not accurately reflected in single modality mea-

surements. The relevance of multiparametric imaging has been explored to provide a more accurate analysis of the disease status [8]. Measurement of tumour metabolism and perfusion, for example, may provide important information for potential tumour biologic characterisation as well as possible predictors of prognosis and response to therapy. For example, studies have shown that tumours with highly increased perfusion and FDG uptake frequently demonstrate higher stages histopathologically [8].

22.6 Evolving Role of Artificial Intelligence (AI) in Imaging of CRC

Until recently, the standard method of tumour characterisation, and assessment has been a fairly qualitative and semi-quantitative visual assessment of the modalities available by a radiologist [16, 17]. This however is open to significant subjectivity due to equipment performance, patient factors, experience of the reporting radiologist, and inter- and intra-observer reliability [16, 17]. Current research into the use of AI hopes to provide a more accurate and objective assessment of tumour characteristics, staging and potential prognostication. Methods of AI that are currently being used in CRC imaging include radiomics, and deep learning (DL). Radiomics, by utilising various computer algorithms, converts images into mineable data and thereafter allows for the extraction of investigator-defined quantitative parameters to provide a more detailed analysis of tumour heterogeneity [16, 18]. Radiomic determination is a multistep process involving image acquisition, segmentation, and feature extraction [16, 17]. Radiogenomics as a further development attempts to show a relationship between quantitative imaging features and gene expression patterns, particularly the *K-ras* gene mutation status in CRC [8, 16]. It is important to note that radiomics and radiogenomics are not equivalent [8]. DL is a more recent advancement in AI; it avoids the step of extracting manually designed features by utilising a self-learning algorithm based on useful representations of images [17, 18].

In addition to providing greater clarity on the heterogeneity of the primary tumour, AI-assisted imaging has shown promise in the distinction between benign and malignant lymphadenopathy [18]. Furthermore with the advent of a 'watch and wait' approach being explored following chemoradiotherapy, AI-assisted MR imaging has shown the potential to predict complete clinical response as well as the identification of possible tumour recurrence [16].

At this stage, however, the clinical utilisation of AI-assisted imaging is limited due to several factors, including the variations in imaging hardware, techniques, and protocols. Several different algorithmic models exist in the radiomic-DL programming with no standardisation of protocol, data pooling, and insufficient analysis to identify the more proficient choices. Further research is needed to evaluate the added value in comparison with current methods, the cost-effectiveness of their implementation and the clinical impact thereof [16].

Key Messages

- Abdominal ultrasonography is performed for detection of visceral metastatic disease, abdomino-pelvic fluid and lymphadenopathy.
- Patients for MRI require extensive screening for metallic objects prior to entering the imaging room.
- Optimal bowel preparation is essential for MRC, particularly for detection of polyps and screening for early neoplasms.
- MRI of the rectum provides accurate depiction of mural invasion by the tumour as well as possible extension beyond the muscularis layer up to the mesorectal fascia (MRF) (T-staging).
- MRI of the rectum is of value in the primary staging of rectal carcinoma as well as in the evaluation of tumour response and determination of tumour recurrence.
- Accuracy of tumour burden evaluation is difficult in the post-treatment patient due to the

change in tumour characteristics as well as the presence of fibrosis.
- Advancements in MRI, particularly with regard to volumetry and magnetisation transfer imaging have shown promise particularly in distinguishing between residual tumour and fibrotic change in the post-treatment patient.
- AI has shown promise in providing greater accuracy in the characterisation, staging, and potential prognostication of CRC. Further research is however required to assess the possible impact in the clinical diagnosis and management of CRC.

22.7 Summary

In this chapter, we discuss the suitability, advantages, and disadvantages of ultrasonography and MR imaging in the staging, restaging, and surveillance of CRC. TRUS is most useful in early stage lesions for evaluation of depth of infiltration of the rectal wall but limited in terms of detection of pathologic lymphadenopathy and MRF involvement. CTC is preferred to MRC in clinical use. Rectal MRI provides the best possible imaging for local staging of rectal carcinoma and has shown value in post-treatment and surveillance imaging. Advancements in MRI have also shown promise in providing more accurate assessment of tumour burden particularly in the post-treatment stage and assessment of recurrence.

AI as a further evolution in the imaging of CRC has shown promise in providing more accurate tumour characterisation and staging as well as identifying features for prognostication. Additional research is however required to assess the clinical impact thereof.

References

1. Lincender-Cvijetić L, Banjin-Čardžić M, Vegar-Zubović S, Vrcić D. Radiological imaging of rectal cancer. Acta Med Acad. 2012;41(2):199–209. https://doi.org/10.5644/ama2006-124.52.
2. Liang TY, Anil G, Ang BW. Imaging paradigms in assessment of rectal carcinoma: loco-regional and distant staging. Cancer Imaging. 2012;12(1):290. https://doi.org/10.1102/1470-7330.2012.0034.
3. Laghi A, Bellini D, Petrozza V, Piccazzo R, Santoro GA, Fabbri C, van der Paardt MP, Stoker J. Imaging of colorectal polyps and early rectal cancer. Color Dis. 2015;17:36–43. https://doi.org/10.1111/codi.12820.
4. Unsal B, Alper E, Baydar B, Arabul M, Aslan F, Celik M, et al. The efficacy of endoscopic ultrasonography in local staging of rectal tumors. Turk J Gastroenterol. 2012;23(5):530–4. https://doi.org/10.4318/tjg.2012.0359.
5. Tapan Ü, Özbayrak M, Tatlı S. MRI in local staging of rectal cancer: an update. Diagn Interv Radiol. 2014;20(5):390–8. https://doi.org/10.5152/dir.2014.13265.
6. Cârțână ET, Gheonea DI, Săftoiu A. Advances in endoscopic ultrasound imaging of colorectal diseases. World J Gastroenterol. 2016;22(5):1756–66. https://doi.org/10.3748/wjg.v22.i5.1756.
7. Jhaveri KS, Hosseini-Nik H. MRI of rectal cancer: an overview and update on recent advances. Am J Roentgenol. 2015;205(1):W42–55. https://doi.org/10.2214/AJR.14.14201.
8. García-Figueiras R, Baleato-González S, Padhani AR, Luna-Alcalá A, Marhuenda A, Vilanova JC, Osorio-Vázquez I, Martínez-de-Alegría A, Gómez-Caamaño A. Advanced imaging techniques in evaluation of colorectal cancer. Radiographics. 2018;38(3):740–65. https://doi.org/10.1148/rg.2018170044.
9. Chavhan GB, Babyn PS, Singh M, Vidarsson L, Shroff M. MR imaging at 3.0 T in children: technical differences, safety issues, and initial experience. Radiographics. 2009;29(5):1451–66.
10. Thornton E, Morrin MM, Yee J. Current status of MR colonography. Radiographics. 2010 Jan;30(1):201–18. https://doi.org/10.1148/rg.301095519.
11. Dieguez A. Rectal cancer staging: focus on the prognostic significance of the findings described by high-resolution magnetic resonance imaging. Cancer Imaging. 2013;13(2):277–97. https://doi.org/10.1102/1470-7330.2013.0028.
12. Rafaelsen SR, Vagn-Hansen C, Sørensen T, Pløen J, Jakobsen A. Transrectal ultrasound and magnetic resonance imaging measurement of extramural tumor spread in rectal cancer. World J Gastroenterol. 2012;18(36):5021–6. https://doi.org/10.3748/wjg.v18.i36.5021.
13. Kijima S, Sasaki T, Nagata K, Utano K, Lefor AT, Sugimoto H. Preoperative evaluation of colorectal cancer using CT colonography, MRI, and PET/CT. World J Gastroenterol. 2014;20(45):16964–75. https://doi.org/10.3748/wjg.v20.i45.16964.
14. Kaur H, Choi H, You YN, Rauch GM, Jensen CT, Hou P, Chang GJ, Skibber JM, Ernst RD. MR imaging for preoperative evaluation of primary rectal cancer: practical considerations. Radiographics. 2012;32(2):389–409. https://doi.org/10.1148/rg.322115122.

15. Horvat N, Carlos Tavares Rocha C, Clemente Oliveira B, Petkovska I, Gollub MJ. MRI of rectal cancer: tumor staging, imaging techniques, and management. Radiographics. 2019;39(2):367–87. https://doi.org/10.1148/rg.2019180114.
16. Stanzione A, Verde F, Romeo V, Boccadifuoco F, Mainenti PP, Maurea S. Radiomics and machine learning applications in rectal cancer: current update and future perspectives. World J Gastroenterol. 2021;27(32):5306–21. https://doi.org/10.3748/wjg.v27.i32.5306.
17. Zhang X, Zhang Y, Zhang G, Qiu X, Tan W, Yin X, Liao L. Deep learning with radiomics for disease diagnosis and treatment: challenges and potential. Front Oncol. 2022;12:773840. https://doi.org/10.3389/fonc.2022.773840.
18. Bedrikovetski S, Dudi-Venkata NN, Kroon HM, Seow W, Vather R, Carneiro G, Moore JW, Sammour T. Artificial intelligence for pre-operative lymph node staging in colorectal cancer: a systematic review and meta-analysis. BMC Cancer. 2021;21(1):1058. https://doi.org/10.1186/s12885-021-08773-w.

Role of Nuclear Medicine in the Evaluation of Colon Cancer

23

Fozy Peer

23.1 Introduction

Imaging has a crucial role in all aspects of the approach to colorectal neoplasms; namely screening, diagnosis, staging, and surveillance. Colorectal cancer (CRC) is the third most common cancer in the world and is the second leading cause of death from cancer [1]. Accurate and reproducible imaging is necessary to determine the appropriate course of clinical management. As discussed in Chap. 15 current staging of CRC utilises the TNM staging system which analyses tumour extension into the bowel wall and surrounding tissue (T-stage), nodal involvement (N-stage), and the presence of distant metastases (M-stage). CTC has replaced barium enema as the first line alternative imaging modality to colonoscopy [2, 3]. The use of radiomics in artificial intelligence (AI) has proved valuable in the effectiveness of treatment by predicting response to treatment in CRC patients [1]. In this chapter, nuclear medicine imaging using PET-CT, in terms of its role as an imaging technique for screening, diagnosis, and staging of CRC, is discussed.

F. Peer (✉)
Formerly Nuclear Medicine Department,
Inkosi Albert Luthuli Hospital Central Hospital,
Durban, South Africa

23.2 Nuclear Medicine Imaging in Colon Cancer

Nuclear medicine imaging differs from other imaging modalities in that diagnostic tests primarily show physiological function as opposed to traditional anatomical imaging. It is generally more organ- or tissue-specific than those in conventional radiology imaging. Its imaging procedures employ the use of radiotracers called radiopharmaceuticals, which are medical formulations containing radioisotopes for the imaging of organ function and disease states; hence mapping physiological function and metabolic activity and thereby giving more specific information about the organ's function/dysfunction [4].

Radioisotopes decay with the emission of electromagnetic radiation, that is, gamma, X-radiation, or positrons. The annihilation of a positron with an electron generates two gamma rays of 511 KeV almost immediately after the emission of the positron. This radiation has a high penetrating power and is absorbed only to a limited extent by tissues. The gamma radiation emitted after the administration of a diagnostic radiopharmaceutical in the body of a patient may be detected outside the body using a positron emission tomography (PET) scanner. With the aid of computer programmes, this information is converted into scintigraphic images showing the distribution of the radioactive compound in a patient's body. If the radiopharmaceutical is

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taken up by pathological tissue or organ to a different extent than by healthy tissues, the scintigraphic image shows the localisation and status of a particular disease, such as a tumour, metastasis, or infection. The images can also allow the evaluation of, for example, the functional status of an organ, the density of receptors at a particular site, or the levels of metabolism in some tissues [5]. The rate of decay of a radioisotope is known as the half-life and is peculiar to that radioisotope. For example, the half-life of Flourine-18 is 110 min.

PET scans may be used to image the whole body based on certain cellular receptors or functions. Where PET scans are superimposed on images from modalities such as computed tomography (CT) or magnetic resonance imaging (MRI), using software or hybrid cameras it is referred to as image fusion, for example, PET-CT. When compared to PET imaging alone, the fusion imaging technique offers improved anatomic localisation of disease and increased certainty in image interpretation [6].

Change in bowel habits, abdominal pain, and blood in the stool are some of the clinical presentations of colon cancer. Patients with advanced stage cancers may present with subtle symptoms [6]. Many colon carcinomas arise from adenomas, but not all adenomas result in carcinomas [6]. Chapter 15 deals with colon cancer and the adenoma-carcinoma sequence. The diagnosis and management of many cancers is being influenced by advanced imaging techniques.

23.2.1 Radiopharmaceutical

PET-CT imaging using F-18-fluoro-deoxyglucose (F-18-FDG) is being increasingly used for evaluating colon cancers, especially CRC [6]. This tracer is a glucose analogue, which may be actively transported into the cell mediated by a group of structurally related glucose transport proteins. Once in the cell, FDG is phosphorylated and becomes effectively trapped. Tumour cells display an increased number of glucose transporters, and are highly metabolically active displaying high mitotic activity, and favour the more inefficient anaerobic pathway adding to the already increased glucose demands. Hence, these combined mechanisms allow for tumour cells to take up and to retain the higher levels of FDG in comparison to normal tissues. FDG is not cancer specific and accumulates in any areas with high levels of metabolism and glycolysis; hence, there is increased uptake in areas of hyperactivity, active inflammation, and tissue repair [7]. As a result, FDG-PET can be used for diagnosis, staging, and monitoring treatment of cancers.

23.2.2 PET-CT: Patient Preparation

There may be slight variations in patient preparation at the different nuclear medicine centres depending on their individual protocols. The following are recommended.

(a) Informed consent: The procedure should be explained to the patient and written informed consent obtained prior to ordering the radiopharmaceutical as in centres obtaining doses from a remote cyclotron, individual doses based on patient weight are ordered. Also due to the relatively short half-life and the high cost of the radiopharmaceutical, should the patient refuse to have the study on the day of the appointment this could result in a financial loss.
(b) Diet: Patient should be nil per mouth for at least 4–6 h prior to the scan appointment.
(c) Exercise: Strenuous exercise should be avoided for at least 24 h before the scan so as to prevent unnecessary uptake by muscles as FDG is a glucose analogue which is taken up by muscle.
(d) Plasma glucose level: Plasma glucose level should be checked prior to injection. If glucose levels are greater than 10 mmol/L (180 mg/dL), patient can wait, recheck, and inject once level is below 10 mmol/L or rebook patient. It is necessary to advise diabetic patients regarding their diabetic medication (each patient is different, depending on the medication that they are taking). Rebooking a patient can be an expensive

option as the isotope dose may have to be discarded.

(e) Dress: Patient should be comfortable, changed preferably into a patient gown. Ensure there are no metal objects. Record any prosthetics as these could cause artefacts on the final image.

(f) Patient dose: Calculate radiopharmaceutical dose of ^{18}F-FDG according to patient's mass ([patient mass/10] + 1), for example, 70 Kg adult: 70/10 = 7 + 1 = 8 mCi ^{18}F-FDG. Measure F-18 FDG dose and note time.

23.2.3 How to Perform a PET Study

1. Establish intravenous access.
2. If necessary, where a patient is anxious or restless and will possibly not be able to lie still during the scan, a mild sedative may be administered.
3. If protocol includes an oral contrast agent for the CT scan, and the patient is nauseous, an antiemetic drug may be administered intravenously.
4. Ensure the patient is comfortable and fairly warm (cover with a blanket).
5. Inject measured dose intravenously and note time of injection.
6. Once injected, the patient is requested to rest in a quiet room for about 60 min prior to the scan for maximum distribution of the F-18-FDG. In this time, physical activity must be kept to a minimum, to minimise uptake of the F-18-FDG into muscles as this could cause artefacts on the final image hence interfering with interpretation.
7. Measure post-injection syringe and note time. Subtract from pre-injection dose to get total injected dose.
8. Patient to drink one cup (250 mL) water every 15 min until scan is performed.
9. Immediately before the patient is taken to the scan room, he/she must be requested to empty his/her bladder as the radiopharmaceutical is excreted via the urinary system and uptake in this area could obscure pathology on the final image. As the PET scan is usually approximately 20 min in duration, it is preferable for the patient to empty their bladder prior to the scan so that the patient will not need to request this during the scan.
10. Position the patient on the imaging bed, usually, in the supine, head-in position with arms raised above the head.

Scanning begins usually 60 min following injection. This time lapse allows sufficient time for the FDG to be trapped and for adequate intracellular uptake, and for its clearance from the blood while minimising the loss of activity due to decay. Some tumours may continue to concentrate the FDG with time and the background activity may continue to decrease. However, inflammatory lesions could wash out activity with increased time [7]. The time for each bed position and the number of bed positions depends on the patient size and hence the total scan time is approximately 30 min, but could vary from 20 to 60 min. Normally, whole body scans are obtained from the base of the skull to the proximal femurs [7]. It is preferable to cover this entire area during imaging as colon cancers are known to metastasise widely, mainly to the liver and lungs.

23.2.4 Interpretation

PET-CT scans are reviewed and interpreted by qualified imaging professionals, usually nuclear medicine physicians and/or radiologists who then share the results with the patient's physician. In terms of CRC, PET-CT studies are useful for the following.

- The initial diagnosis and staging of the cancer by determining the exact location of a tumour, the extent of disease and whether the cancer has metastasised.
- Treatment plan by selecting the most effective therapy based on the unique molecular properties of the disease and of the patient's genetic makeup.
- The evaluation of the effectiveness of treatment by determining the response to specific

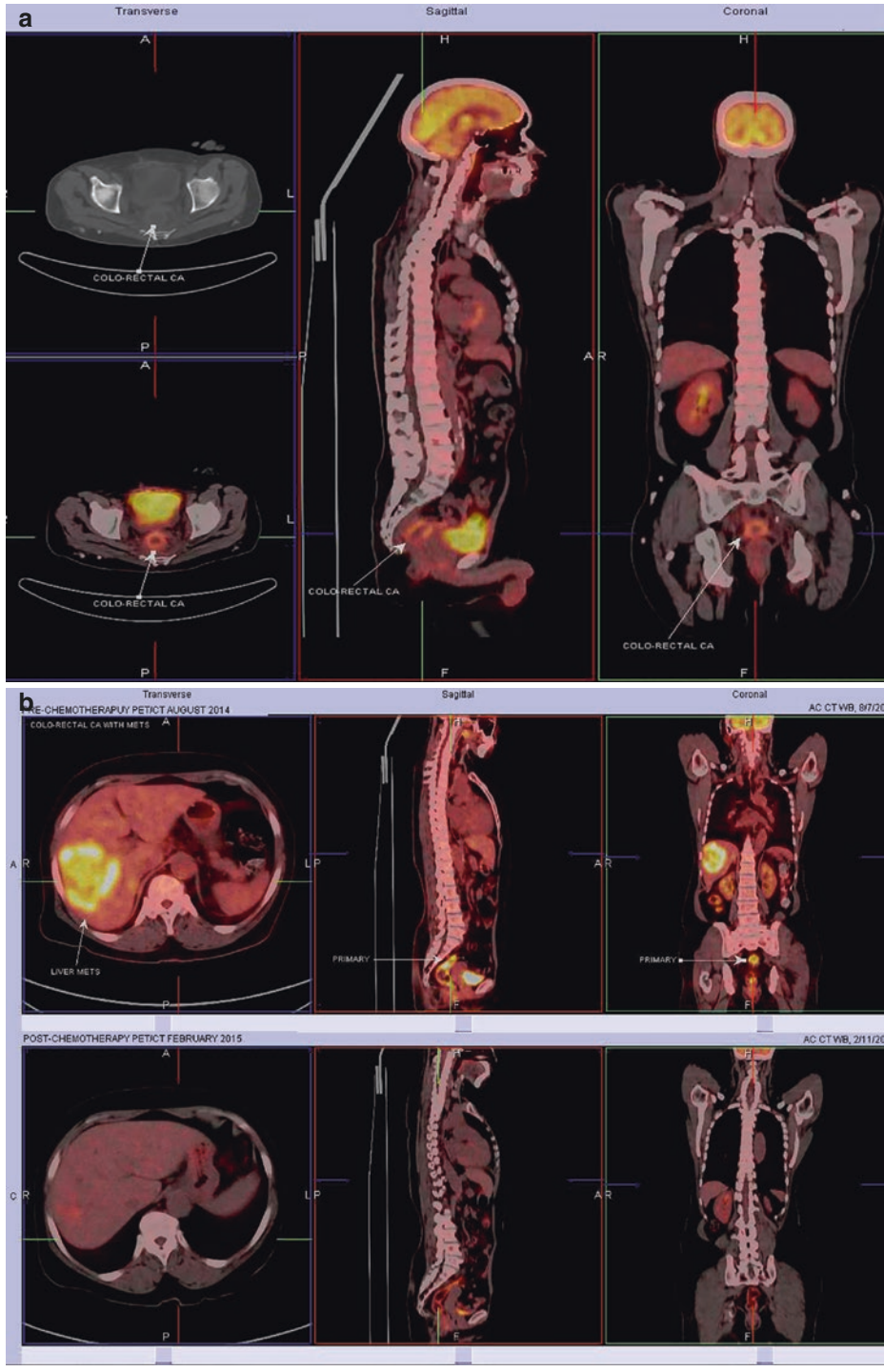

Fig. 23.1 (**a**) PET-CT scan of a patient following surgery and chemotherapy for rectosigmoid cancer. The scan shows significant rectal cancer recurrence with sigmoid involvement and mesenteric and left external nodal spread. Fat stranding noted in the mesorectal fascia on the CT component (non-FDG avid) and infiltration cannot be excluded. Infective changes noted in the lungs bi-basally. (**b**) Top row: pre-chemotherapy PET-CT images of a patient with metastatic rectosigmoid cancer. These images demonstrate metabolically active rectosigmoid cancer with hepatic and pelvic nodal secondaries. Bottom row: These post-chemotherapy PET-CT images show that the metastatic lesions have significantly improved significantly

drugs and ongoing therapy (see Fig. 23.1a and b). Based on changes in cellular activity observed on PET-CT images, treatment regimens may be changed.
- The detection of recurrence of disease and to manage ongoing care [8].

It has been reported [9] that PET-CT is superior to contrast enhanced CT (ceCT) for detection of recurrent intrahepatic tumours after hepatectomy, extrahepatic metastases, and local recurrence at the site of the initial colorectal surgery although PET-CT and ceCT provide similar information regarding hepatic metastases of CRC. PET-CT is routinely performed on patients with metastatic CRC who are being evaluated for liver resection [9].

In a study of 62 patients by Even-Sapir et al. [10], it was concluded that after surgical removal of rectal cancer PET-CT is an accurate technique in the detection of pelvic recurrence. Since metabolic changes under treatment are likely to precede anatomic alterations, [11] PET-CT may also be used to assess tumour response to chemotherapy and radiotherapy in lymphomas, non-small cell lung, head and neck, and colorectal and breast cancers.

23.2.5 Advantages of PET Imaging for CRC Patients

- As PET imaging is a powerful tool for diagnosing and determining the stage of many types of cancer, including colorectal, by detecting whether lesions are benign or malignant, the scans are able to eliminate the need for surgical biopsies.
- PET imaging can guide treatment options as it is more accurate than CT for staging of CRC; PET is able to confirm or rule out the presence of metastases in the liver or lung.
- The 5-year survival rate of patients who are screened with PET prior to undergoing the surgery is higher than for patients who are not imaged with PET prior to surgery [12]; hence, PET-CT is recommended for CRC patients with liver metastases who opt for surgery to remove the affected areas of the liver.
- Changes in the treatment of more than one-third of patients registered in the National Oncologic PET Registry have been influenced by PET-CT scans [8].
- PET imaging is most effective in the detection of cancer recurrence.
- PET-CT imaging is not only helpful for nearly all aspects of diagnosis and treatment of CRC, but also for identifying incidental cancers in the colon.
- The difference between cancer recurrences and post-therapy scarring in the colon may be distinguished on PET images.
- PET imaging is useful in detecting cancer recurrence, in patients who demonstrate increased values of the blood protein known as carcinoembryonic antigen (CEA) [8].

23.3 The Role of Artificial Intelligence (AI) in PET-CT

The incorporation of AI into medical imaging is fast changing the imaging landscape [13]. Recent studies have employed AI using machine learning (ML) and deep learning (DL) to provide computer-assisted methods to screen, diagnose and treat cancer, and to assist in prognosis in CRC [1]. An imaging workflow in nuclear medicine usually comprises planning, image acquisition, interpretation, and reporting [14, 15]. So as to improve patient survival rates, early detection and or diagnosis, response to treatment and prognosis are of primary importance [1]. Although prediction of response to treatment is challenging, research in ML and radiomics has shown great potential for the use of AI in CRC [1]. Modern PET-scanner technology already makes increasing use of ML [14]. The use of radiomics has allowed for more information to be obtained from a single medical image, as hundreds of imaging features may be extracted and analysed [15]. Radiomics is an advanced method to extract imaging features and thereby quantify tumour phenotype from medical images.

In patients with gastrointestinal cancer, radiomics is being increasingly used to predict treatment response [15]. Existing AI systems may provide great results as regards detection of pathologies, but human supervision remains prime [14]. A detailed discussion of AI and machine learning is presented in Chap. 25.

23.4 Clinical Audits for Good Practice

There needs to be standardisation of clinical practice so as to ensure quality, safety, and effectiveness as variability in practice could affect patients' results [16]. Monitoring systems and quality control measures need to be standard practice especially as regards clinical appropriateness, patient and staff/public safety and the use of ionising radiation. Clinical audits of the processes involved are essential to evaluate the service and to detect deviations from standard clinical practice. Routine clinical audits are recommended and considered good practice by most scientific organisations [16]. Clinical audit principles are presented in Chap. 27.

Key Messages

- Nuclear medicine imaging differs from other imaging modalities in that diagnostic tests primarily show physiological function as opposed to traditional anatomical imaging.
- Patient preparation with respect to diet and lack of strenuous exercise is important.
- PET-CT imaging using F-18-fluoro-deoxy-glucose (F-18-FDG) is being increasingly used for evaluating colon cancers, especially CRC.
- PET imaging can guide treatment options as it is more accurate than CT for staging of the CRC; PET is able to confirm or rule out the presence of metastases in the liver or lung.
- AI has proved valuable in the effectiveness of treatment by predicting response to treatment.
- Based on changes in cellular activity observed on PET-CT images, treatment regimens may be changed.

23.5 Summary

The advantages and disadvantages of PET-CT are discussed in terms of CRC management. Nuclear medicine imaging shows physiological function and is helpful to assess for metastatic disease. PET-CT modality plays a complementary role in imaging patients with CRC.

References

1. Qiu H, Ding S, Liu J, Wang L, Wang X. Applications of artificial intelligence in screening, diagnosis, treatment, and prognosis of colorectal cancer. Curr Oncol. 2022;29:1773–95. https://doi.org/10.3390/curroncol2903014.
2. Lincender-Cvijetic L, Banjin-Cardzic M, Vegar-Zubovic S, Vrcic D. Radiological imaging of rectal cancer. Acta Med Acad. 2012;41(2):199–209.
3. Liang TY, Anil G, Ang BW. Imaging paradigms in assessment of rectal carcinoma: loco-regional and distant staging. Cancer Imaging. 2012;12:290–303.
4. IAEA policy. https://www.iaea.org/About/Policy/GC/GC51/GC51InfDocuments/English/gc51inf-3-att2_en.pdf.
5. IAEA radiopharmacy. http://nucleus.iaea.org/HHW/Radiopharmacy/VirRad/Introduction/Radiopharmaceuticals/.
6. Coleman RE. Utility of PET scanning in the management of colorectal cancer. Medscape. http://www.medscape.org/viewarticle/461315.
7. Boellaard R, O'Doherty MJ, Weber WA, Mottaghy FM, Lonsdale MN, Stroobants SG, Oyen WJG, Kotzerke J, Hoekstra OS, Pruim J, Marsden PK, Tatsch K, Hoekstra CJ, Visser EP, Arends B, Verzijlbergen FJ, Zijlstra JM, Comans EFI, Lammertsma AA, Paans AM, Willemsen AT, Beyer T, Bockisch A, Schaefer-Prokop C, Delbeke D, Baum RP, Chiti A, Krause BJ. FDG PET and PET/CT: EANM procedure guidelines for tumour PET imaging: version 1.0. Eur J Nucl Med Mol Imaging. 2010;37(1):181–200. https://doi.org/10.1007/s00259-009-1297-4.
8. Society of Nuclear Medicine and Molecular Imaging. Fact sheet: molecular imaging and colorectal cancer. http://www.snmmi.org/AboutSNMMI/Content.aspx?ItemNumber=5658.
9. Selzner M, Hany TF, Wildbrett P, McCormack L, Kadry Z, Clavien PA. Does the novel PET/CT imaging modality impact on the treatment of patients with metastatic colorectal cancer of the liver? Ann Surg. 2004;240(6):1027–34; discussion 1035-6. https://doi.org/10.1097/01.sla.0000146145.69835.c5.
10. Even-Sapir E, Parag Y, Lerman H, Gutman M, Levine C, Rabau M, Figer A, Metser U. Detection of recurrence in patients with rectal cancer: PET/CT after abdominoperineal or anterior resection. Radiology.

2004;232(3):815–22. https://doi.org/10.1148/radiol.2323031065.

11. Vera P, Dubray B, Palie O, Buvat I, Hapdey S, Modzelewski R, Benyoucef A, Rousseau C, Meyer ME, Bardet S, Gardin I, Fiore FD, Michel P. Monitoring tumour response during chemo-radiotherapy: a parametric method using FDG-PET/CT images in patients with oesophageal cancer. EJNMMI Res. 2014;4(1):12. https://doi.org/10.1186/2191-219X-4-12.
12. Tapan U, Ozbayrak M, Tatlı S. MRI in local staging of rectal cancer: an update. Diagn Interv Radiol. 2014;20(5):390–8. https://doi.org/10.5152/dir.2014.13265.
13. Lewis SJ, Gandomkar Z, Brennan PC. Artificial Intelligence in medical imaging practice: looking to the future. J Med Radiat Sci. 2019;66(4):292–5. https://doi.org/10.1002/jmrs.369.
14. Nensa F, Demircioglu A, Rischpler C. Artificial intelligence in nuclear medicine. J Nucl Med. 2019;60(Supplement 2):29S–37S. https://doi.org/10.2967/jnumed.118.220590.
15. Wesdorp NJ, Hellingman T, Jansma EP, van Waesberghe JTM, Boellaard R, Punt CJA, Huiskens J, Kazemier G. Advanced analytics and artificial intelligence in gastrointestinal cancer: a systematic review of radiomics predicting response to treatment. Eur J Nucl Med Mol Imaging. 2021;48(6):1785–94. https://doi.org/10.1007/s00259-020-05142-w.
16. Torras MG, Canals E, Jurado-Bruggeman D, Marín-Borras S, Macià M, Jové J, Boladeras AM, Muñoz-Montplet C, Molero J, Picón C, Puigdemont M, Aliste L, Torrents A, Guedea F, Borras JM. Clinical audit of the radiotherapy process in rectal cancer: clinical practice guidelines and quality certification do not avert variability in clinical practice. Transl Oncol. 2018;11(3):794–9. https://doi.org/10.1016/j.tranon.2018.03.015.

24 Legal and Professional Requirements: A Framework for Practice

Richard Price

24.1 Introduction

The past 50 years have witnessed dramatic changes in the scope of imaging. For example, the introduction of computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound have increased the capacity and capability of imaging. CT colonography (CTC) is an example of the impact of technology where radiographers' roles have developed and extended beyond image acquisition and manipulation to embrace reporting. Indeed, reporting is the prime example of role extension in the modern era where radiographers are making significant contributions to the radiology workload which is facing an exponential demand for services. Initially, most of the reporting undertaken by radiographers with the exception of ultrasound was on the appendicular system but over a period of just over two decades the scope of reporting practice has advanced from the musculo-skeletal system to mammograms, gastro-intestinal studies, chest X-rays, MRI, CT, and nuclear medicine studies. What has not changed however is the basic premise for practice to be safe and effective. Where a role is extended, it must be in the best interests of patients with the requirement to meet the appropriate standards of patient care. In considering a framework for practice, there is a primary recognition that radiographers owe a duty of care to patients and to those who are affected by their actions. In the first instance, the critical relationship between an employer and employee will be considered.

24.2 Employment

It is in the context of employment that a radiographer will come into direct contact with a patient. Let us consider the starting point as the contract of employment where there are obligations placed on an employee and employer.

Employees are accountable for following the reasonable instructions of their employer; this will be normally through their line manager. On an employer's side the obligation is to take all reasonable care for an employee's safety. This would include ensuring a safe system of work and providing effective and safe equipment in appropriate premises.

The keyword here on both sides is reasonable. So, what is reasonable? Reasonableness is based on what is sensible to do in each situation. A manager and employee, by virtue of their respective education, training, and experience, should have the background and skills to take the right decisions at the right time. For a manager to ask an employee to perform a task for which they have not been trained would be unreasonable as it

R. Price (✉)
Retired, University of Hertfordshire, Hertfordshire, UK
e-mail: r.c.price@herts.ac.uk

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would be for an employee to undertake the task. So what safeguards are in place for a member of staff being asked to take on a new or extended role task?

Guidance on extended roles was provided as long ago as 1977. The then Department of Health and Social Security [1] recognised the importance of extended roles for clinical nurses and set out four conditions that would have to be met by a nurse delivering an extended role. Applying those conditions in the case of a radiographer about to adopt a practice considered as an extended role would be as follows.

1. The radiographer has been specifically and adequately trained for the performance of the new task and agrees to undertake it.
2. The training has been recognised as satisfactory by the employing authority.
3. The new task has been recognised by the professions and by the employing authority as a task which may be properly delegated to a radiographer.
4. Where a task is delegated, the person delegating must be assured of the competencies of the individual radiographer concerned.

The conditions place clear obligations on both the employee and employer. Regarding training for CTC, firstly, it must be specific to CTC, and the level of education must be adequate to support the tasks to be undertaken. The threshold standard of education is normally specified by an approved course, for example, approved or accredited by a professional body. Employers are unlikely to support training if they have no intention of recognising the task as suitable for their employees. If an employer has sent an employee on a course or provides a suitable alternative, then the training is recognised *de facto.*

In the case of CTC, the UK professional body, the Society and College of Radiographers, (SCoR) publication *Guidelines for the provision of a safe and effective CT colonography service* [2] is implicit in the recognition of CTC, including reporting, as a role appropriate for radiographers.

To consolidate the position, an employer should have a scheme of work or guidelines that cover the new task and in particular the radiographer reporting element of CTC. Initially, it may be that the reporting element is delegated to radiographers by the employing authority probably via the clinical director. However, there is an interesting consequence that over time, task(s) initially recognised as extended do become integrated in the scope of radiographic practice and would no longer be seen as extended.

The conditions listed above, although initially set out some time ago, provide important safeguards for employers and employees wishing to adopt new or extended roles. Meeting the conditions to adopt an extended role is an important step; continuing to practise must however also be taken into account and supported.

24.3 Professional Regulation

As well as a radiographer being accountable to their employer, accountability to the public in the UK is through the regulatory body the Health and Care Professions Council (HCPC). The title ‘Radiographer’ is protected in law and the use of the title by someone not on the HCPC radiographer’s register is committing a criminal offence. Qualifying from an HCPC approved programme gives eligibility to apply for registration. Once on the register, registered radiographers are recognised as practitioners with special skills and when in employment they are placed in a position of trust by an employer and by the general public and will be accountable for their actions.

Radiographers are therefore accountable and responsible for providing a duty of care for patients to the appropriate standard. The standard here is for radiographers to practise within their scope of practice and not attempt tasks for which they are not competent. The HCPC standards of proficiency for radiographers [3] set the threshold level for entry onto the register, but beyond initial registration the obligation is for

registrants to maintain their competence and to continue to develop their practice throughout their career, which is explicit from the HCPC standards of continuing professional development [4] and to comply with the HCPC standards of conduct, performance, and ethics [5]. The consequence of failing to meet the standards, if proven, after due process of investigation could result in a radiographer being sanctioned. The ultimate sanction would be having their name removed from the register and thus be prevented from practising and therefore employment as a radiographer.

In the UK, the SCoR's standards and behavioural norms are set out in its code of professional conduct [6]. The SCoR also plays a key role in supporting developing, for example, accreditation of training, supporting research into practice development, supporting continuing professional development and hosting special interest groups. Important information is also set out in its document *Current and future roles of diagnostic radiographers* [7]. On role development and role extension, the SCoR has a prime role and responsibility in promoting safe practice.

24.4 Duty and Standard of Care

As discussed above, ongoing practice places a responsibility on radiographers to maintain their skills and competence. Legally the obligation is specific; the requirement is to exercise a duty of care and to provide that care to the required standard. The ultimate test of whether the duty and standard of care concerning an allegation of negligence would ultimately be determined through the civil law; there would however be attempts to resolve an issue at local level in the first instance.

Negligence is a civil wrong and due to practice that falls below the acceptable standard of care. It can be because of a radiographer doing something that ought not to have been done or omitting to do something that should have been done. A civil wrong is referred to as a 'tort' and is an unintentional violation of another person's rights, usually due to negligence: 'carelessness' in other words. A claim for compensation is subject to common or case law, which has been developed by judicial decisions over time through civil courts and tribunals. Common law is pertinent for practice as it determines the rights and duties individuals have towards each other. The professional and the regulatory codes of conduct and standards have their origin in common law. It is important, however, to distinguish a tort from a crime, which is an intentional violation of someone's rights and subject to the criminal law. Although it should be noted that alleged negligence due to behaviour that is considered reckless can be dealt with by the criminal courts.

Before negligence can be proven the onus is on the claimant to prove that:

(a) The defendant owed the claimant a duty of care.
(b) The defendant was in breach of that duty.
(c) The breach caused a type of harm which the law recognises as giving rise to damages.

One important point to note is that employers are vicariously liable for the actions or omissions of their employees within their employment. This is a basic common law principle where an employer is liable for the wrongdoings committed by an employee in the course of employment. If a case is pursued through the courts, an employer would be the defendant rather than the individual radiographer. However, it does not mean that an individual employee is unaffected by any action as they could be subjected to a disciplinary procedure by their employer plus a referral to their regulatory body who would be bound to investigate whether there is a case to answer, and if so, act as deemed necessary. Sanctions could include conditions placed upon practice, temporary suspension from the register or, in the most serious case, removal of the person's name from the register.

In most cases, it would be relatively straightforward to prove that a radiographer and employer owed a duty of care to a patient. However, more

difficult to prove are (b) and (c) above. The Bolam test [8] is used to determine whether the reasonable standard of care has been given and hence whether a practice has been negligent. The patient in the Bolam case was receiving electro convulsive therapy. The doctor did not give any relaxant drugs; during the procedure, the patient sustained fractures and brought a claim of negligence for damages against the hospital. The court ruled in favour of the doctor and found that the hospital (and therefore the doctor) was not negligent. While the patient had undeniably been harmed, the doctor had not breached his duty of care as he had followed a practice followed by other medical practitioners and the standard of care was appropriate. Of course, these matters can only be judged at the time and not by hindsight.

For well over half a century, Bolam has provided an important test for the standard of care which a health professional must reach. It is the standard of the ordinary competent practitioner in the given specialism. Specialism is key as it is reasonable to assume that a practitioner in that field has the skill and competence to undertake the duties required of them.

For example, the direct implication for a reporting radiographer is that they must perform to the standard of the ordinary competent practitioner in the field, i.e. radiologists or where radiographer reporting is established by other reporting radiographers. However, a question often asked is: 'Does someone who is new to reporting or other practice have to follow the same standard of care as an experienced radiologist or radiographer?' The answer is 'yes'. There can be no duality of standards between professions or for someone just starting to report. These situations do need to be managed carefully, and it is important that a practitioner is supported following their course of training. One such approach is for a new practitioner to be directly supervised for an agreed number of procedures and to have a mentor for a given period. To assure continuing competence such a practitioner would be subject to audit and further training as appropriate.

24.5 A Framework for Practice

So far we have considered essential information whose origins are in common law, contract law, and standards set by the HCPC and the SCoR. A framework for practice is an integration of those various elements, which should provide the assurance that a patient is being cared for and treated to the appropriate standard.

Now let us consider some specifics about clinical reporting as it will be recognised as a new task to many. For many radiographers who have qualified in recent years, they will have already acquired a number of key skills on graduation that provide the basis for further progression and ultimately lead to reporting. Threshold requirements are clearly set out in the HCPC standards of proficiency for radiographers [3]. While all the standards are complementary to providing the standard of care, two are worth considering further [1], namely

> 13.14 be able to distinguish between normal and abnormal appearances evident on images (p. 13)
>
> 14.35 be able to distinguish disease and trauma processes as they manifest on diagnostic images (p. 17)

While these skills may be appropriate for initial commenting, they are insufficient for formal clinical reporting and further training would be necessary. However, the standards do consolidate the position of a radiographer in regard to clinical evaluation of images and do instil a different mind-set from when image acquisition and technical evaluation were the prime considerations. However, there are further steps required before someone is recognised to undertake formal clinical reporting. We have identified the importance of continuing education and training that is adequate and specific to the role in question. In the case, CTC reporting the position of the professional body on training is via an approved or accredited course leading to a postgraduate qualification. Such a qualification is good practice, but legally, in-house training is approved and underwritten by an employer within its scheme of clinical governance can be viewed as adequate and

specific. From a radiographer's perspective having achieved a qualification from an accredited course would seem to be the preferred option for career development: it implies transferability and wide recognition of the qualification.

When a radiographer is at the stage to commence clinical reporting, they will do so with the context of clinical governance. This is a framework through which organisations are accountable for continually improving the quality of their services and safeguarding high standards of care by creating an environment to assure excellence in clinical care. Key elements for reporting will be as follows.

- An agreed scheme of work which is unambiguous on the scope of practice.
- Continuing professional development.
- Ongoing clinical audit.
- Risk and information management.

In formulating practice guidelines, the following provide the essential elements of a practice framework that should avoid a radiographer exceeding their scope of practice.

1. You agree to undertake the task.
2. There is responsibility with accountability.
3. You have a duty of care to your patients.
4. You do not need to be an expert but you must provide the standard of care as the 'ordinary' (average) competent practitioner in the field (Bolam test).
5. You must follow the reasonable instructions of your employer.
6. An extension of the role demands training.
7. Do not exceed the scope of your practice.
8. An understanding of what constitutes negligence.
9. Recognise the need for effective self-management of workload and be able to practise accordingly.
10. Understand the obligation to maintain fitness to practise and the need for career-long self-directed learning.

Furthermore, ongoing clinical audits cover CTC reporting, and all aspects the study. The principles of clinical audit are discussed in Chap. 27.

Key Messages

In considering a framework for practice, there has to be recognition that radiographers owe a duty of care to their patients and to those who are affected by their actions.

- Radiographer reporting is recognised by the SCoR as a legitimate activity for radiographers.
- Employers are unlikely to support training if they had no intention of recognising the task as suitable for their employees.
- The title 'radiographer' is protected in law and the use of the title by someone not on the HCPC register is a criminal offence.
- Negligence is a civil wrong and due to practice that falls below the acceptable standard of care.
- The Bolam test is used to determine whether the reasonable standard of care has been given and hence whether a practice has been negligent.
- Clinical governance is a framework through which organisations are accountable for continually improving the quality of their services and safeguarding high standards of care by creating an environment to assure excellence in clinical care.
- Ongoing clinical audits of reporting of CTC examinations should be performed.

24.6 Summary

A framework for practice is based on a contract of employment, common law, and regulatory and professional body standards. Practitioners must feel secure within their practice framework and comfortable with their scope of practice and know their limitations. Individual radiographers must be able to recognise the relationship between professional, statutory, and legal requirements that impact on practice. Given an understanding of the principles of practice that

influence it, radiographers should not have major concerns about adopting new tasks.

References

1. Department of Health and Social Security Health Circular 1972 (22). The extended role of the clinical nurse. Legal implications and training requirements. London: Department of Health and Social Security; 1977.
2. BCSP CTC Radiographer Education Development Group. Guidelines for the provision of a safe and effective CT colonography service. London: The Society and College of Radiographers; 2018.
3. Standards of proficiency for radiographers. Health and Care Professions Council. 2013. http://www.hpc-uk.org/assets/documents/10000DBDStandards_of_Proficiency_Radiographers.pdf.
4. Standards of continuing professional development. Health Professions Council. 2018. https://www.hcpc-uk.org/standards/standards-of-continuing-professional-development/.
5. Standards of conduct, performance and ethics. Health and Care Professions Council. 2016. https://www.hcpc-uk.org/standards/standards-of-conduct-performance-and-ethics/
6. The Society of Radiographers. Code of professional conduct. 2013. Code of Professional Conduct (sor.org).
7. The Society of Radiographers. Current and future roles of diagnostic radiographers. London: The Society of Radiographers; 2021.
8. Bolam v Friern Hospital Management Committee [1957] 1 WLR 583. http://www.e-lawresources.co.uk/Bolam-v%2D%2DFriern-Hospital-Management-Committee.php.

25 Artificial Intelligence and Machine Learning in Cross-Sectional Imaging

Riaan van de Venter

25.1 Introduction

Artificial intelligence (AI) has impacted our lives significantly and can continue to influence societies through many industrial revolutions. It has received much attention in the last decade owing to an increased understanding of human intelligence, greater computing power, as well as an increase in access and availability to big data. Developments in machine learning (ML), and deep learning (DL), further attributed to this focus on AI [1, 2]. The healthcare sector is not precluded from the impact of AI; it has been increasingly implemented as a supportive technology in healthcare services, including medical imaging [3]. In this chapter, terminology related to AI, ML, and DL, is explained. The potential impact of AI on radiography and ethical considerations pertaining to AI are discussed. An overview of AI-enabled image interpretation in cross-sectional imaging, in particular computed tomography colonoscopy (CTC), is also provided. See Chap. 1 for literature pertaining to AI training and protocols for radiographers.

The following abbreviations are used in this chapter.

- AI: Artificial intelligence
- ANNs: Artificial neural network
- AUC: Area under curve
- CAD: Computer-aided diagnosis
- CNNs: Convolutional neural networks
- CRC: Colorectal cancer
- CTC: Computed tomography colonoscopy
- DL: Deep learning
- DNNs: Deep neural networks
- GAN: Generative adversarial network
- HCPs: Healthcare practitioners
- ML: Machine learning
- NNs: Neural networks
- RNNs: Recurrent neural networks
- TDSNs: Tensor deep stack networks

25.2 Artificial Intelligence, Machine Learning, and Deep Learning

AI refers to a broad field of computer techniques that can imitate human intelligence and behaviour, for example, sensing, reasoning, decision-making, prediction, visual perception, speech recognition, learning, organisation, and planning [1, 2, 4–6]. It can be divided into a virtual and a physical branch. The former encompasses ML and DL [5]. Figure 25.1 provides a visual overview of the relationship of AI, ML, and DL.

R. van de Venter (✉)
Department of Radiography, Faculty of Health Sciences, School of Clinical Care Sciences, Nelson Mandela University, Gqeberha, South Africa
e-mail: riaan.vandeventer@mandela.ac.za

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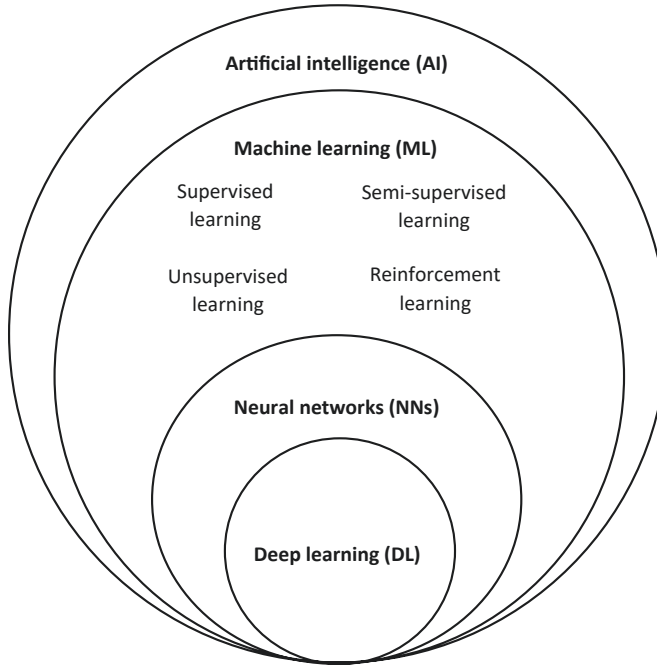

Fig. 25.1 A visual overview of the relationship between AI, ML, NNs and DL. (Author's own work)

25.2.1 Machine Learning

ML relates to a subset of AI algorithms that can use statistical tools to discover hidden patterns in data and improve or learn as more data are inputted in the model. ML models can further make predictions by adapting as new data are introduced in them, even if this data were not used to initially train the ML model. Through this analysis of input data (i.e., training), ML models improve the mapping of observed variables: features and predictors to provide sets of output variables: labels and targets [1, 5–7]. With respect to labels, four distinct types of ML model training can be done.

25.2.1.1 Supervised Learning

Supervised learning is used to signify ML models that are trained with data labelled through human intervention (i.e., an operator). These models predict outcomes (i.e., predicted labels) relative to the true value (i.e., ground truth or known labels). Examples of ML techniques belonging to this group include support vector machines, linear and logistic regression, Naïve Bayes classification, and random forests [1, 6, 7].

25.2.1.2 Unsupervised Learning

Unsupervised learning ML models are trained using unlabelled input data to allow for these models to discover patterns, structures, and relationships based on the innate characteristics of the dataset without human intervention. Examples of ML techniques associated with unsupervised learning are k-means clustering, autoencoders, and principal component analysis [6, 7].

25.2.1.3 Semi-supervised Learning

Semi-supervised learning encompasses the use of both labelled and unlabelled data to train ML models. It is beneficial as it can use readily available unlabelled data to improve labelled tasks in the absence or scarcity of labelled data, for example, in cases of computer-aided diagnosis (CAD) [8].

25.2.1.4 Reinforcement Learning

Reinforcement learning is a ML technique that allows an intelligent agent (i.e., computer) to learn to perform a required task in an interactive, trial-and-error environment using feedback and unlabelled data only. The agent is not necessarily pre-programmed and therefore learns how to

behave and solve a problem based on previous experience to continuously improve its performance with respect to the task to be accomplished [6, 7].

25.2.2 Deep Learning

Deep learning (DL) is a subset of ML. It is the training process used to train deep neural networks (DNNs) [6]. Deep in DL acts as a qualifier to indicate that DNNs are multi-layered neural networks (NNs) comprising many hidden layers that mimic the neuronal pathways in the human brain. NNs are also known as artificial NNs (ANNs). DNNs primarily use unsupervised learning to extricate features from datasets to make accurate predictions [1, 5, 6]. DNNs require large datasets for higher accuracy and longer training times. DNNs can provide useful information about the intricate relationships that exist in a dataset of interest [1, 6, 7]. Convolutional neural networks (CNNs) are the most frequently used DNNs in medical imaging due to its high efficiency in image classification [5, 7, 9]. There are other DNNs that are used in healthcare, such as generative adversarial network (GAN), recurrent NNs (RNNs), and tensor deep stack networks (TDSNs), for example [9]. CNNs comprise convolutional layers, pooling layers, dropout layers, and an output layer. Each layer learns specific features of the input data. Each layer analyses and processes data coming from a previous layer until a classification label, or other evaluative property, is identified as an output from the output layer [7, 9].

From the above explanation of the different subsets of AI one can appreciate that this vast technological field has and will have significant influences on radiography practice and regulation.

25.3 Impact of AI on Radiography

Digitisation of radiography is not new: radiographers have embraced technologically enabled working environments for many years [4]. In the same vein, AI will transform the profession of radiography [10]. Literature confirms acceptability of AI among radiographers; there are however concerns related to job security, competence to perform optimally in an AI-enabled work environment, data security, and ethico-legally acceptable practices [11].

It is envisaged that AI will impact on radiographic practice with respect to patient identification through electronic health records, vetting and justification of request forms, examination planning in terms of patient positioning, selection of appropriate imaging protocols, contrast medium volume, and injection rate determination, as well as auto-segmentation of tumours and automated AI-driven measurements: for example, renal function or tumour size. It can therefore be appreciated that all imaging modalities are impacted by AI, from projectional radiography to cross-sectional imaging as well as ultrasound, nuclear medicine, and radiotherapy [4, 10]. The impact of these changes could be improved workflow, dose reduction to patients, greater throughput rates due to shortened examination times and high resolution of images. Precision medicine would be possible since medical images could become mineable datasets to discover radiomic features to inform clinical decisions about patients' management and treatment plans. Clinicians will be able to tailor healthcare interventions earlier and with cognisance of patients genes, lifestyle, and environment, for example [4, 10, 12].

In view of the impact that AI-technologies have, and could have on radiographic practice, means that opportunities for radiographers may arise whilst at the same time taking the necessary steps to facilitate efficient integration of AI in radiography practice. There is an opportunity to expand and revise radiography curricula to include AI-related and data science content, which can assist in upskilling radiographers to mitigate the effects of over-reliance on AI-technology and to enable them to competently work with and alongside AI and to explain this technology's function to patients appropriately [4, 13]. The importance of informing patients of the role of AI is covered in Chaps. 2 and 3.

Enhanced adoption of person centred-care practices is another opportunity brought about by AI. This allows for greater care and patient engagement, but also requires an increase in interpersonal skill development among radiographers [4]. Moreover, AI-programme developers need to include patients in the development stages to ensure the latter will address their needs as health service users [13]. There is an opportunity to improve radiographer reporting where AI-tools can be harnessed to act as second readers to reduce the risk of interpreter bias and missing abnormalities presented on radiographic images [4, 14]. Policies and ethico-legal frameworks should also be developed and be in place to ensure the safe and ethical use of AI-tools in terms of data sharing, accountability, explainability, reducing biases and evaluation and validation. This will facilitate the process of patient and practitioner acceptability of the technology, as well as assist in building trust among all role-players using and being supported by AI-enabled technologies [13].

25.4 Ethical Considerations for AI-Enabled Healthcare Settings and Systems

Given the healthcare transformation promise associated with a disruptive technology such as AI comes a need to ensure that AI-tools are clinically applicable whilst mitigating preventable error and harm to users [15]. There is a need to consider the societal implications of AI-enabled healthcare environments and systems to ensure ethical practice and implementation [13, 16]. This section provides a discussion of three pertinent ethical considerations associated with AI-technologies.

25.4.1 Bias

ML models are prone to biases, as these can happen at any stage of the DL process [17]. This can result in unjust healthcare practices and harm patients. AI-tools have the power to narrow the existing health disparities that exist, but only if they are developed purposefully and involve the intended users at the development stage to eliminate potential bias. This means datasets used for training and validating these models should be representative of target populations to ensure that the principle of justice is maintained [13, 15, 17]. So, all biological sex, gender-related constructs, environmental factors, age, comorbidities, and environmental factors, for example, should be considered when developing an ML model. It is also necessary to mitigate bias as it may cause more harm to various groups if the datasets are skewed, or the appropriate predictors are not included in the algorithmic design to accurately train ML models. The outputs from these may provide inaccurate information, make the model less effective regarding its purpose, and could lead to poor health outcomes for patients [16, 18]. Developers, intended users, and policymakers have a greater responsibility to ensure that this is mitigated as far as possible using appropriate datasets and accurate labelling to represent the full spectrum of the target population equally and fairly, and not only the majority [16, 17]. Doing this could also lead to greater generalisability of the AI-tool and enhance in situ performance, for example, in the case of seasonal diseases. It also requires constant monitoring and evaluation of the models through training on new datasets to ensure they are reliable and valid [16, 19].

25.4.2 Interpretability and Accountability

DNNs are complex and described as black-box models since their internal decision-making processes are not well known, in many cases [6, 15]. This has implications for the interpretability of an AI-system. The interpretability (aka explainability) influences how well users can make sense of an AI system's decisions and procedures used to reach these as well as to recognise when such a system erred. The greater the interpretability of an AI-system is directly proportional to its trustworthiness [19]. This is because radiographers,

and other healthcare practitioners (HCPs), will be able to make informed decisions before adopting such technologies in a clinical setting [13]. Moreover, having a greater understanding of an AI-system's decision-making and analytic features will assist healthcare providers to better make sense and interpret the results and reports provided by the system [15]. These benefits are directly linked to the ethical principle of non-maleficence, i.e. doing no harm to patients and improving patient outcomes through provision of the most appropriate patient management with the assistance of an AI-system [13, 15]. Addressing the interpretability and transparency of AI-systems will contribute to addressing concerns about accountability related to patient management and treatment decisions, as this will enable HCPs to provide complete explanations for their clinical choices and conclusions [16].

In a similar vein, medico-legal liabilities associated with the use of AI-technologies need to be discussed and agreed upon between end users and developers of such technologies. This requires regulations and legislation to be in place to govern these matters [16]. Hence, this calls for multi-stakeholder involvement in the development stage of AI-systems as well as quantification of the level of uncertainty of these systems [19].

25.4.3 Data Privacy and Security

To develop accurate scalable AI-systems that are universal and have robust big data is indispensable. There is a need to increase the availability and accessibility of data required for this purpose. There is a risk of misuse of such data which can result in invasion of patient privacy. Additionally, the uncertainty about who will be liable and responsible for breaches and data leakage adds another ethico-legal dimension that needs consideration [13, 19]. It can therefore be argued that this can lead to an aversion to adoption and integration of AI in a clinical environment. To overcome these concerns requires an organisation wide AI governance structure to promote data security, appropriate use of data, and upholding patient privacy. This would require integrating AI governance into an organisation's governance framework and make explicit how AI relates to corporate, information technology, and data governance, with due consideration for the wider environmental impact such as existing legislation and stakeholder requirements [20, 21]. It is advised that platforms that host AI-systems, and that will be used to transfer data between users, should be encrypted, access controlled, and subjected to continuous audits and security testing. Users should also receive training to use these systems appropriately and to enhance their knowledge and awareness related to data security and its importance [19]. Notwithstanding the importance of the points raised, patients should also be involved as their permission through informed consent is required to use their data for AI-system developments with explicit indications of how their data will be used, by who, how it will be stored, and what will happen if there is a breach of the AI-system and unwarranted access to their data occurs (see Chap. 3).

25.5 AI-Enabled Image Interpretation in Cross-Sectional Imaging and CTC

An overview of AI in radiography and associated ethical considerations were described and discussed above. This section focuses on the use of AI in cross-sectional imaging, in particular CTC and its role in image interpretation.

Colorectal cancer (CRC) is common with an incidence in the region of 1.9 million and accounting for 9.96 million cancer-related deaths globally, in 2020. This figure is projected to increase with 3.2 million new cases by 2040. There are also significant increases in incidence of earlier onset of CRC among younger patients. One can appreciate that this is a significant health concern that health systems the world over would need to grapple with [22]. Thus, early detection and screening for CRC becomes imperative to improve patient outcomes and to mitigate the effects of an overburdened health system. The use of AI shows promise in the screening,

detection and treatment of CRC which could lead to improved clinical outcomes and prognoses for patients [5].

Literature underscores the relatively high accuracy of AI-based algorithms to improve earlier detection and classification of CRC lesions. The accuracy ranged with an area under curve (AUC) value of between 0.75 and 0.91 [5]. Polyp detection and classification is one such area explored. Premalignant colorectal polyps have successfully been differentiated from benign ones by means of AI including identifying patients, with polyps between 6 and 9 mm in size, who would benefit from endoscopic polypectomy [23]. Automatic AI-enabled segmentation of CRC lesions is another area where high accuracy has been achieved to delineate the tumours for analysis and diagnosis purposes [24]. Evidence exists that indicates that AI-tools can provide timely provisional information about the histopathology of CRC lesions, with a 91.7% accuracy, to support pathologists' decision-making processes and inform patient management and treatment plans [25]. Metastases due to CRC can also be detected by AI-enabled algorithms. Liver metastases, which would be undetectable using current standard protocols, can be detected using AI-technologies. Additionally, CRC lesion budding can be detected early and quantified, which will enable earlier intervention and better prognosis for patients [1]. Some AI-models can also identify potential lymph node metastases, which can influence staging of CRC and surgical intervention planning [26]. AI-based algorithms also demonstrated accuracy to personalise patient treatment and can assist in determining the best and most effective treatment options with the least amount of toxicity possible and best possible prognosis [27]. The potential to sub-categorise tumours into more genomic subtypes can promote even further targeted therapy to improve the clinical outcomes for patients [28]. This demonstrates the promising role of precision medicine in oncology to ensure patients receive the most effective treatment to improve their outcome [5].

One can appreciate that AI-enabled technologies provide promising future directions for CRC screening, detection, diagnosis, and treatment. However, more work is required to have a broader body of evidence to validate current results of research before translating and deploying these technologies into clinical settings [28].

Key Messages

- The role of AI continues to increase in the management and treatment of CRC.
- Ethics in the use of AI in imaging must be adhered to.
- Informed consent must include the possible use of AI in CTC examinations.
- Patients are an important role-player in the development of AI models.

25.6 Conclusion

AI will impact the role of radiographers significantly but will not replace them. Instead, it will lead to an amended, and perhaps even an extended role in practice such as in CTC examinations. DL CNNs are common AI-enabled ML algorithms used in image interpretation. AI has considerable supportive prospects in a clinical environment to aid in timeous and accurate detection, diagnosis, and management of CRC at screening or diagnostic CTC. However, before full integration and adoption into practice requires that more work needs to be done to address the existing ethical concerns as well as to increase the existing body of evidence in this area.

References

1. Busnatu Ş, Niculescu A-G, Bolocan A, Petrescu GDE, Păduraru DN, Năstasă I, Lupuşoru M, Geantă M, Andronic O, Grumezescu AM, Martins H. Clinical applications of artificial intelligence—an updated overview. J Clin Med. 2022;11:2265. https://doi.org/10.3390/jcm11082265.
2. Xu Y, Liu X, Cao X, Huang C, Liu E, Qian S, Liu X, Wu Y, et al. Artificial intelligence: a powerful paradigm for scientific research. Innovation. 2021;2(4):100179. https://doi.org/10.1016/j.xinn.2021.100179.
3. Wiljer D, Hakim Z. Developing an artificial intelligence-enabled health care practice: rewiring

health care professions for better care. J Med Imaging Radiat Sci. 2019;50(4 Suppl 2):S8–S14. https://doi.org/10.1016/j.jmir.2019.09.010.
4. Hardy M, Harvey H. Artificial intelligence in diagnostic imaging: impact on the radiography profession. Br J Radiol. 2020;93:20190840. https://doi.org/10.1259/bjr.20190840.
5. Mitsala A, Tsalikidis C, Pitiakoudis M, Simopoulus C, Tsaroucha AK. Artificial intelligence in colorectal screening, diagnosis and treatment. A new era. Curr Oncol. 2021;28(3):1581–607. https://doi.org/10.3390/curroncol28030149.
6. Pramoditha R. The relationship between AL, ML, NNs and DL. 2022. https://rukshanpramoditha.medium.com/the-relationship-between-ai-ml-nns-and-dl-60bd40069908.
7. Liberini V, Laudicella R, Balma M, Nicolotti DG, Buschiazzo A, Grimaldi S, Lorenzon L, Bianchi A, et al. Radiomics and artificial intelligence in prostate cancer: new tools for molecular hybrid imaging and theragnostics. Eur Radiol Exp. 2022;6:27. https://doi.org/10.1186/s41747-022-00282-0.
8. van Engelen JE, Hoos HH. A survey on semi-supervised learning. Mach Learn. 2020;109:373–440. https://doi.org/10.1007/s10994-019-05855-6.
9. Pandey B, Pandey DK, Mishra BP, Rhmann W. A comprehensive survey of deep learning in the field of medical imaging and medical natural language processing: challenges and research directions. J King Saud Uni Comput Inform Sci. 2022;34:5083–99. https://doi.org/10.1016/j.jksuci.2021.01.007.
10. Lewis SJ, Gandomkar Z, Brennan PC. Artificial intelligence in medical imaging practice: looking to the future. J Med Radiat Sci. 2019;66(4):292–5. https://doi.org/10.1002/jmrs.369.
11. Antwi WK, Akudjedu TN, Botwe BO. Artificial intelligence in medical imaging practice in Africa: a qualitative content analysis study of radiographers' perspectives. Insights Imaging. 2021;12:80. https://doi.org/10.1186/s13244-021-01028-z.
12. Subramanian M, Wojtusciszyn A, Favre L, Boughorbel S, Shan J, Letaief KB, Pitteloud N, Chouchane L. Precision medicine in the era of artificial intelligence: implications in chronic disease management. J Transl Med. 2020;18:472. https://doi.org/10.1186/s12967-020-02658-5.
13. Malamateniou C, McEntee M. Integration of AI in radiography practice: ten priorities for implementation. RAD Magazine. 2022;48(567):19–20. https://www.radmagazine.com/scientific-article/integration-of-ai-in-radiography-practice-ten-priorities-for-implementation/.
14. van de Venter R. Moving towards automated digitised image interpretation Friend or foe? SA Radiographer. 2019;56(1):7–10.
15. Doyen S, Dadario NB. 12 plagues of AI in healthcare: a practical guide to current issues with using machine learning in a medical context. Front Digit Health. 2022;4:765406. https://doi.org/10.3389/fdgth.2022.765406.
16. Goisauf M, Abadía MC. Ethics in AI in radiology: a review of ethical and societal implications. Front Big Data. 2022;5:850383. https://doi.org/10.3389/fdata.2022.850383.
17. Kalm CE. Hitting the mark: reducing bias in AI systems. Radiol Artif Intell. 2022;4(5):e220171. https://doi.org/10.1148/ryai.220171.
18. Mehrabi N, Morstatter F, Saxena N, Lerman K, Galstyan A. A survey on bias and fairness in machine learning. ACM Comput Surv. 2021;54(6):1–35. https://doi.org/10.1145/3457607.
19. Bernal J, Mazo C. Transparency of artificial intelligence in healthcare: insights from professionals in computing and healthcare worldwide. Appl Sci. 2022;12(20):10228. https://doi.org/10.3390/appl122010228.
20. Mäntymäki M, Minkkinen M, Birkstedt T, Viljanen M. Defining organizational AI governance. AI Ethics. 2022;2:603–9. https://doi.org/10.1007/s43681-022-00143-x.
21. Mäntymäki M, Minkkinen M, Birkstedt T, Viljanen M. Putting AI ethics into practice: the hourglass model of organizational AI governance. 2022. https://arxiv.org/ftp/arxiv/papers/2206/2206.00335.pdf.
22. Xi Y, Xu P. Global colorectal cancer burden in 2020 and projections to 2040. Transl Oncol. 2022;14(10):101174. https://doi.org/10.1016/j.tranon.2021.101174.
23. Wesp P, Grosu S, Graser A, Maurus S, Schulz C, Knösel T, Fabritius MP, Schachtner B, Yeh BM, Cyran CC, Ricke J, Kazmierczak PM, Ingrisch M. Deep learning in CT colonography: differentiating premalignant from benign colorectal polyps. Eur Radiol. 2022;32:4749–59. https://doi.org/10.1007/s00330-021-08532-2.
24. Wang K-W, Dong M. Potential applications of artificial intelligence in colorectal polyps and cancer: recent advances and prospects. World J Gastroenterol. 2020;26(34):5090–100. https://doi.org/10.3748/wjg.v26.i34.5090.
25. Ho C, Zhao Z, Chen XF, Sauer J, Saraf SA, Jialdasani R, Taghipour K, Sathe A, Khor K-Y, Lim K-H, Leow W-Q. A promising deep-learning assistive algorithm for histopathological screening of colorectal cancer. Sci Rep. 2022;12:2222. https://doi.org/10.1038/s41598-022-06264-x.
26. Bedrikovetski S, Dudi-Venkata NN, Kroon HM, Seow W, Wather R, Carneiro G, Moore JW, Sammour T. Artificial intelligence for pre-operative lymph node staging in colorectal cancer: a systematic review and meta-analysis. BMC Cancer. 2021;21:1058. https://doi.org/10.1186/s12885-021-08773-w.
27. Cianci P, Restini E. Artificial intelligence in colorectal cancer management. Artif Intell Cancer. 2021;2(6):79–89. https://doi.org/10.35713/aic.v2.i6.79.
28. Cheung HMC, Rubin D. Challenges and opportunities for artificial intelligence in oncological imaging. Clin Radiol. 2021;76(10):728–36. https://doi.org/10.1016/j.crad.2021.03.009.

Dual-Energy CT and Photon Counting CT

26

Christoph J. Trauernicht

26.1 Introduction

Dual-energy CT (DECT) and photon counting CT are fairly recent advances in CT imaging which have shown tremendous promise for many clinical applications. In DECT, two different X-ray spectra are used to acquire two datasets of the same region. It is possible for two different materials to have the same CT number on an CT image, making the differentiation of different tissue types very difficult. However, imaging at a second energy or X-ray spectrum potentially allows an analysis of energy-dependent changes in the attenuation of different materials [1], which in turn enables tissue composition characterisations [2].

26.2 X-Ray Interaction Mechanisms

There are two relevant X-ray interaction mechanisms that occur when X-rays with energies that are common in CT interact with the human body.

1. Compton scatter

   In Compton scatter (see Fig. 26.1), a relatively high-energy photon interacts with a loosely bound electron in an atom's outer shell. Some of the energy of the incoming photon knocks the electron out of the atom, leaving behind a positively charged ion. The remaining energy emerges as a new photon with reduced energy and a change in direction [3]. Compton scatter is the largest component of attenuation and predominates in areas of the human body rich in atoms with low atomic number (like soft tissue) [2]. Scattered photons degrade image contrast. The Compton effect depends on the electron density of the material, which in turn is proportional to the mass density for most materials.
2. Photoelectric effect

   In the photoelectric effect (Fig. 26.2), an incoming photon interacts with a tightly bound inner orbit electron and transfers all its energy to the electron, which is ejected from the atom. The atom is left with a positive charge. Immediately an electron from an outer shell fills this hole, bringing the atom closer to its ground state. When this electron falls to a lower orbit, photons are produced, with an energy equal to the energy difference between the electron shell levels. These photons are known as characteristic radiation since the energy differences between the different electron orbits are characteristic for each element. A competing process with characteristic X-ray production is Auger electron emission, which is not relevant for X-ray imaging.

C. J. Trauernicht (✉)
Division of Medical Physics, Tygerberg Hospital and Stellenbosch University, Cape Town, South Africa
e-mail: cjt@sun.ac.za

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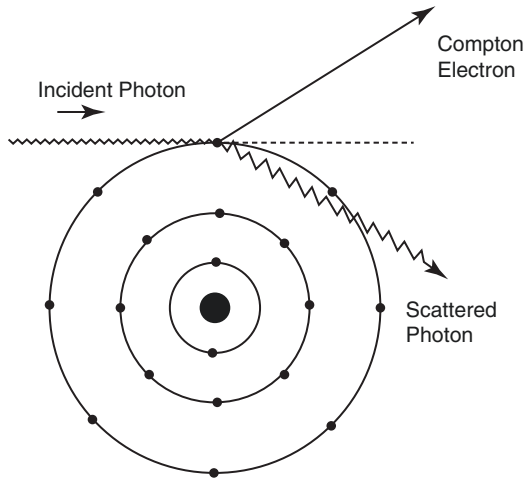

Fig. 26.1 Campton scatter

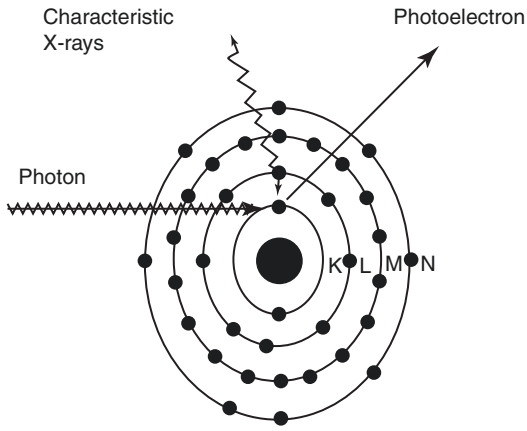

Fig. 26.2 Photoelectric effect

The photoelectric effect is more likely to occur at lower photon energies and in materials with a high atomic number. The interaction probability is larger when the energy of the incoming photon is only slightly larger than the binding energy of the electron in its orbit.

In general, the probability of photoelectric interaction is roughly proportional to the cube of the atomic number for heavy elements, and slightly more than that for lighter elements. It is also inversely proportional to the cube of the incoming photon energy, meaning lower photon energies are more likely to interact through the photoelectric effect ($\approx Z^3/E^3$).

26.3 Material Decomposition

Dual-energy can be defined as the use of attenuation measurements at different X-ray energies, together with the use of the known changes in attenuation between the two energies, to differentiate and quantify material composition [4]. It works better for materials with a high atomic number, like iodine contrast. This was already explored by Hounsfield in 1973, but only gained clinical traction in the 2010s [4].

For a given energy spectrum, two materials can have the same attenuation μ, even if they differ in chemical composition and material density. In CTC, this applies, for example, to soft tissue that may appear very similar (in terms of the CT number) to unclearly tagged faecal matter and partial-volume mixtures with air.

The X-ray attenuation μ at a point has components that are attributable to Compton scatter and to the photoelectric effect.

Therefore, $\mu = \mu_{Compton} + \mu_{Photoelectric}$.

The material decomposition of two materials can be performed by expressing the linear attenuation coefficient of a dual-energy CT image as a linear combination of the two basis materials at two energy levels, for example, at 80 keV and at 140 keV.

1. $\mu^{80keV} = \mu^{80keV}{}_{Compton} + \mu^{80keV}{}_{Photoelectric}$
2. $\mu^{140keV} = \mu^{140keV}{}_{Compton} + \mu^{140keV}{}_{Photoelectric}$

Since Compton scatter depends on the density of the material, and the photoelectric effect depends on the cube of the atomic number, one can now solve these two equations for the density and the atomic number, for example, for water and iodine in each image voxel. This makes use of the fact that the attenuation of X-rays increases with a decrease in energy, but that high atomic number materials (e.g., iodine with $Z = 53$) will show a larger change in differential absorption because the photoelectric effect becomes more dominant at lower energies and higher atomic number materials. This change in attenuation from the high to the low X-ray energy characterises the material.

26.4 Different Approaches to DECT

There are two key requirements for multi-energy CT imaging:

- The acquisition should happen simultaneously if possible, to avoid motion artefacts.
- There must be sufficient energy separation between the high and low energy spectrum, which will improve the contrast to noise ratio.

There are a number of different approaches to dual-energy CT [5, 6].

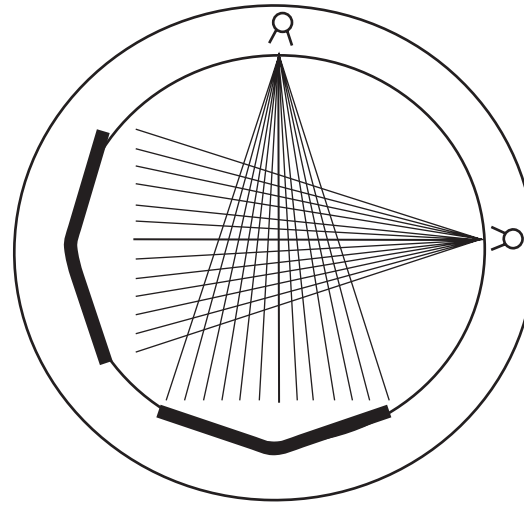

Fig. 26.3 Dual-source CT

26.4.1 Dual-Source CT

The most straightforward approach is dual-source CT (Fig. 26.3) with two X-ray sources running at different voltages, with two corresponding sets of detectors, offset within the CT gantry at a known angle. Additional filters (e.g. tin filters) can be used to adjust the X-ray spectrum at the X-ray tube exit window to better separate the low and high energy spectra.

Siemens implemented this approach. Scan parameters can be individually adjusted for both measurement systems and tube current modulation is possible. The two perpendicular (or in later versions near-perpendicular) X-ray beams image the same slice of the patient at the same time.

The current limitations of this technique are that there is a smaller central scan field-of-view for dual-energy imaging and that cross-scattered radiation may affect image quality [6].

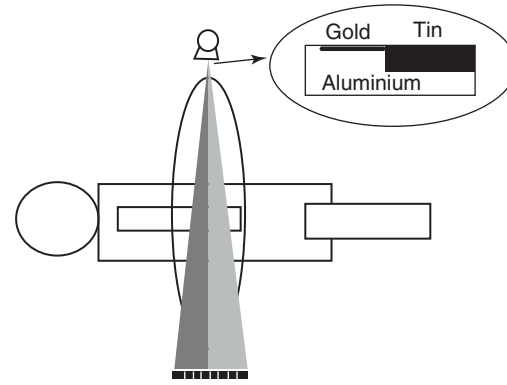

Fig. 26.4 Two halves of a beam filtered differently to achieve energy separation

26.4.2 Twin Beam Dual-Energy

In twin beam DECT, two different filters are used to split the X-ray beam from a single source into two beams of different energies. This is achieved by adding either a tin (Sn) or gold (Au) filter and thus filtering two halves of an X-ray beam differently in the longitudinal direction (Fig. 26.4). This is possible because of multi-row detector technologies. Siemens also implemented this technique. The advantages are that no special X-ray tube requirements are necessary, that a full field of view is achievable, that tube current modulation is possible, and that these systems are more affordable. However, the spectrum separation is smaller compared to a two-kV method, and the substantial filtration may require a powerful X-ray generator [6].

26.4.3 Rapid Tube Potential Switching

Two different energies can also be obtained by rapidly switching the tube potential back and

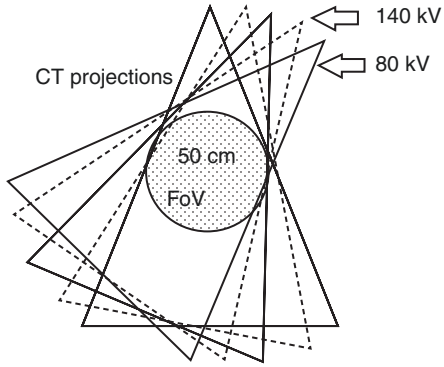

Fig. 26.5 Rapid kV switching

forth between the high and low energy setting on a view-by-view basis during one scan (Fig. 26.5). This technique was implemented by GE. It allows precise temporal registration of the datasets and delivers a full 50 cm material decomposition scan field of view. The interleaved high- and low-kVp projections are split into low-energy and high-energy projections before reconstruction. Additionally, material decomposition can be done and material density images, based, for example, on iodine and water, can be composed [5]. The downside of this method is that tube current modulation is not available, but the kVp switches from 80 to 140 kVp in less than 0.5 ms [7]. Gantries typically rotate around the patient around three times per second.

26.4.4 Dual-Layer Detectors

Philips Healthcare has successfully implemented dual-layer detector technology to achieve the energy separation. The dual-layer detector acquires single X-ray source CT data using two scintillation layers on top of each other, which are used to acquire two energy datasets simultaneously [5, 6].

A single CT scan is performed at a high kVp. The first layer of the detectors absorbs most of the low-energy spectrum (approximately 50% of the beam), while the bottom layer of the detector absorbs the remaining higher energy photons. Images are reconstructed separately from each layer of the detectors (Fig. 26.6). This technique

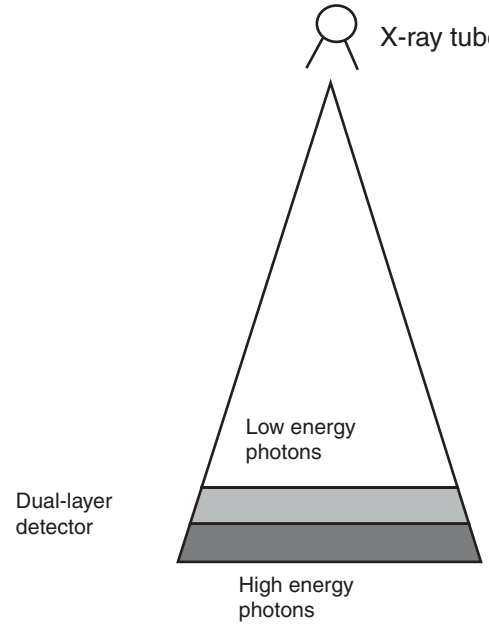

Fig. 26.6 Dual-layer detector

has full spatial and temporal registration of both data sets and allows full field-of-view imaging. The top layer consists of a low-density garnet scintillator, while the bottom layer consists of Gadolinium Oxysulfide (Gd_2O_2S).

Every 120 and 140 kV scan provides both conventional images, as well as dual-energy images. The detector layers are optimised, both in terms of thickness and materials, for 120 kV and 140 kV, but not for lower energies. The energy separation is smaller than other two-kV methods. Detector cross-talk between layers can affect the acquired signal, when photon interactions on one detector pixel results in scattered photons that interact in a different pixel.

26.5 The Use of DECT in CTC

Karcaaltincaba et al. [8] were the first group to describe a DECT colonography technique that has the potential to obviate non-contrast prone images from diagnostic CTC protocols. Colonic polyps and masses are enhanced by about 40–50 HU on post-contrast images; iodine DECT images allow the enhancement of colonic masses

relative to faecal matter through virtual non-contrast images acquired by DECT. Virtual non-contrast imaging is a post-processing technique used to generate 'non-contrast' images of contrast-enhanced scans via the subtraction of iodine.

DECT can be used for electronic cleansing in CTC [9, 10]. Özdeniz et al. [10] found that it is possible to differentiate tumour from faecal matter with no requirement for bowel preparation or scanning the patient in two positions. They did not test the effectiveness of DECT in polyp detection. Boellard et al. [11] also found that colorectal cancers are visible on the contrast-enhanced dual-energy CT without bowel preparation or insufflation. This could make it a very useful tool in the imaging of frail and elderly patients.

26.6 Photon Counting CT

Detector advancements have made photon counting CT possible [6]. Scintillation detectors in use today's CT scanners convert X-rays into visible light, which is detected by photodiodes coupled to these scintillators. The intensity of the emitted light is proportional to the amount of deposited X-ray energy.

Photon counting detectors are based on semiconductors like cadmium-telluride (CdTe) or cadmium-zinc-telluride (CdZT). The difference with these detectors is that X-ray energy is directly converted to an electrical signal, without the conversion of X-rays to light through a scintillator first.

The absorbed X-rays create electron-hole pairs that are separated in a strong electric field. The moving electrons induce short voltage pulses, the height of which are approximately proportional to the deposited X-ray energy. These pulses are individually counted as soon as they exceed a given energy threshold. This threshold is set in such a way that low-level electronic noise below the threshold is disregarded, resulting in less image noise. This in turn opens the door for potential dose reduction.

It is also possible to set more than one threshold (up to six thresholds in prototype testing),

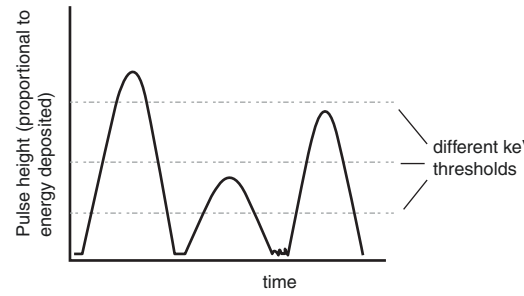

Fig. 26.7 Photon counting: photons are counted in the respective energy bins as soon as they exceed the corresponding energy threshold

based on the voltages that are fed into a pulse-height discriminator circuit [6]. Figure 26.7 illustrates photon counting.

By implementing two or more energy thresholds for data read-out, dual- or multi-energy data can be provided from standard CT scanners without any modifications, other than the detector type. There are no limitations with regard to choice of scan parameters, pitch, tube current modulation, or similar. Data are temporally and spatially aligned and there is no additional scatter radiation that needs to be considered.

The first photon counting CT scanner was approved by the US Food & Drug Administration (FDA) in the United States in 2021. All major CT vendors are currently developing photon counting CT systems. It is likely that photon counting detectors will become the next major shift in CT technology in the next few years.

The major benefits of photon counting CT include:

- no electronic noise
- smaller detector pixels
- photon contributions of different energies can be enhanced to improve contrast
- any scan can become a multi-energy scan

The photoelectric effect is much more likely to occur if the energy of the incoming X-ray only slightly exceeds the binding energy of the innermost electron in the atom. The innermost orbit is called the K-shell. K-edge imaging follows a similar argument as dual-energy imaging, with a sudden increase in the likelihood for a photoelec-

tric interaction in a material when the photon energy only just exceeds this K-edge. This can be used as an additional basis for material imaging. This can include the separation of gadolinium and iodine contrast agents. Muenzel et al. [12] have shown that dual-contrast photon counting CTC with iodine-filled lumen and gadolinium-tagged polyps may enable ready differentiation between polyps and faecal material.

Multi-energy CT also allows for more robust beam hardening correction and metal artefact reduction algorithms.

Key Messages

- DECT is an innovative technology that takes advantage of the differential absorption differences of different materials at different energies, in order to classify materials.
- Different vendors use different methodologies to implement DECT, ranging from two X-ray sources imaging at different energies, to one X-ray source with different filters in the longitudinal direction, to one X-ray source where the tube potential is rapidly switched between higher and lower kV, to dual layer detectors, where each layer preferentially absorbs either higher or lower energies.
- Photon counting CT makes use of detectors that directly convert X-ray energy to electrical signals. This allows electronic binning of signals in different energy bins, which means that any standard CT scanner can become a photon counting CT scanner if the correct detector is used.

26.7 Summary

Dual-energy CT (DECT) makes use of the fact that the differential absorption of X-rays changes with energy of the X-rays, as well as the atomic number of the traversed materials. This is particularly the case for high atomic number materials. This allows for material decomposition in a dual-energy scan, which in turn allows for attempts at, for example, electronic cleansing of the bowel in CTC. Different vendors implement DECT in different ways: either through the use of two X-ray tubes operating at different energies; or applying two different filters to split the X-ray beam from a single source into two beams of different energies; or by rapidly switching the kV in an X-ray tube during the acquisition; or by implementing dual-layer detectors, with one layer preferentially absorbing the lower energy component, and the other layer the higher energy component of the beam.

Photon counting CT was made possible by advancements in detector technology. The direct conversion from deposited X-ray energy to an electronic signal allows for energy discrimination, as well as electronic noise removal. In theory, the application of this detector technology can turn any CT scanner into a dual- or multi-energy CT scanner.

References

1. Sanghavi P, Jankharia B. Applications of dual energy CT in clinical practice: a pictorial essay. Indian J Radiol Imaging. 2019;29:289–98.
2. De Cecco C, Laghi A, Schoepf U, Meinel F. Dual energy CT in oncology.. Springer International Publishing Switzerland; 2015. ISBN 978-3-379-19562-9. https://doi.org/10.1007/978-3-319-19563-6.
3. Compton A. A quantum theory of the scattering of X-rays by light elements. Phys Rev. 1923;21:483.
4. McCollough C, Leng S, Yu L, Fletcher J. Dual- and multi-energy CT: principles, technical approaches, and clinical applications. Radiology. 2015;276(3):637–53.
5. Johnson T, Fink C, Schönberg S, Reiser M. Dual energy CT in clinical practice. Berlin Heidelberg: Springer-Verlag; 2011. ISBN: 978-3-642-01739-1. https://doi.org/10.1007/978-3-642-01740-7.
6. McCollough C, Boedeker K, Cody D, Duan X, Flohr T, Halliburton S, Hsieh J, Layman R, Pelc N. Principles and applications of multienergy CT: report of AAPM Task Group 291. Med Phys. 2020;47(7):e881–912. https://doi.org/10.1002/mp.14157.
7. Karcaaltincaba M, Aktas A. Dual-energy CT revisited with multidetector CT: review of principles and clinical applications. Diagn Interv Radiol. 2011;17:181–94.
8. Karcaaltincaba M, Karaosmanoglu D, Akata D, Sentürk S, Ozmen M, Alibek S. Dual energy virtual CT colonoscopy with dual source computed tomography: initial experience. Rofo. 2009;181:859–62.
9. Eliahou R, Azraq Y, Carmi R, Mahgerefteh S, Sosna J. Dual-energy based spectral electronic cleansing in non-cathartic computed tomography colonography:

an emerging novel technique. Semin Ultrasound CT MR. 2010;31:309–14.
10. Özdeniz I, Idilman I, Köklü S, Hamaloglu E, Özmen M, Akata D, Karcaaltincaba M. Dual-energy CT characteristics of colon and rectal cancer allows differentiation from stool by dual-source CT. Diagn Interv Radiol. 2017;23:251–6.
11. Boellard T, Henneman O, Streekstra G, Venema H, Nio C, van Dotrh-Rombouts M, Stoker J. The feasibility of colorectal cancer detection using dual-energy computed tomography with iodine mapping. Clin Radiol. 2013;68(8):799–806. https://doi.org/10.1016/j.crad.2013.03.005.
12. Muenzel D, Bar-Ness D, Roessl E, Blevis I, Bartels M, Fingerle M, Ruschke S, Coulon P, Daerr H, Kopp F, Brendel B, Thran A, Rokni M, Herzen J, Boussel L, Pfeiffer F, Proksa R, Rummeny E, Douek P, Noel P. Spectral photon-counting CT: initial experience with dial-contrast agent K-edge colonography. Radiology. 2019;283(3):723–8. https://doi.org/10.1148/radiol.2016160890.

27 Application of Clinical Audit Principles for Good Practice in CT Colonography

Leonie Munro and Aarthi Ramlaul

27.1 Introduction

Computed tomography colonography (CTC) is the main radiological method for diagnosis and exclusion of colorectal cancer (CRC) and polyps in asymptomatic patients, as well as in patients with comorbidities that preclude colonoscopy (see Chaps. 7 and 10). CTC is also performed for assessment of patients with incomplete colonoscopy (see Chap. 20). The demand for CTC examinations is increasing due to a number of factors; namely, greater life expectancy, improved sensitivity and specificity for colorectal masses, large and medium polyps and excess demand on endoscopy departments [1]. It is important that all aspects of a CTC examination/procedure are of a consistently high standard. Appropriate audits to demonstrate this are required.

Audits can be used to assess all aspects of a CTC procedure including: the appropriateness of requests; bowel preparation adequacy; effectiveness in identifying abnormalities; and diagnostic value [2]. A clinical audit can also be used for assessing adequate distension of bowel segments; administration rates of iv hyoscine butylbromide (Buscopan) and use of oral faecal tagging (e.g., Gastrografin) [1]. In order to do this, it requires the use of a tool to evaluate the entire provision of a screening or diagnostic CTC service in terms of best practice. All of the imaging modalities used in CRC, as well as management and treatment, should be a high standard. A clinical audit is a quality improvement process that focuses on patient care, management, treatment, and outcomes [3–8]. The purpose of a clinical audit is to improve quality of services. It should not be perceived as judgemental or a punitive measure. Using audit data can be a powerful means to drive changes to improve the service provision and patient and service user experience.

27.2 The Value of Audit Data

CTC audit data can be used to bring about valuable changes. Implementations in practice from audit data should make a positive impact on patient experience, the quality of a CTC examination and the standard of interpretation [9]. In their audit Sharp et al. [9] reported that the verbal consent process was changed to written consent with a focus on the risks especially in relation to bowel perforation (see Chap. 3). Another change was seen in using a decubitus position rather than supine position during a CTC procedure. This change resulted in improved colonic distension on imaging and with reduced premature colonic desufflation [9]. A further change was the intro-

L. Munro (✉)
Formerly School of Radiography, King Edward V111 Hospital, Durban, South Africa

A. Ramlaul
Buckinghamshire New University, High Wycombe, Buckinghamshire, UK
e-mail: aarthi.ramlaul@bucks.ac.uk

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duction of a coding system for all BSCP (bowel cancer screening programmes) CTCs to differentiate intracolonic from extracolonic findings (ECFs) to help highlight the severity of any findings, and ensure appropriate follow-up investigations, if required (see Chap. 18 for a detailed presentation of ECFs).

A clinical audit by Tryb, Haldar, and Prezzi [1] reported the implementation of the following actions from their data: offered further support and training of radiographers to identify inadequate segments and administer further insufflation and additional views; glaucoma questions were removed from their patient group directive (PGD) and replaced with visual symptom guidance. All CTC examinations should therefore have adequate bowel preparation and distension [1] (see Chap. 10).

In January 2021, the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and the Royal College of Radiologists (RCR) published new standards of practice for CTC [10, 11]. A 2018 document of the Society and Colleges of Radiographers (SCoR) [12] includes detailed guidance for radiographers for the provision of a safe and effective CTC service and includes audit examples and tools in relation to best practice guidelines. These guidelines include recommendations for best practice from BCSP [13], BSGAR [10], ESGAR, and RCR [14]. A clinical audit entails several stages and are discussed below.

27.3 Audit Cycle

A clinical audit is a systematic process. It involves an audit team who identify a topic for audit, prepare the audit, define audit criteria and standard, collect data, analyse collected data and implementation of changes, check improvements and maintenance in terms of best practice. It is a continuous cycle to ensure that a high standard of service is delivered and not a one-off procedure [15]. Audits must be conducted periodically and, if changes are implemented, then a re-audit must take place within 6–12 months. Depending on the audit topic, the recommended period for an audit is 2 years [10].

There is consensus in the literature that a clinical audit entails: identify the problem and aim of an audit, set standard, data collection, data analysis and writing a report, implement change, and conduct another audit [3, 4, 16]. It is important that a clinical audit is transparent and is undertaken within an ethical framework. The identity of patients and staff must be protected [3]. In other words, the principles of biomedical ethics must be adhered to.

27.3.1 Preparing for an Audit

This stage pertains to selecting a topic for audit and should include all stakeholders: a clinical audit is a team effort. All aspects of a CTC procedure must be auditable for compliance against expected standards as published by BSGAR and Royal College of Radiologists [10] and SCoR [12]. In addition, there are examples of audit protocols available in the public domain that can be referred to when preparing your audit.

In order to get started, however, an audit question has to be designed [3, 17]. The question must include objectives. For example, an audit could be conducted on patient compliance regarding diet before a CTC study (see Table 9.1).

Indicators are measurable variables and should be identified during the planning stage [15]. When undertaking a local audit that has been conducted before, it is advisable to use the same indicators so that comparisons can be drawn in a reliable manner.

27.3.2 Criteria and Standard to Be Set

All audits require standards to measure the accuracy of the audit [15]. The standard that is being measured against has to be clearly defined. It is important to have clear criteria to measure outcomes [3]. Criteria underpin an audit to ensure that relevant data are collected. A clinical audit must have objectives that are specific, measurable, and achievable [3]. See for example the joint guidance for CTC standards of practice of

the British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiology [10], as well as a list of completed audits with standards which can be referred to for conducting local audits. See also the SCoR document [12] and that of ESGAR [14].

27.3.3 Data Collection

The size of a sample is very important in order to obtain an accurate result of any audit; the timescale used will have a direct bearing on the sample size [15]. During an audit, it must be ensured that there is a high confidence of accuracy levels in your results to give an honest picture of the entire service.

A clinical audit could be retrospective or prospective. Both involve identifying source/s of data [3]. For example, a retrospective audit of CTC bowel cleansing for the past year would require retrieval of data from a PACS. The sample size should be specific based on the total number of CTC studies over the past year. Collection of data will depend on resources available hence the sample size should be manageable. The BSGAR recommends that a spreadsheet containing all relevant data on RIS (radiology information system) [nd] [18] should be used for clinical audit of CTC examinations.

27.3.4 Data Analysis

This stage entails comparing actual performance, in terms of collected data, with the set standard. The data are reviewed to determine whether the standard was met. This stage requires documenting possible reasons for failures in terms of the set standard [3]. When results do not meet the standards, all possible reasons for not meeting the standards must be examined, such as target level, process, technical factors and such. The possibility of sampling bias must also be considered before recommending any changes [15].

The process must be transparent hence the findings need to be shared with relevant stakeholders. The NHS bowel cancer screening programme (BCSP) [13] recommends that audit data should be presented at BCSP team meetings, as well as at local, regional, or national BCSP audit meetings.

27.3.5 Improvements and Maintenance

An action plan should be developed, in terms of recommendations for improvements within a specific timeframe. An action plan should include who will be responsible for implementing changes. It is important that changes or best practice standards should be evaluated with respect to completing an audit cycle [3]. A review clinical audit should be done. An improvement in service can only be proved following a repeat audit and only if it shows an improvement in results [15].

27.4 Is a Clinical Audit the Same as Research?

Research is a systematic process, which contributes to the body of knowledge, because a researcher looks for information in terms of a gap in the literature or if there is no generally accepted evidence available [19]. As unpacked above a clinical audit is central to finding out whether we are doing what is required in terms of best practice. Research and a clinical audit are systematic processes. A clinical audit, however, focuses on the quality of a service provided to patients in order to improve their outcomes and experience, and not on contributing new knowledge.

27.5 Proposed Layout of a Clinical Audit Report

Based on the discussion above, it is suggested that a clinical audit report should include the following.

- Title
- Date

- Names: lead team member and co-team members
- Name of department
- Re-audit date
- Introduction: reason for the audit
- Aims and objectives: criteria and standards
- Sample and methodology
- Results
- Discussion
- Recommendation
- Action plan: what requires improvements in terms of best practice standards; who will be responsible for overseeing required improvements and when will this be done; date for re-audit

Key Messages

- All aspects of a CTC procedure or examination are potentially auditable.
- Audits are an important quality monitoring process.
- Audit data can be used to bring about change for better impact on service delivery, patient outcomes, and experience.
- There are a number of steps within the audit process; the process followed must be robust to validate audit findings.
- Depending on the aspect of the CTC procedure being audited, audits can be repeated every 6 months to 2 years.
- There are a number of key documents that set out clear guidelines to be followed when conducting an audit.

27.6 Summary

CTC is the best method for radiologically diagnosing colorectal cancers and extracolonic pathologies. Best practice guidelines have been produced for the safe and effective monitoring of quality standards when performing CTC examinations for symptomatic and asymptomatic persons. The guidelines recommend that departments monitor their CTC services and outcomes in relation to patient outcomes and experience. CTC audit data are valuable in driving evidence-based changes for implementation within CTC service provision. Audits are conducted through systematic steps. There are numerous examples of audits and audit templates available in the public domain to help in planning and conducting these valuable imaging studies.

References

1. Tryb S, Haldar S, Prezzi D. CT colonography e audit of technical adequacy. Clin Radiol. 2017;72:S14–23.
2. Rooney A, Vijendren A, Obichere M. Audit of CT colonography: does it answer our questions? Int J Surg. 2012;10(8):S1–S52.
3. Esperanto. ESR guide to clinical audit in radiology. 3rd ed. Vienna: ESR; 2022.
4. Bwanga O, Bwalya M. Clinical audit in diagnostic radiography. BJ Med Health Sci. 2021;3(10):1168–72.
5. Torras MG, Canals E, Muñoz-Montplet C, Vidal A, Jurado D, Eraso A, et al. Improving quality of care and clinical outcomes for rectal cancer through clinical audits in a multicentre cancer care organisation. Radiat Oncol. 2020;15:28. https://doi.org/10.1186/s13014-020-1465-z.
6. Quality management audits in nuclear medicine practices. IAEA human health series No 33. Vienna: International Atomic Energy;2015.
7. Dilnawaz M, Mazhar H, Shaikh ZI. Clinical audit: a simplified approach. J Pakistan Ass Dermatol. 2012;22(4):358–62.
8. Comprehensive clinical audits of diagnostic radiology practices: a tool for quality improvement. Quality assurance audit for diagnostic radiology improvement and learning (QUAADRIL). IAEA Human Health Series No 4. Vienna: International Atomic Energy Agency; 2010. https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1425_web.pdf.
9. Sharp S, Lee J, Chawla S. CT colonography practice at a university teaching hospital: improving standards. Color Dis. 2017;19(7):693. https://doi.org/10.1111/codi.13753.
10. British Society of Gastrointestinal and Abdominal Radiology and Royal College of Radiologists. Standards of practice for computed tomography colonography (CTC). 2021. https://www.rcr.ac.uk/system/files/publication/field_publication_files/bfcr201-standards-of-practice-for-computed-tomography-colonography-ctc.pdf.
11. Duxbury O, Burling D, Muckian J, Lung P, Obaro A, Smith K, Plumb A. Meeting the new joint British Society of Gastrointestinal and Abdominal Radiology and Royal College of Radiologists CT colonography standards: a 6-year experience. Clin Radiol. 2021;76:665–73.
12. The Society and Colleges of Radiographers. Guidelines for the provision of a safe and effec-

tive CT colonography service, 2018. https://www.sor.org/learning-advice/professional-body-guidance-and-publications/documents-and-publications/policy-guidance-document-library/national-best-practice-guidelines-for-the-ct-colon.
13. NHS Bowel Cancer Screening Programme (BCSP). Bowel cancer screening: guidelines for CTC imaging. 2021. https://www.gov.uk/government/publications/bowel-cancer-screening-imaging-use/bowel-cancer-screening-guidelines-for-ctc-imaging.
14. The European Society of Gastrointestinal and Abdominal Radiology (ESGAR): 2021 guidelines in progress. Guideline for training and quality assurance in CT colonography. https://www.esgar.org/.
15. Thakor K, Major V, Ramlaul A. Clinical audit. In: Ramlaul A, editor. Medical imaging and radiotherapy research: skills and strategies. 2nd ed. Switzerland: Springer Nature; 2020.
16. Esposito P, Dal Canton A. Clinical audit, a valuable tool to improve quality of care: general methodology and applications in nephrology. World J Nephrol. 2014;3(4):249–55. https://doi.org/10.5527/wjn.v3.i4.249.
17. An introduction to clinical audit for radiographers. ISRRT. https://www.elearning.isrrt.org/mod/book/tool/print/index.php?id=349.
18. CTC database quality assurance and audit; n.d. https://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwiexMLmraX6AhVkRUEAHYW1CbQQFnoECAcQAQ&url=https%3A%2F%2Fwww.bsgar.org%2Fmedia%2FCTC%2520DATABASE.pdf&usg=AOvVaw3lOZlYaOKO8Ekd9xk8uR7p.
19. Brink H. Fundamentals of research methodology for health care professionals. Cape Town: Juta; 2000. p. 3.

28 Self-Assessment of CT Colonography Images

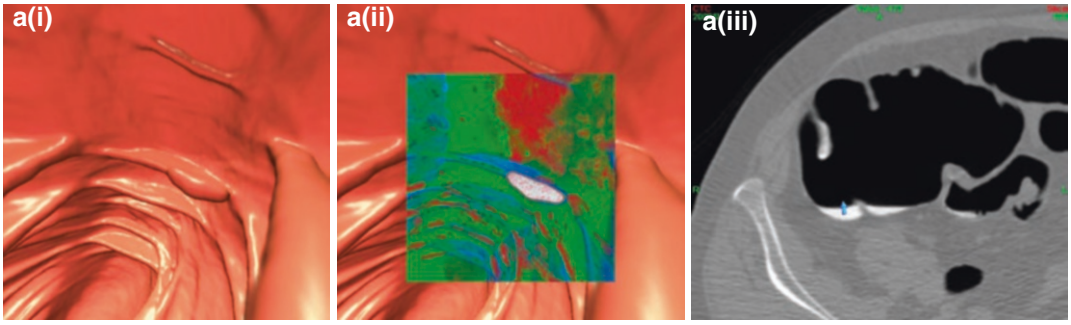
Joel H. Bortz, Aarthi Ramlaul, and Leonie Munro

28.1 Introduction

Interpretation of both colonic and extracolonic images is essential in all CTC studies. Fifty CTC images are embedded in the self-assessment questions. Our aim in these questions is to provide a platform for readers to assess their knowledge and understanding of CTC as presented in this book. It is important to refer to the C classification in Table 10.3 when interpreting CTC images. A C3 classification requires recommending colonoscopy follow-up, for example. Some questions require knowledge of the E classification presented in Table 18.4. Where applicable, reference is made to the reporting template in Chap. 21. Sixty-four images with labels/arrows are embedded in the answers. The majority of the answers include comments with additional information. In some images there is a small blue arrow generated by software discussed in Chaps. 10 and 21. Ignore these arrows unless specifically referred in the text.

28.2 Self-Assessment Questions

Question 1
Describe the image appearances on Fig. 28.1a(i–iii).



J. H. Bortz (✉)
LSG Imaging, Los Angeles, CA, USA

A. Ramlaul
Buckinghamshire New University, Buckinghamshire, UK
e-mail: aarthi.ramlaul@bucks.ac.uk

L. Munro
Formerly King Edward V111 Hospital, Durban, South Africa

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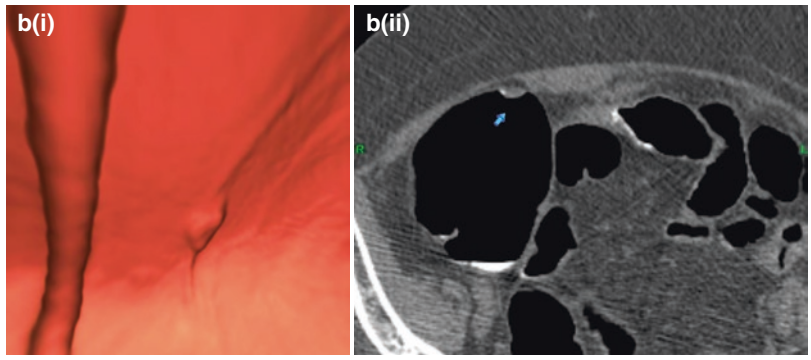
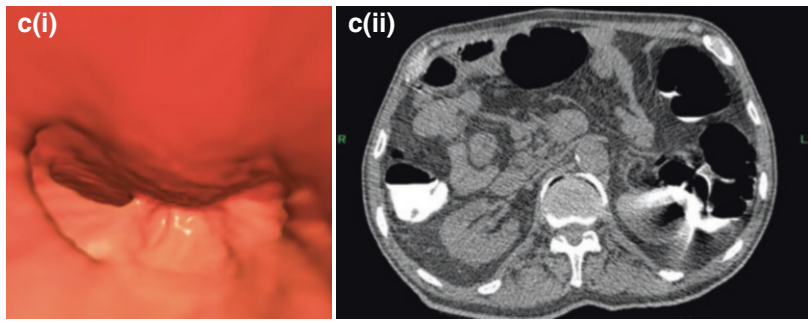
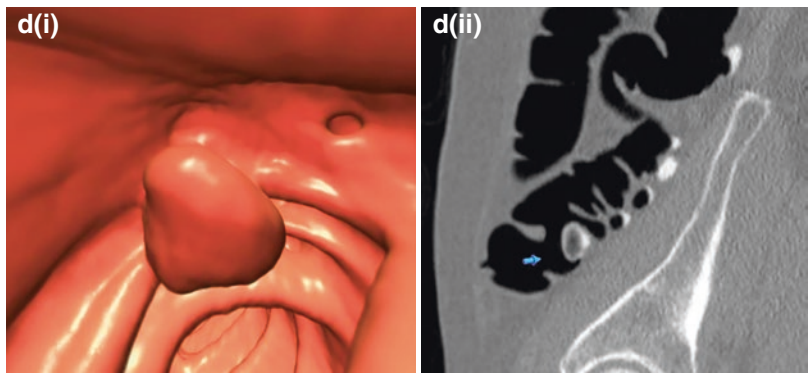
Question 2
Describe the image appearances on Fig. 28.1b(i, ii).



Question 3
Describe the image appearances on Fig. 28.1c(i, ii). What causes these appearances?

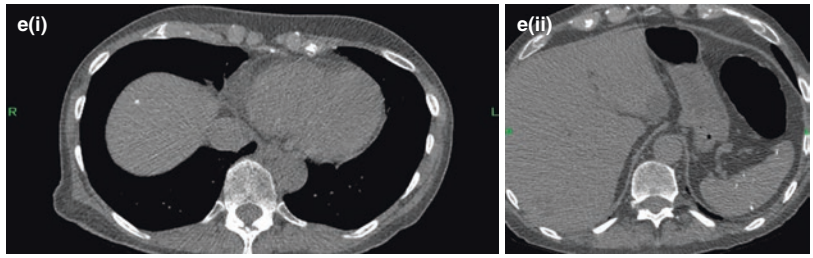


Question 4
Describe the image appearance on Fig. 28.1d(i, ii). Does this pathology have complications?



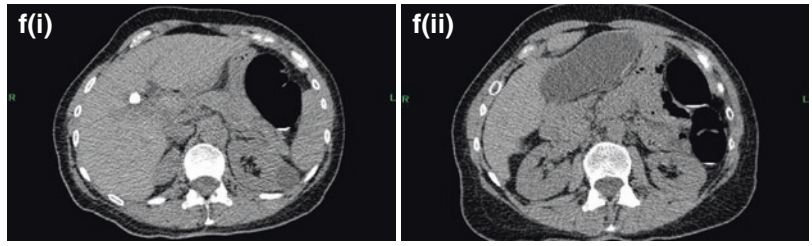
Question 5

Describe the appearances on Fig. 28.1e(i, ii) in an asymptomatic patient at a screening CTC study. What could be the cause of these appearances? Are they of clinical significance?



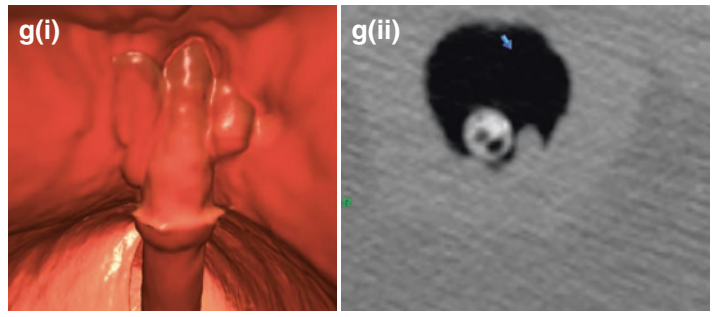
Question 6

The images in Fig. 28.1f(i, ii) are of two asymptomatic patients who had screening CTC examinations. Describe your findings for each patient. Under which E classification would you list your findings?



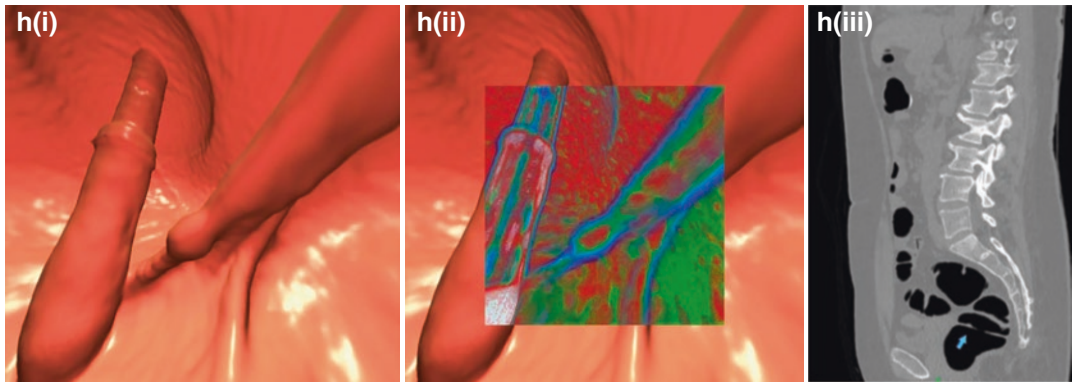
Question 7

Figure 28.1g(i) is a 3D supine view. Describe your findings. Describe your findings of Fig. 28.1g(ii). Should further views be checked and if so provide reason for your answer.



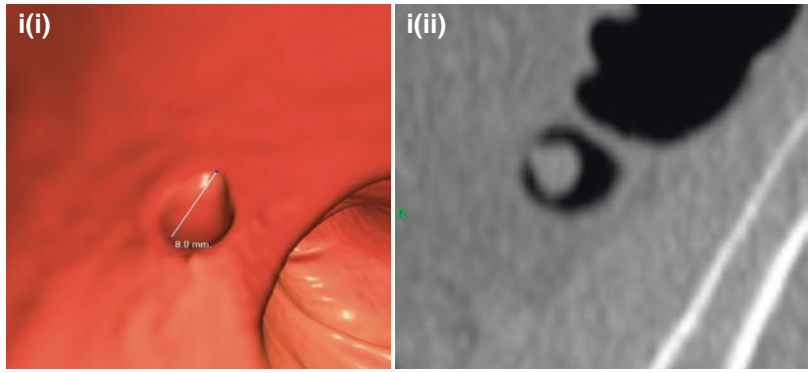
Question 8

Which region of the colon is depicted in Fig. 28.1h(i–iii)? Describe your findings of all the images.

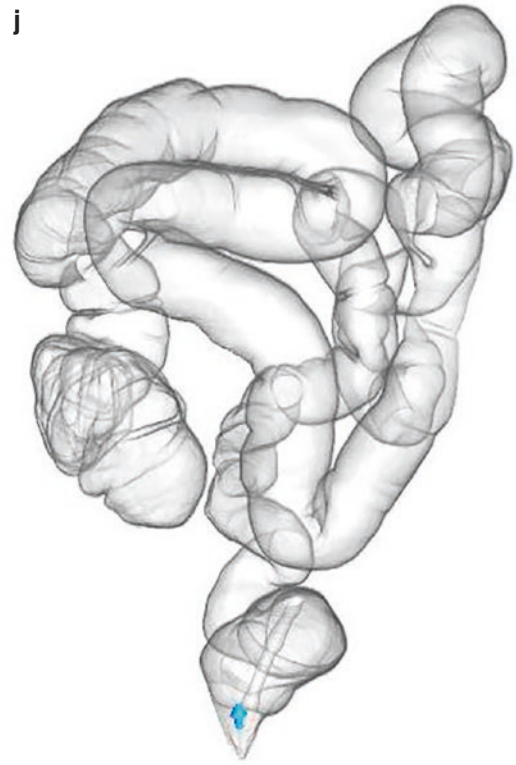


Question 9

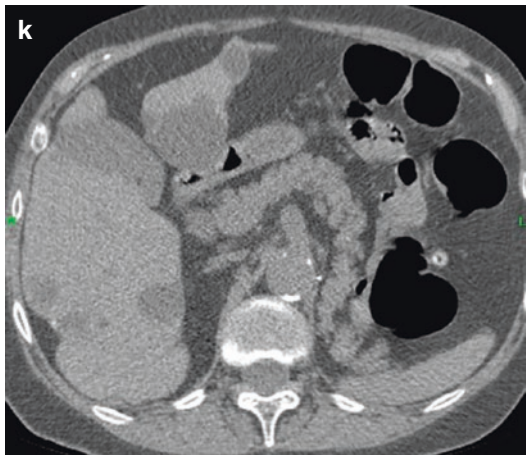
Do you agree that Fig. 28.1i(i) shows a 8 mm sessile polyp? What is the appearance in Fig. 28.1i(ii)?



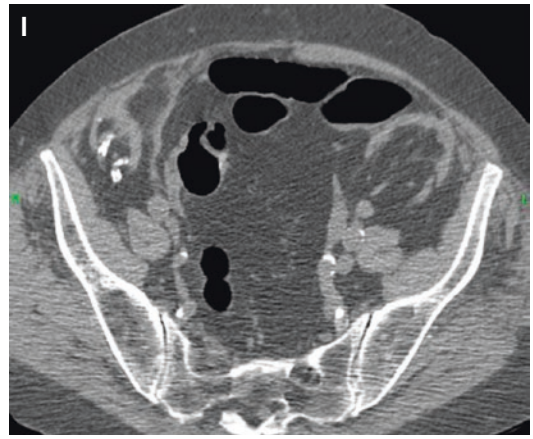
Question 10
Describe the bowel segments on the colon-map in Fig. 28.1j and comment on them.



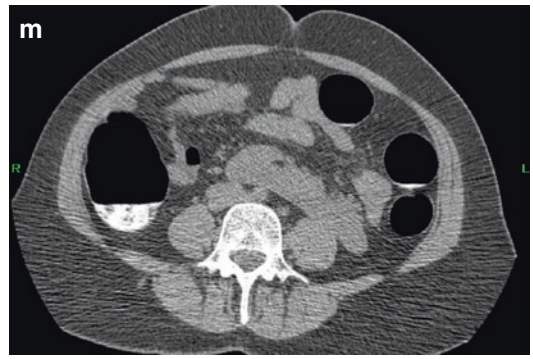
Question 11
Describe the ECFs in this image (Fig. 28.1k) and state E classification. What could be the reason for the position of the pancreas and spleen?



Question 12
Describe the appearance on Fig. 28.1l. Give reason for your answer and indicate E classification.

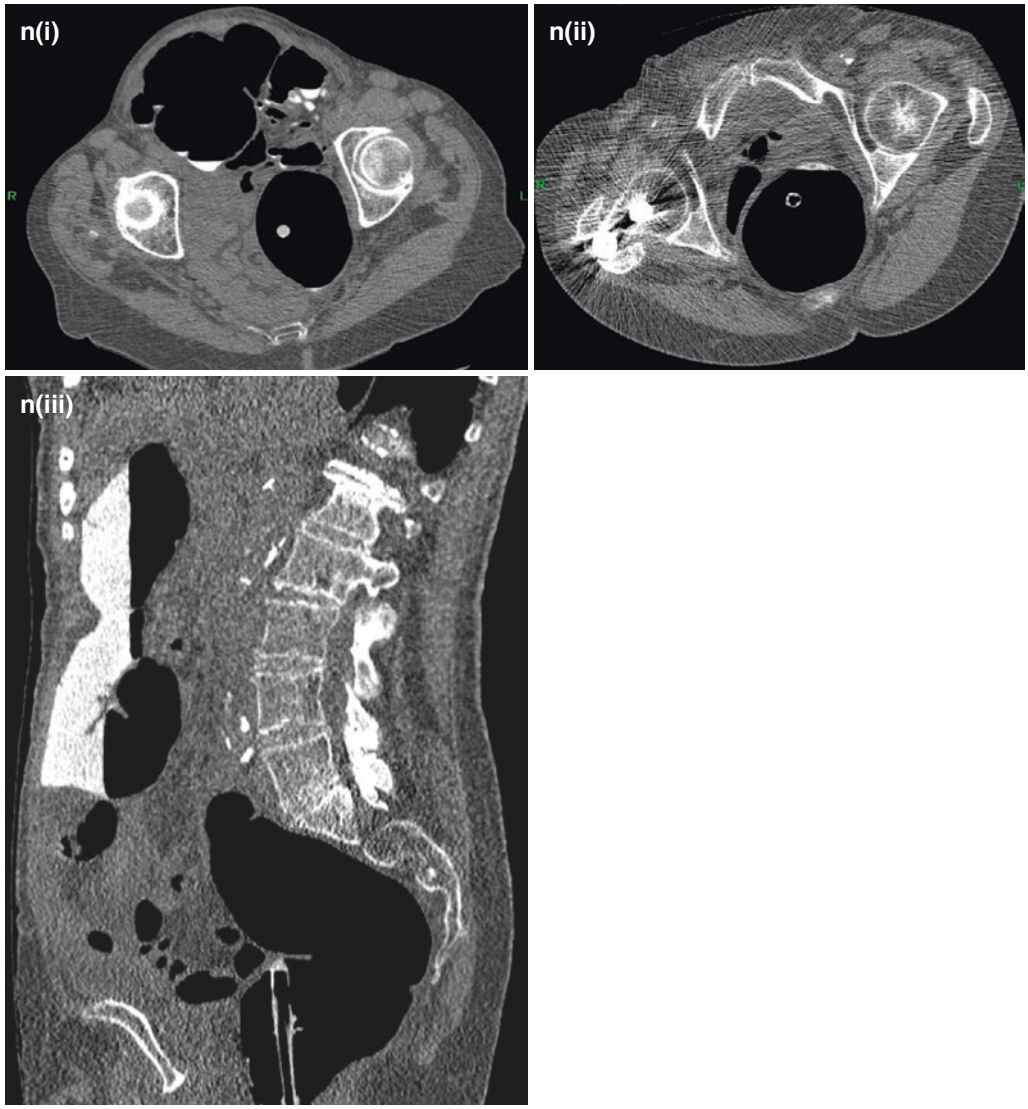


Question 13
Describe the appearance of this ECF on Fig. 28.1m. Indicate E classification.



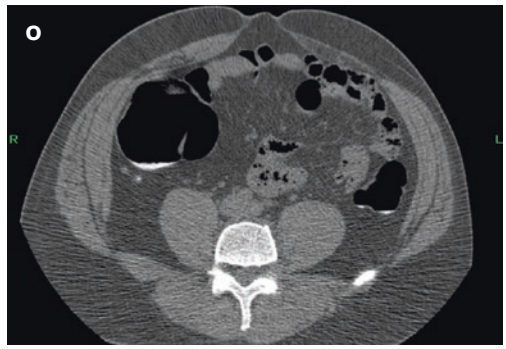
Question 14

Describe the appearances in Fig. 28.1n(i–iii). Does this pathology occur equally in males and females?



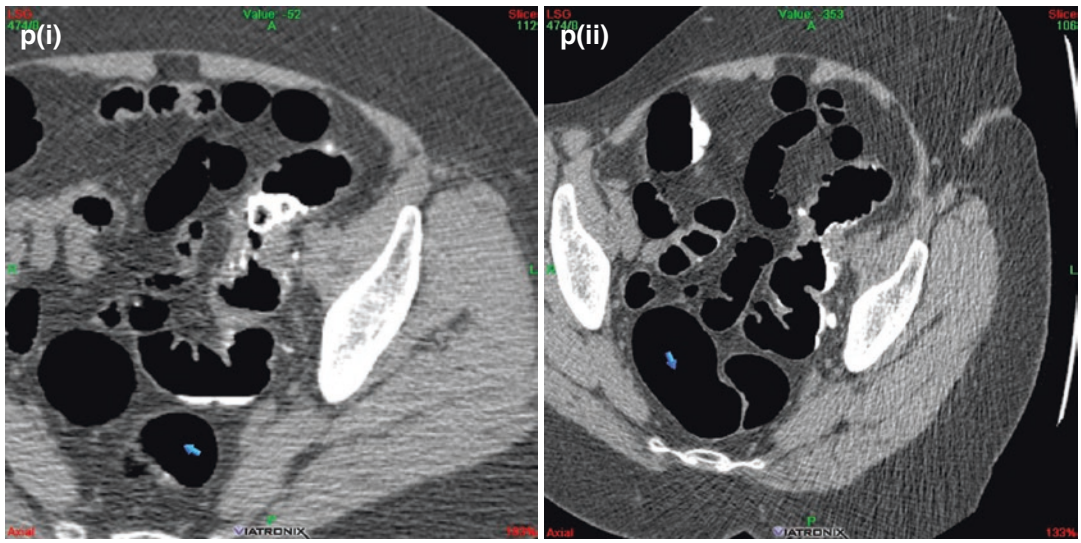
Question 15

Describe the appearance in Fig. 28.1o. State E classification.

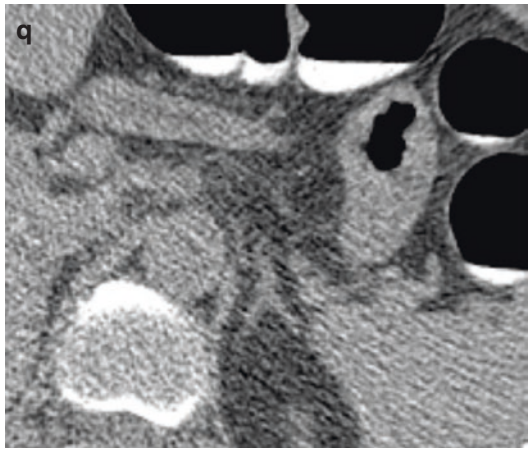


Question 16

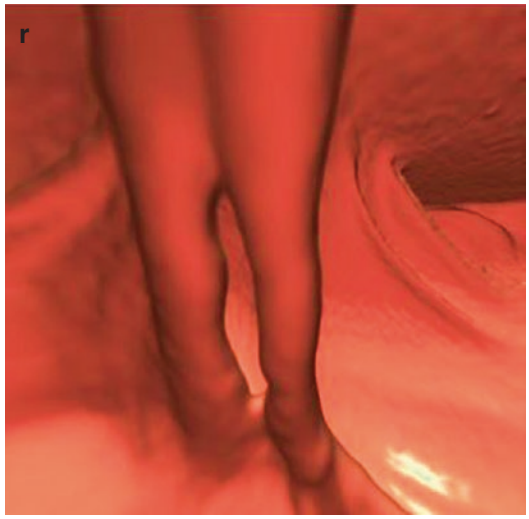
Describe the appearances in Fig. 28.1p(i, ii).



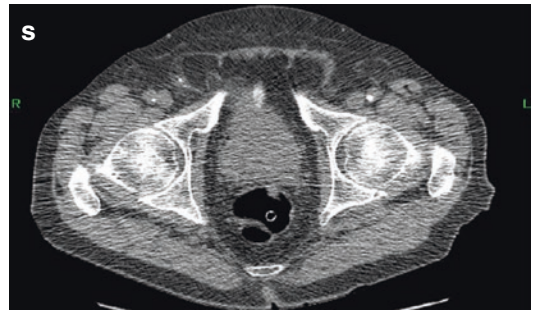
Question 17
Describe this ECF in Fig. 28.1q. State E classification.



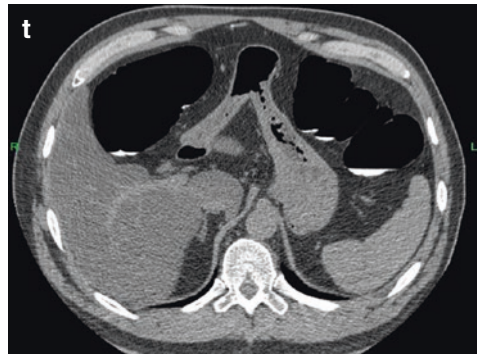
Question 18
Describe the appearance in Fig. 28.1r.



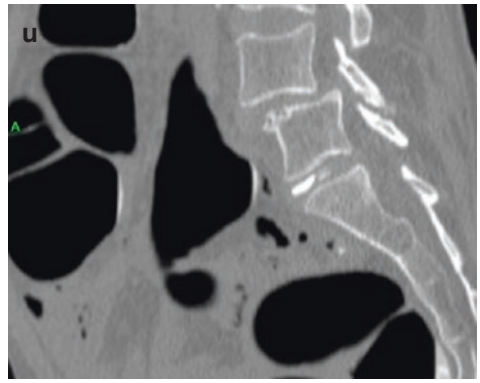
Question 19
Describe the appearance in Fig. 28.1s. State E classification.



Question 20
Describe the ECF seen on Fig. 28.1t. State E classification.

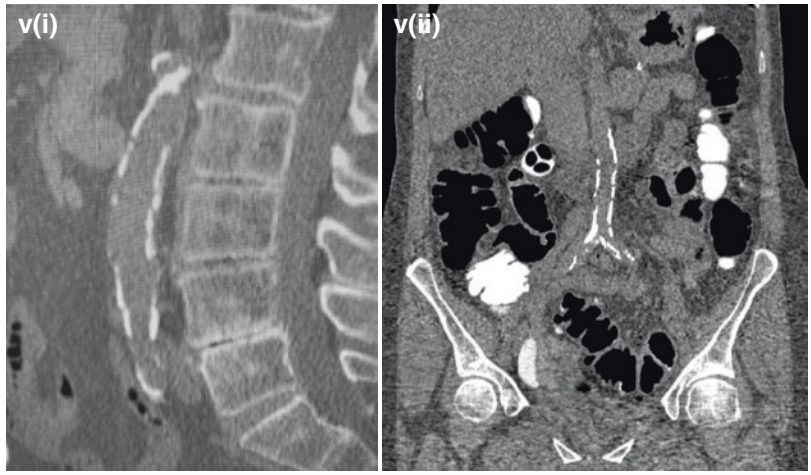


Question 21
Describe the ECF seen on Fig. 28.1u. State E classification.



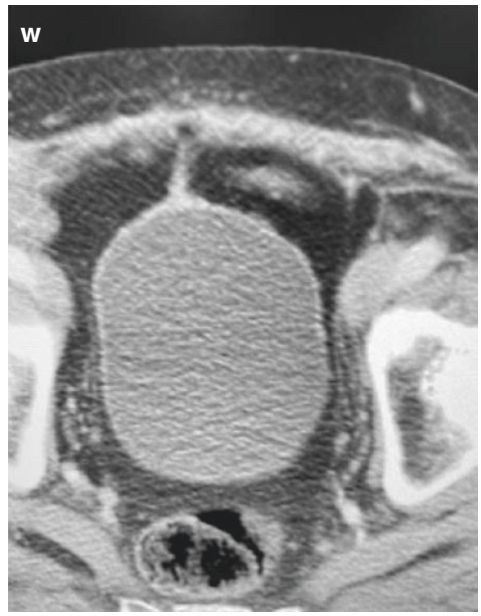
Question 22

Describe the ECF seen on Fig. 28.1v(i) and state E classification. Figure 28.1v(ii) is of another patient. Describe the finding and state E classification.



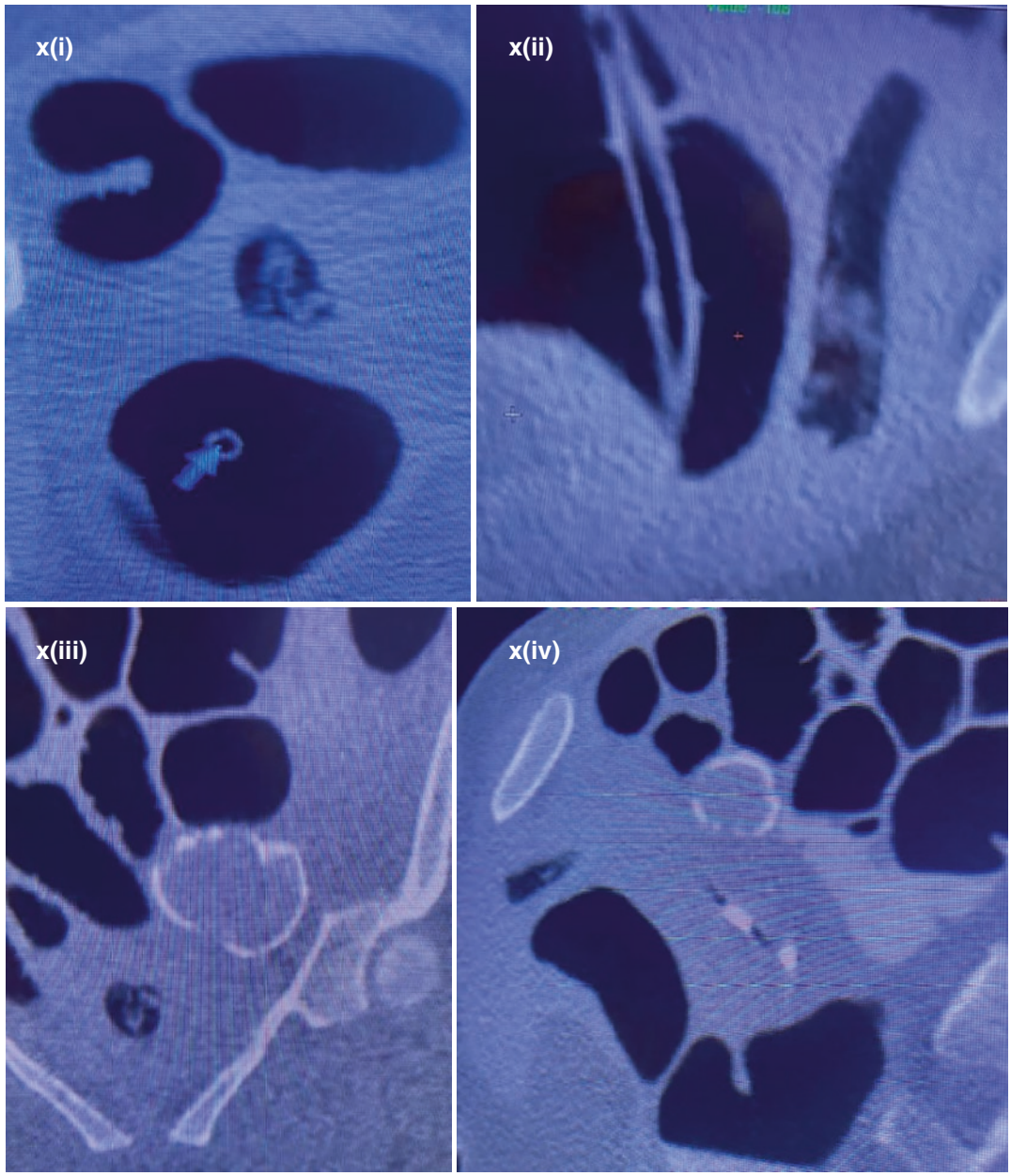
Question 23

Describe the ECF seen on Fig. 28.1w.

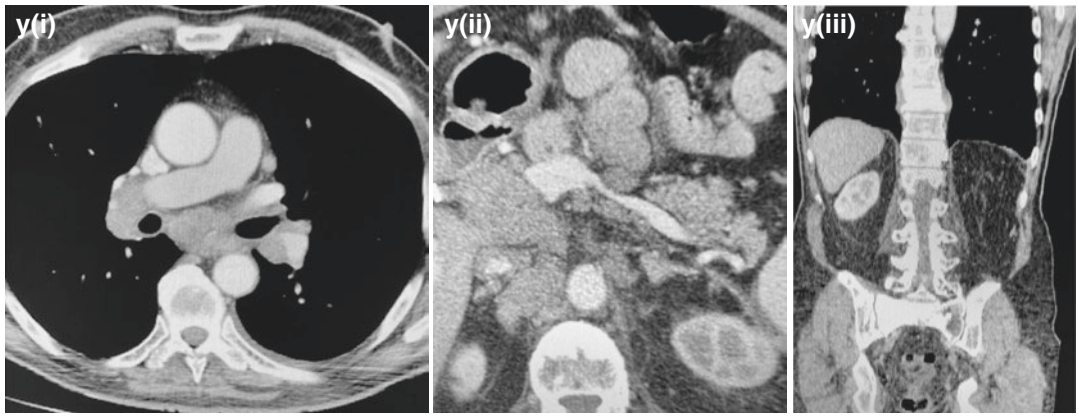


Question 24

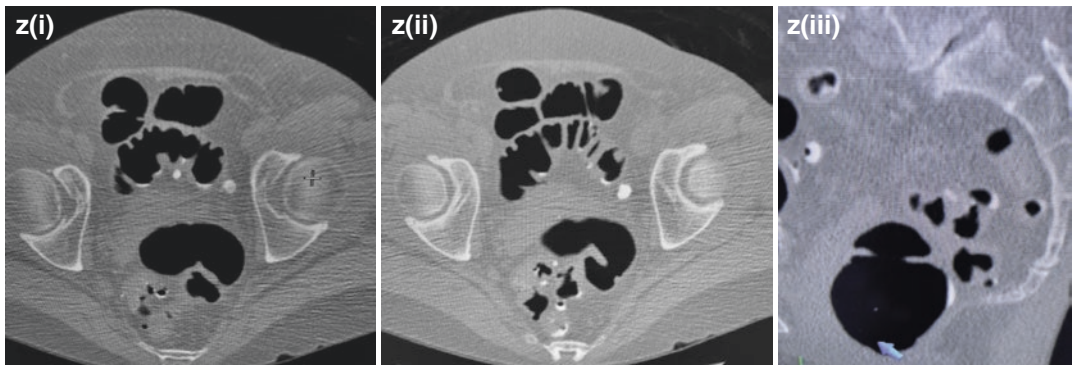
Describe the ECFs seen on Fig. 28.1x(i–iv). State E classification.



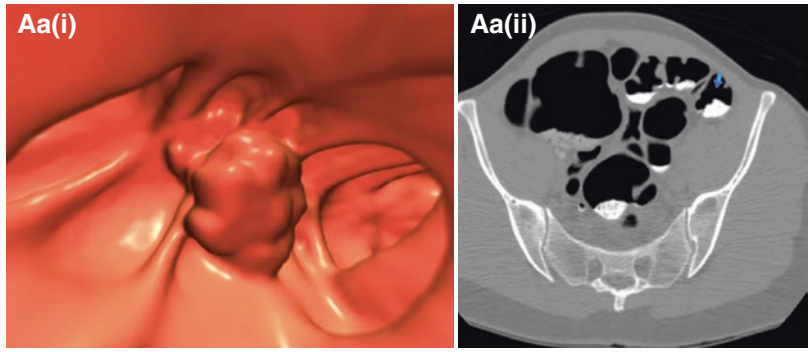
Question 25
Describe the ECFs on Fig. 28.1y(i–iii). State E classification.



Question 26
Describe the ECFs on Fig. 28.1z(i–iii), and state E classification.



Question 27
Figure 28.1aA(i, ii) is of a patient who presented for a screening CTC. Describe the appearances of the images. What would be the future management of the patient?



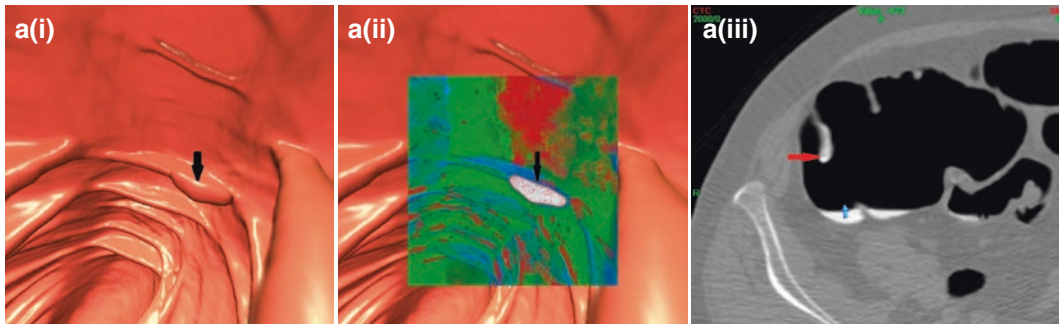
Question 28
Define an anal papilla and state what causes it.

Question 29
Patient preparation is an essential step in a CTC study. What should be done if several patients present with poor bowel preparation?

Question 30
Describe the features of a colon lipoma image.

28.3 Answers

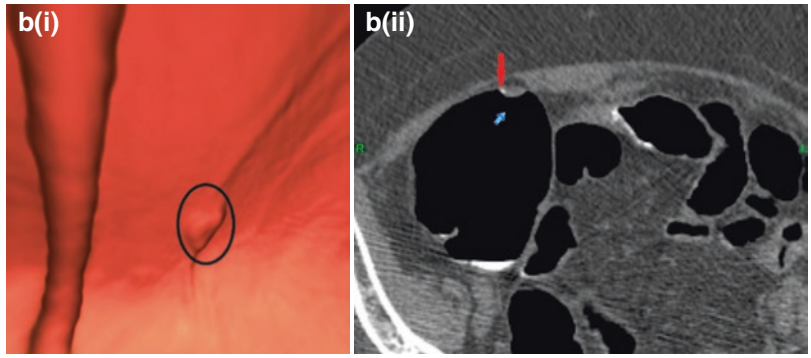
Question 1
3D fly-through (Fig. 28.2a(i)) shows a polypoidal lesion on a haustral fold suspicious for a polyp (black arrow). Figure (ii) is a translucent display (TD) showing the lesion is white indicating barium on a fold and not a polyp (black arrow). 2D axial view (Fig. 28.2a(iii)) shows barium attached to a fold (red arrow) and no evidence of a polyp.



Comment
Colour attenuation values of TD are discussed in 10.5 in Chap. 10. Careful scrutiny of the 2D is required for those sites that do not have TD.

Question 2

Figure 28.2b(i) 3D view shows a non-polypoidal lesion (black circle) corresponding to the flat lesion. Figure 28.2b(ii) 2D axial view of the R colon shows partial covering of a flat lesion by barium (red arrow). Note its position on the non-dependent portion of the bowel wall.

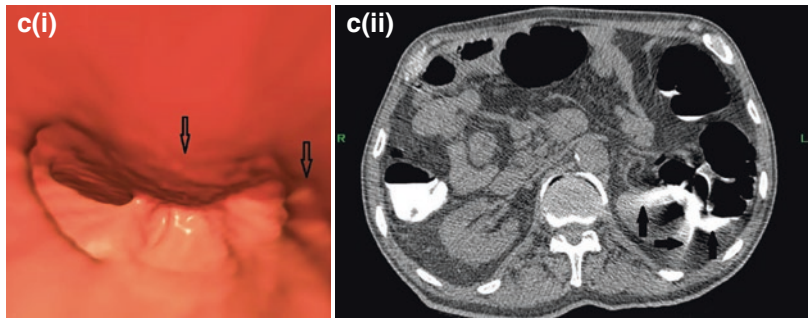


Comment

Tagging is important as 80% of flat polyps have some form of covering aiding in their visualisation. Flat polyps are responsible for 30% of colorectal cancers particularly on the R side of the colon. Important to take accurate measurements of polyps in terms of C classification as shown in Table 14.1.

Question 3

Figure 28.2c(i) 3D view showing an artefact (open black arrows). Figure 28.2c(ii) 2D axial view showing artefact (black arrows). It is a luminal artefact called the 'dense water fall sign' (DWS). It occurs when opacified luminal fluid flows from a higher to a lower level relative to the patient position on the scanner table.

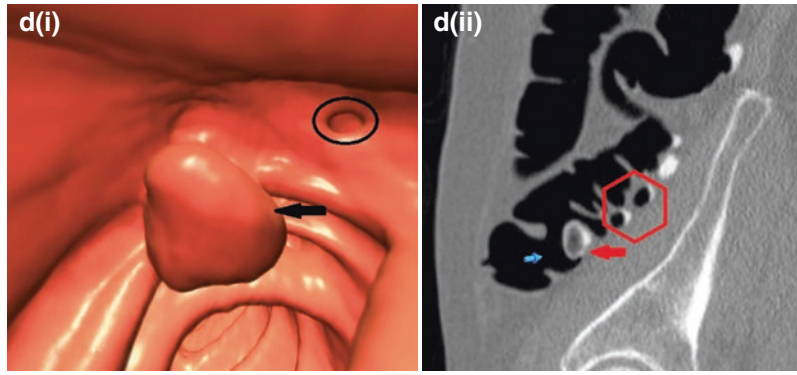


Comment

The DWS is discussed in 12.2.8.1 in Chap. 12. It is a distinctive arciform artefact. It is not due to patient breathing, patient movement, spasm, or beam hardening. It is best seen on 2D views where the artefact is most prominent.

Question 4

Figure 28.2d(i). 3D supine image showing a diverticulum (black circle). There is also a polypoidal lesion simulating a polyp (black arrow). Figure 28.2d(ii) 2D sagittal image shows diverticula (hexagon) and an impacted diverticulum (red arrow) which is the one shown in the black circle on the 3D.

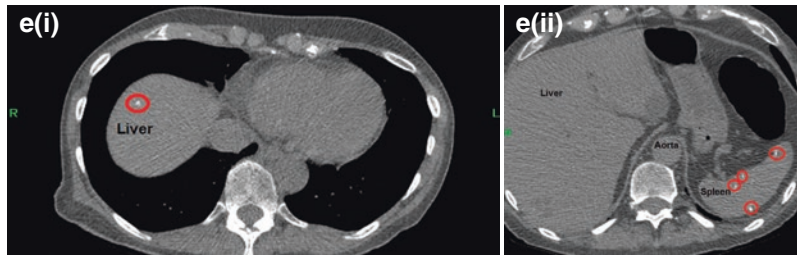


Comment

Diverticular disease (DD) is the most common benign colonic abnormality in people over the age of 50 years. It is considered to be a normal finding as discussed in Chap. 16. However, if a diverticulum becomes filled with thickened or congealed stool and/or barium it may then bulge into the colonic lumen causing a polypoidal defect on 3D endoluminal views. DD does have complications as discussed in 16.10 in Chap. 16.

Question 5

Punctate calcification seen in the liver (red circle) in Fig. 28.2e(i), and in the spleen (red circles) in Fig. 28.2e(ii). The latter is typical granuloma calcification. A history of an infection (e.g., TB) is a cause of granuloma. It is an ECF of low clinical importance (E2).

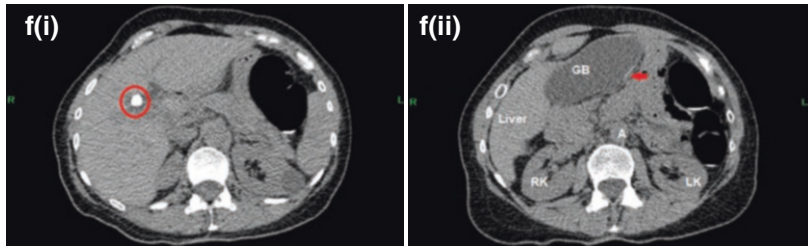


Comment

See Table 18.1 for E classifications. Granuloma is an E2 classification. Granulomas are usually caused by an infection. Most common causes are: (i) tuberculosis, (ii) sarcoidosis, (iii) histoplasmosis, (iv) aspergillosis, and (v) Wegener's granulomatosis.

Question 6

Figure 28.2f(i) is a 2D axial supine image showing a 1 cm calcified calculus in the neck of the gallbladder (red circle). Figure 28.2f(ii) shows a dilated gallbladder and mild calcification (red arrow) of part of the gallbladder wall. E2.

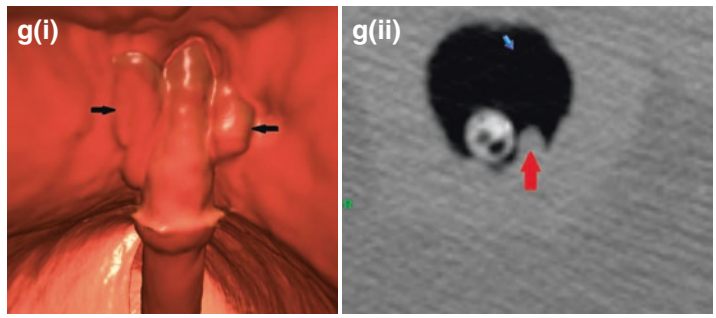


Comment

Dilated gallbladder probably due to fasting. The small area of calcification may relate to a previous inflammation.

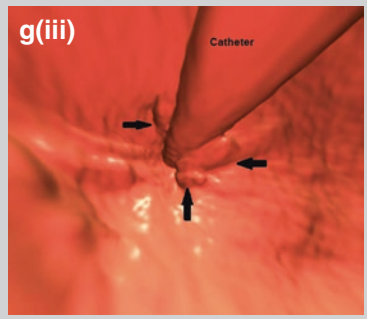
Question 7

Figure 28.2g(i) shows polypoidal swelling (black arrows) around the rectal tube in keeping with large haemorrhoids on the 3D supine view. Figure 28.2g(ii) is a 2D supine axial view. Red arrow indicates polypoidal swelling adjacent to the tube in keeping with haemorrhoids.



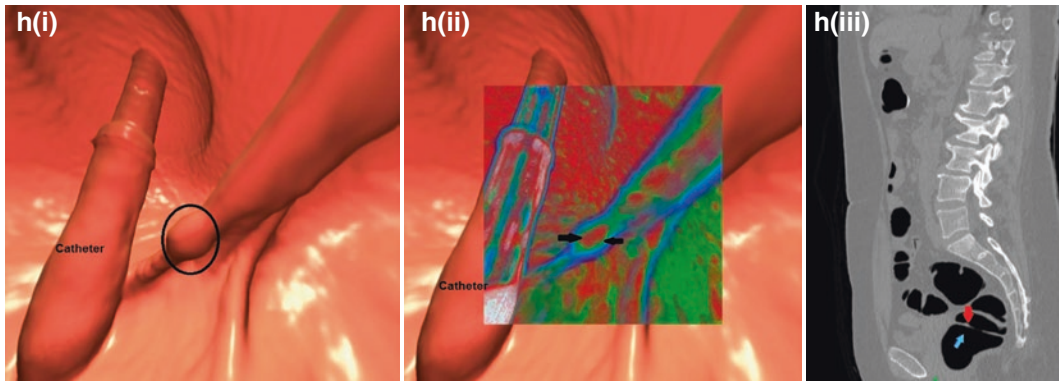
Comment

Haemorrhoids are best visualised in the prone position with the balloon deflated as shown in Fig. 28.2g(iii): numerous vessels are evident (black arrows) in keeping with haemorrhoids. As discussed in Chap. 13, it is important to deflate the balloon in the prone position to best visualise internal haemorrhoids. See 13.4.1 and 13.6 in Chap. 13.



Question 8

The images are of the valves of Houston in the rectum. 3D view (Fig. 28.2h(i)) shows a polypoidal swelling on the valve of Houston fold (black circle). TD (Fig. 28.2h(ii)) confirms that it is a polyp (arrows). 2D sagittal view (Fig. 28.2h(iii)) shows a soft tissue polyp (red arrow) on the inferior valve of Houston.

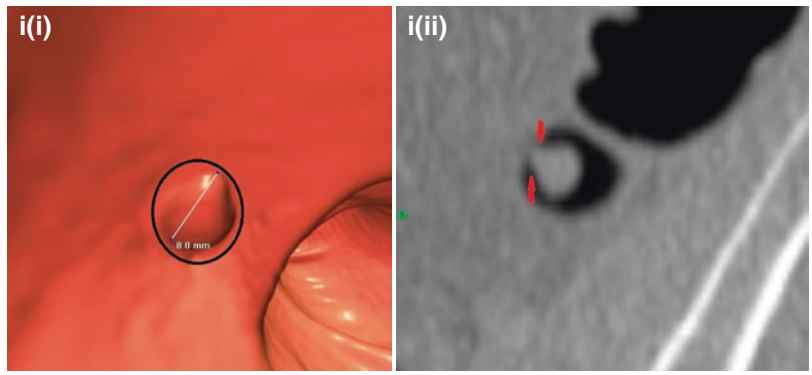


Comment

Histology was that of a tubular adenoma. Colour attenuation values of TD are discussed in 10.5 in Chap. 10. The anatomy of the valves of Houston is described in Chap. 11 (see 11.3.1 and Fig. 11.2(i, ii)).

Question 9

The appearance on Fig. 28.2i(i) is that of 8 mm sessile polyp on the 3D view (black circle). However, a small stalk (red arrows) is noted on Fig. 28.2(ii) depicting a pedunculated polyp.

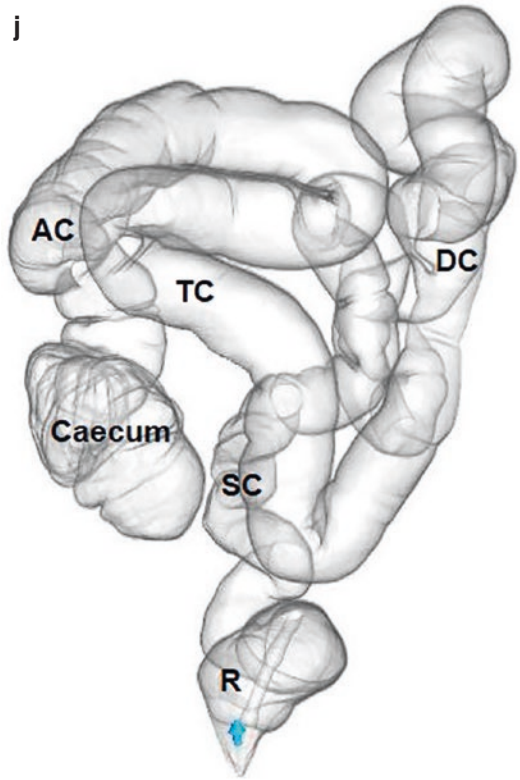


Comment

It is important to carefully look at the features of polyps on 2D views and to check for a stalk, if visualised. How to measure sessile and pedunculated polyps is described in Chap. 10.

Question 10

Colon-map (Fig. 28.2j) simulating a double-contrast barium enema image shows markedly redundant sigmoid colon (SC) and transverse colon (TC), which dips into the pelvic region. AC = ascending colon. DC = descending colon. R = rectum.

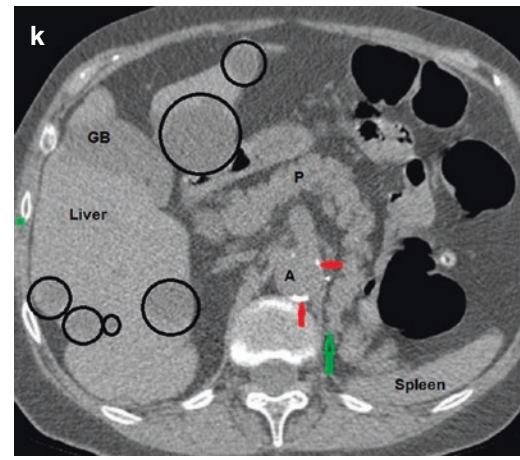


Comment

It is easy to understand how an optical colonoscopy may be unsuccessful in a patient with this bowel configuration. Redundancy is discussed in Chap. 20, and the average colon length is presented in 11.3 in Chap. 11.

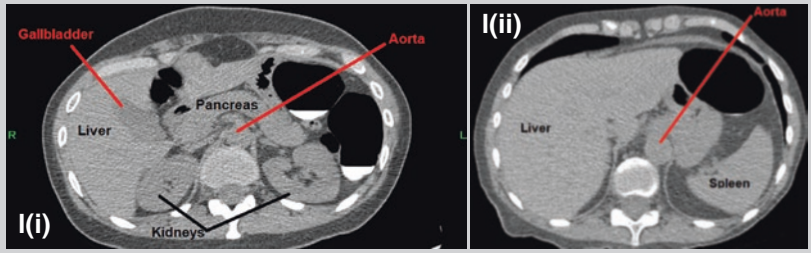
Question 11

As shown on Fig. 28.2k, there are secondary deposits in the liver (black circles). Gallbladder (GB) appears normal. The tail of the pancreas (green arrow) dips vertically towards the renal bed, and the spleen is in a horizontal position. Red arrows = calcification of wall of the aorta in keeping with atherosclerosis. E4. Patient had a left nephrectomy; hence, the position of the spleen and tail of the pancreas. Patient probably had cancer of the kidney in view of secondary deposits in the liver.



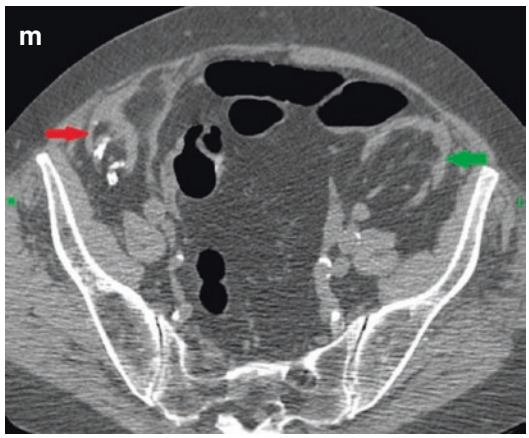
Comment

Note the position of pancreas and spleen in Fig. 28.2l(i, ii). Most spleens are in the left upper quadrant. The position of the spleen usually shifts in a patient who has had a left nephrectomy. It shifts to the area of the left renal bed where the kidney used to be positioned. Its orientation also changes, and it tends to lie in a horizontal position as evident in Fig. 28.2k. The position of the pancreas also changes in these patients. Its body and tail tend to dip vertically towards the renal bed as evident in Fig. 28.2k. The splenic artery and vein accompany the pancreas in this move.



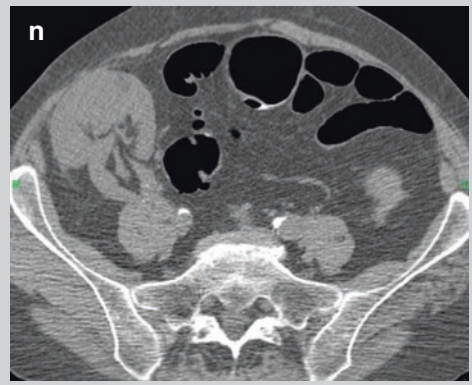
Question 12

As shown on Fig. 28.2m, there is a right transplanted kidney containing calcification (red arrow) and a left transplanted kidney (green arrow). E2 classification.



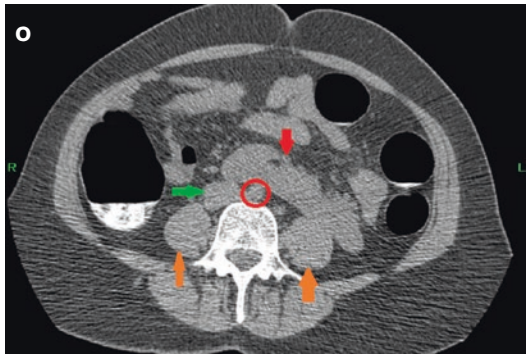
Comment

Both kidneys were not functioning (failed transplants). The patient had a successful third transplant as shown in Fig. 28.2n.



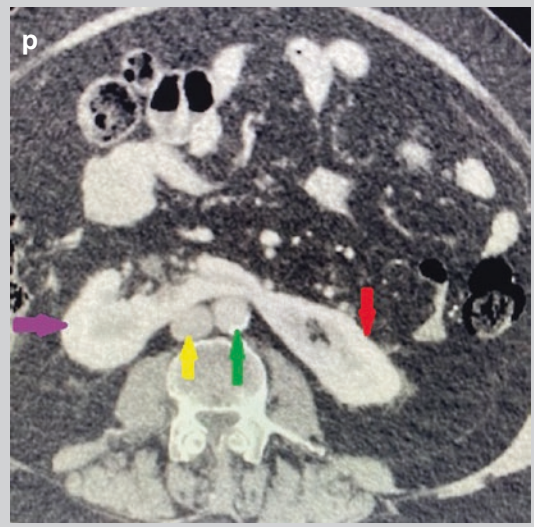
Question 13

Typical kidney appearance in each renal fossa is not seen in Fig. 28.2o. The two kidneys have fused anteriorly (red arrow). Green arrow = IVC. Red circle = aorta. Orange arrows = psoas muscle. Horseshoe kidney (aka renal fusion). E 2.



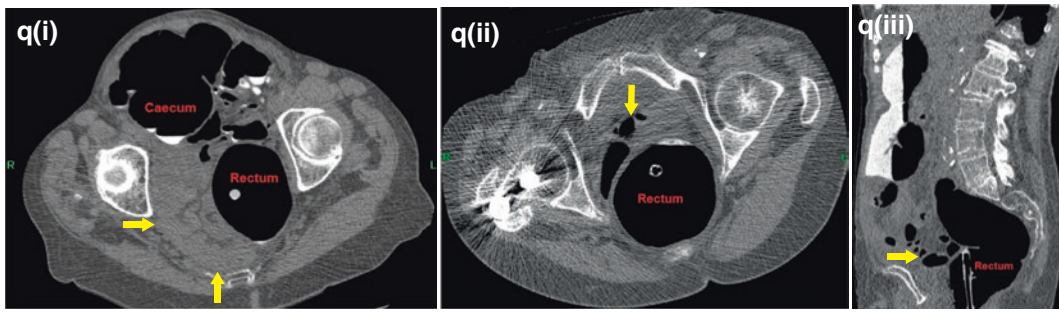
Comment

During foetal development the kidneys rise from the pelvic region and move into their normal position. However, if they become attached during this process they become 'fused' and take on a shape resembling a horseshoe. Figure 28.2p is of a different patient. The shape on each side resembles a kidney joined by a bar of tissue anterior to aorta (green arrow). Yellow arrow = IVC. Red arrow = L kidney. Purple arrow = R kidney.



Question 14

On the 2D axial view (Fig. 28.2q(i)), the rectum is displaced to the left. There is unopacified small bowel (yellow arrows) to the right of the rectum extending to the tip of the sacrum. This is in keeping with an enterocele. The 2D prone axial (Fig. 28.2q(ii) shows the rectum in a more central position. Reduction of enterocele (yellow arrow) anteriorly. There is a streak artefact from a pin in R femoral neck. The 2D sagittal prone view (Fig. 28.2q(iii)) shows rectum in normal position with the small bowel now reduced and lying anteriorly (yellow arrow) to the rectum. E2 classification.

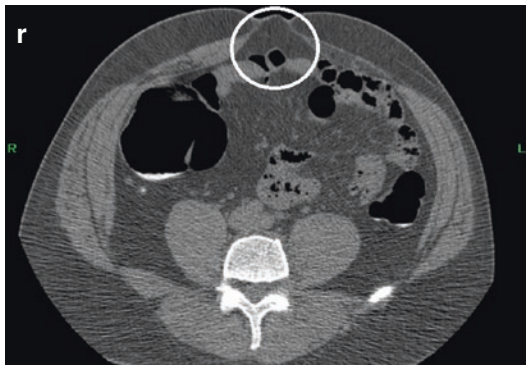


Comment

Streak artefacts are discussed in 12.2.9 in Chap. 12. An enterocele is uncommon in males. It is a prolapse of small bowel which descends into the lower part of the pelvic cavity and displaces the rectum usually to the left. In a sagittal view, loops of small bowel may be seen between the rectum and the sacrum. It is caused by weakness of the muscles and ligaments of the pelvic floor. It may occur after pregnancy and childbirth and is more common in women who have had a previous hysterectomy.

Question 15

White circle in Fig. 28.2r indicates umbilical hernia not containing colon. E2.

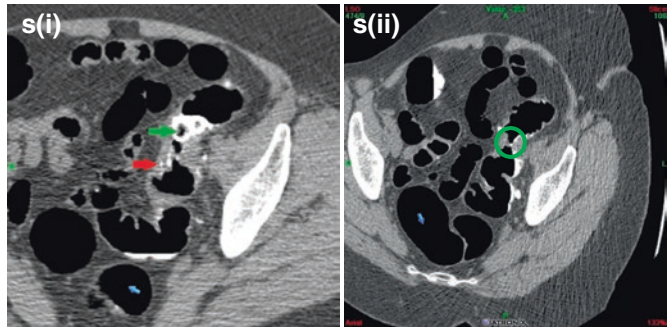


Comment

An umbilical hernia may be congenital or acquired. Causes of the hernia in adults include obesity, lifting or moving heavy objects, and a persistent heavy cough.

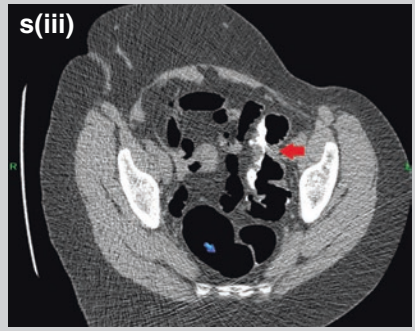
Question 16

Supine axial 2D view of sigmoid colon (Fig. 28.2s(i)) showing marked thickening of the wall of the colon (red arrow). Compare it to the image more posteriorly containing a blue arrow which shows how thin the wall is in normal bowel. Narrowing of the lumen is also present. Green arrow = air in stool. The left lateral decubitus view (Fig. 28.2s(ii)) shows bowel wall thickening as well as narrowing in keeping with a stricture (green circle).



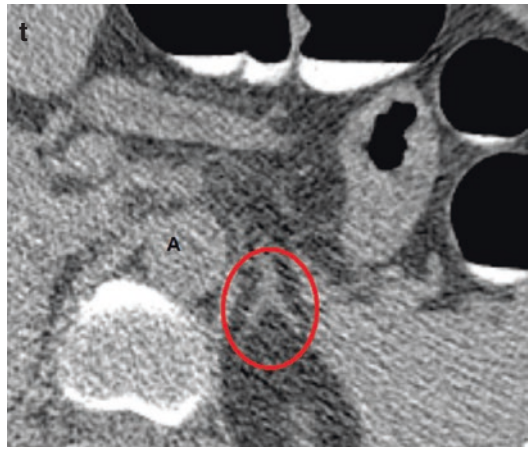
Comment

Diverticular disease is presented in detail in Chap. 16. The value of a right lateral decubitus to resolve image interpretation issues is highlighted. In this case, the right lateral decubitus (Fig. 28.2s(iii)) confirms the stricture in the sigmoid colon (red arrow).



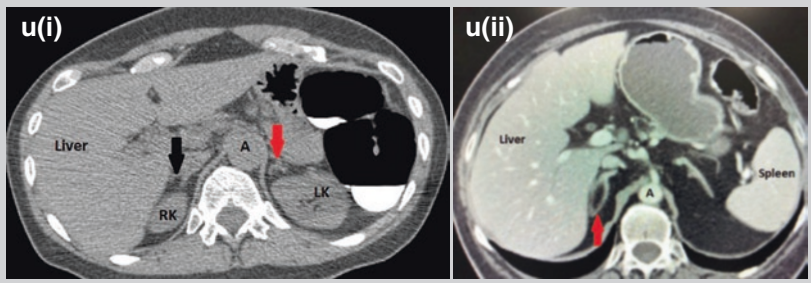
Question 17

Figure 28.2t shows a normal left adrenal gland (red circle). It has a lambda shape and two limbs. A = aorta. E1.



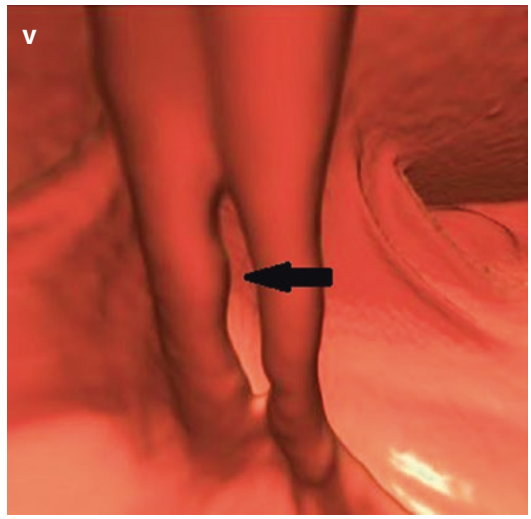
Comment

Knowledge of the structures in the perinephric space is important. Always check the appearance of each adrenal gland for possible pathologies. Figure 28.2u(i) shows the normal position of the adrenal glands situated on top of each kidney. RK = right kidney. Black arrow = right adrenal. LK = left kidney. Red arrow = left adrenal. A = aorta. Figure 28.2u(ii) is an enhanced scan demonstrating the right adrenal. It is an inverted y-shape with two limbs (red arrow). A = aorta.



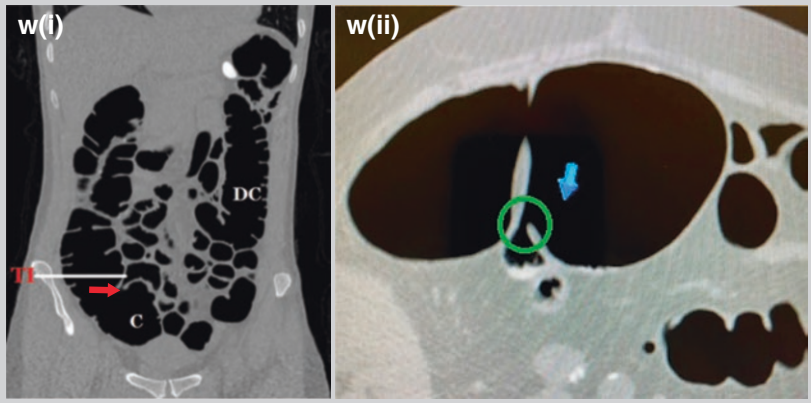
Question 18

Patent ileocaecal valve (black arrow) visualised on Fig. 28.2v.



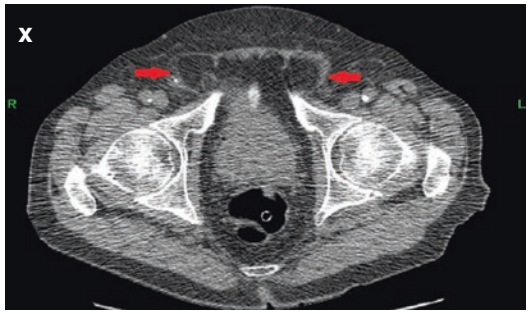
Comment

An open (patent) ICV may result in reflux of carbon dioxide. The 2D coronal view (Fig. 28.2w(i)) shows the terminal ileum (TI), caecum (C), and open ICV (red arrow), descending colon (DC), and Fig. 28.2w(ii) is a 2D supine axial view showing patent ICV (green circle). Examples of reflux are presented in Chap. 10: Fig. 10.2f; Fig. 10.2g(i, ii). The position of an ICV is constant relative to the terminal ileum and caecum (see Fig. 11.9b and Fig. 11.9c(ii, iii). Its various appearances are presented in 11.3.8 in Chap. 11.



Question 19

Figure 28.2x shows bilateral inguinal hernias (red arrows). Neither contain small or large bowel. E2.

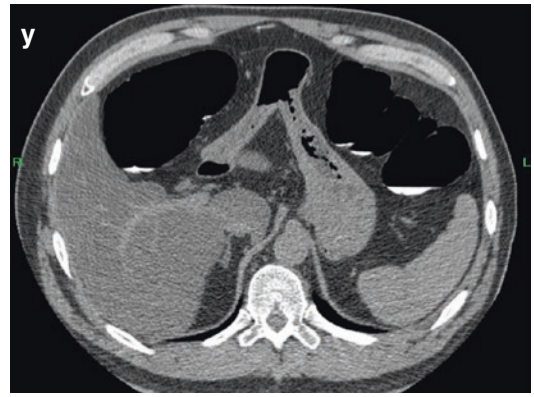


Comment

The different types of abdominal hernias as well as complications are presented 18.8 in Chap. 18.

Question 20

Figure 28.2y shows the liver density is much darker compared to that of the spleen. This indicates fatty liver. E3.



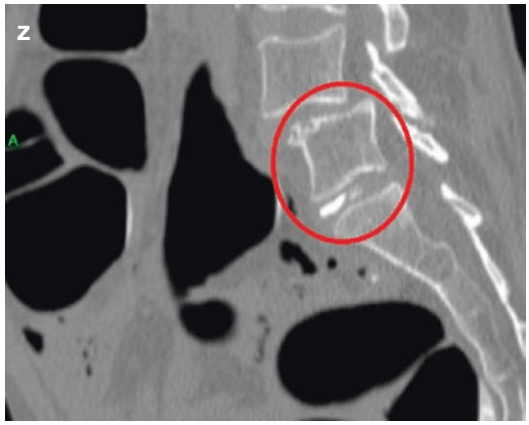
Comment

It is important when you see that the liver density is darker than that of the spleen to ask the patient about their alcohol consumption. As discussed in Chap. 19, there has been a 25% increase in the global prevalence of metabolic-associated fatty liver disease/non-alcoholic fatty liver disease. Until recently, fatty liver was considered a common finding with potential risks. It is now considered to be of clinical importance hence opportunistic screening should be routinely performed at CTC by comparing the respective CT attenuation values (Hounsfield units/HU) of the liver and spleen.

As stated in Chap. 21, a CTC report must include metabolic-associated fatty liver disease, if applicable, and the HU value. Normal HU of liver is 60 HU. Do not call fatty infiltration of the liver until the HU is between 45 and 50 HU. This will equate on MRI to approximately 15% fatty infiltration. If increased >75 HU, think of iron overload.

Question 21

Figure 28.2z shows spondylolisthesis of L4 on L5 (red circle). A possible defect through the pars interarticularis is not demonstrated at this particular level. Slight disc space narrowing is present between L4 and L5, and there is a calcified intervertebral disc between L5 and S1. E2.

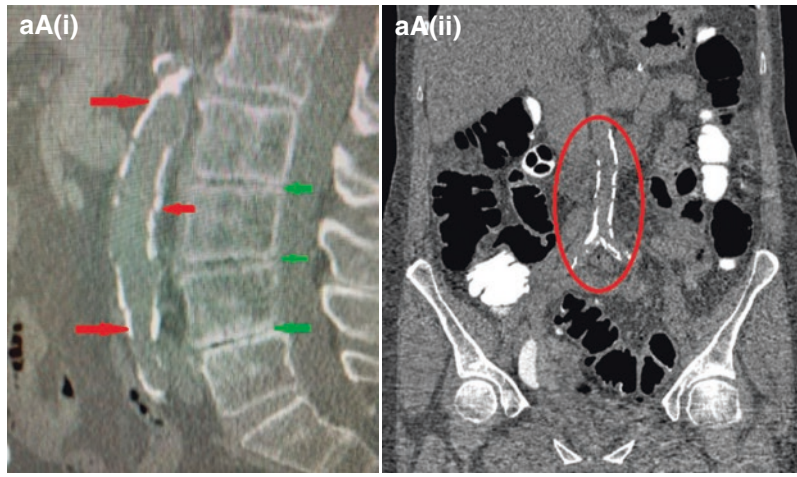


Comment

Types of spondylolisthesis include: congenital spondylolisthesis; isthmic spondylolisthesis due to spondylolysis; and degenerative spondylolisthesis. The latter is the most common type. There are two grades of spondylolisthesis: low grade (Grade 1 and 11) is usually cases of the degenerative type; and high grade (Grade 111 and IV) may require surgery. Figure 28.2z is Grade 1.

Question 22

Figure 28.2aA(i) is a lateral 2D image showing fairly extensive abdominal aortic calcification (red arrows) without aneurysm formation. Extensive disc degenerative disease is seen in the lumbar spine (green arrows). Figure 28.2aA(ii) is a coronal view of another patient showing extensive calcification of abdominal aorta (red oval) and proximal iliac arteries as well as residual barium or omnipaque in the colon. Both are E2 classification.

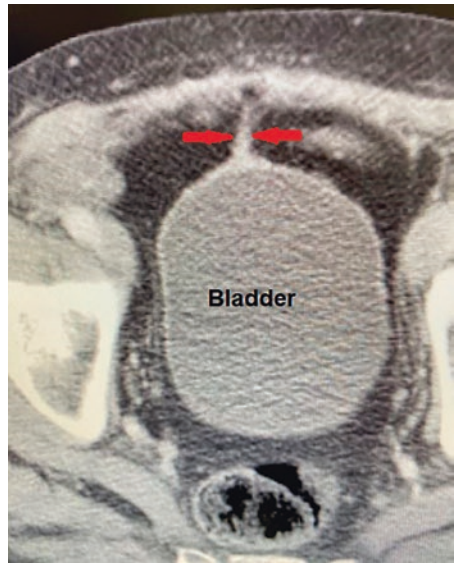


Comment

Aortic abdominal calcification as an ECF is discussed in 18.7 of Chap. 18.

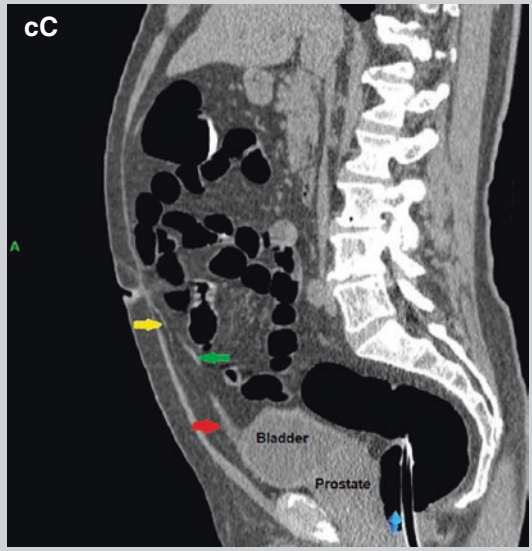
Question 23

Figure 28.2bB is a 2D supine view of the pelvis showing a linear cord-like structure passing from the anterior aspect of the bladder to the region of the umbilicus (red arrows) in keeping with an urachus. E2.



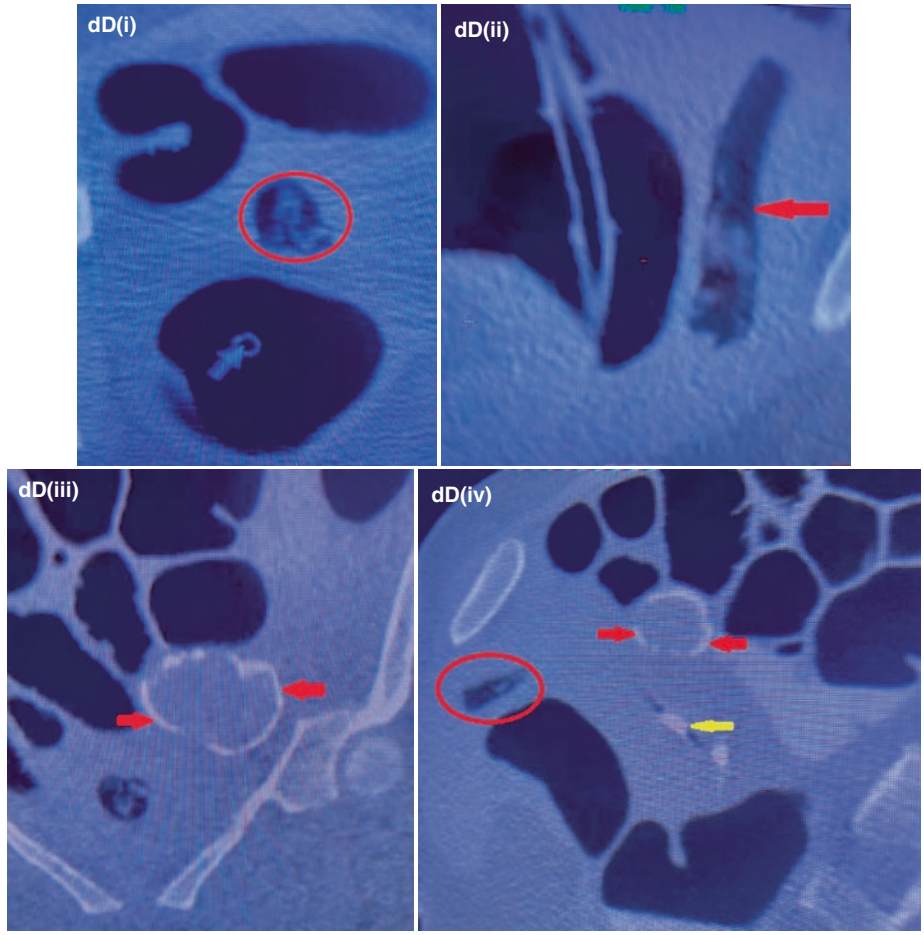
Comment

During foetal development, there is a channel between the bladder and umbilicus through which urine drains in the foetus during the first trimester of gestation. At about 12 weeks, the remnant channel (i.e., urachus) seals off and obliterates. A small fibrous cord remains between the bladder and umbilicus and is known as the median umbilical ligament. At birth, the lumen usually involutes. If this does not happen then urachal remnants may persist. For example, a patent urachus; urachal cyst; urachal-umbilical sinus; and vesicourachal diverticulum. A urachal remnant may transform into an adenocarcinoma. Figure 28.2cC is of another patient showing enlarged prostate. A cord-like structure (red, green, yellow arrows) passes cranially from the anterior aspect of the bladder towards the umbilicus in keeping with an urachus. E2.



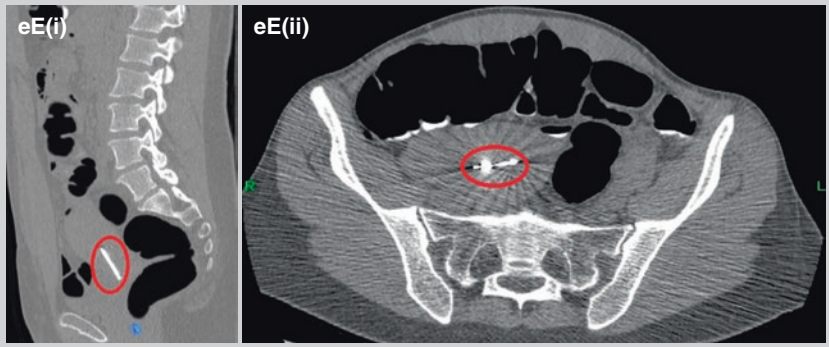
Question 24

Figure 28.2dD(i) shows a tampon in the vagina (red circle). Figure 28.2dD(ii) shows a tampon (red arrow). Figure 28.2dD(iii) shows a calcified fibroid (red arrows). Figure 28.2dD(iv) shows a tampon in the vagina (red circle); calcified fibroid (red arrows) and an intrauterine contraception device (yellow arrow). E2.



Comment

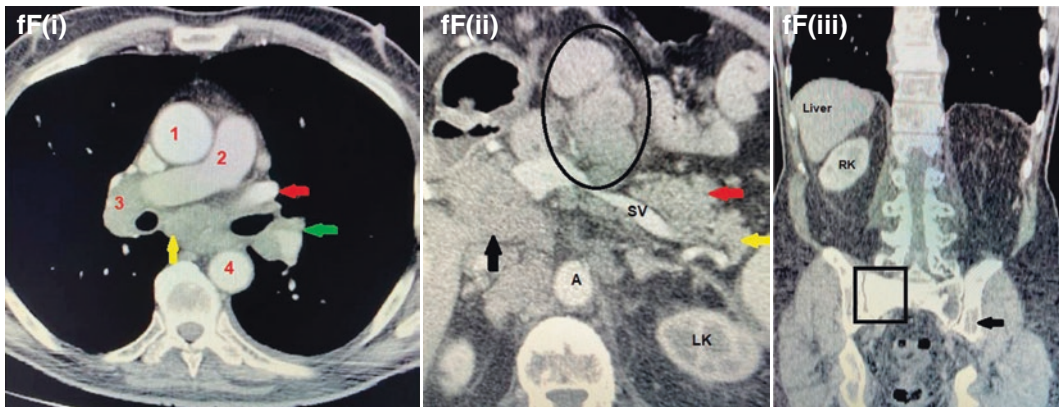
Examples of vaginal tampons are presented in Chap. 12 Sect. 12.2.12. Supine sagittal view (Fig. 28.2eE(i)) is of another case and shows a metallic intrauterine device (IUCD) (red circle) and Fig. 28.2eE(ii) shows streak artefacts due to the IUCD (red circle).



Question 25

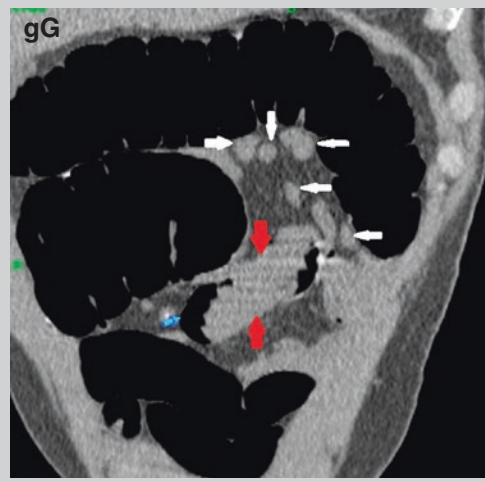
Figure 28.2fF(i) Axial view showing: aorta (1), pulmonary artery (2), low density area in keeping with an enlarged right hilar node (3), descending aorta (4), left pulmonary vein (red arrow), enlarged lymph node with overlying vessel (green arrow), and enlarged carinal node (yellow arrow). Enlarged mediastinal lymph nodes: E4.

Figure 28.2fF(ii) Black arrow = head of pancreas. Red arrow = body of pancreas. Yellow arrow = tail of pancreas. A = aorta. LK = left kidney. SV = splenic vein. Black circle = mesenteric lymph nodes. E4. Figure 28.2fF(iii) Dense sclerosis of the R side of the sacrum in keeping with osteoblastic secondaries (black square). Black arrow indicates a lytic lesion just above the L acetabulum. E4.



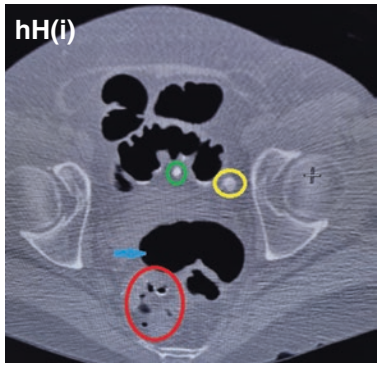
Comment

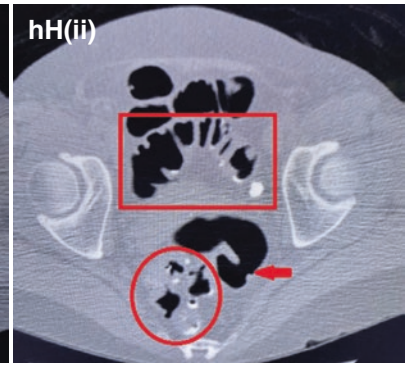
As discussed in Chap. 15 grading of colorectal cancer is important in terms of tumour, node, and metastases(TNM classification). It is important to check for lymph nodes when reading a CTC study because lymph node metastasis (LNM) affects prognosis. The patient in question 25 had prostate cancer. Widespread lymphadenopathy was visualised on the enhanced CT images. Figure 28.2gG is an example of screening CTC showing lymphadenopathy (white arrows). Red arrows show a large ileal carcinoid (see also Fig. 15.1(e)).

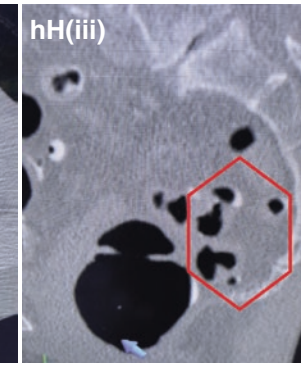


Question 26

Figure 28.2hH(i) 2D axial view shows rectum (blue arrow), loop of sigmoid colon containing diverticula posterior to the rectum (red circle), and diverticula (green and yellow circles). Figure 28.2hH(ii) 2D axial view showing rectum (red arrow), loop of sigmoid colon containing diverticula behind the rectum and displacing it (red circle), and loop of sigmoid anterior to rectum (red rectangle). Figure 28.2hH(iii) is a supine sagittal view showing rectum (blue arrow) and sigmoid colon containing diverticula in the pre-rectal space displacing rectum anteriorly (red hexagon). E2.

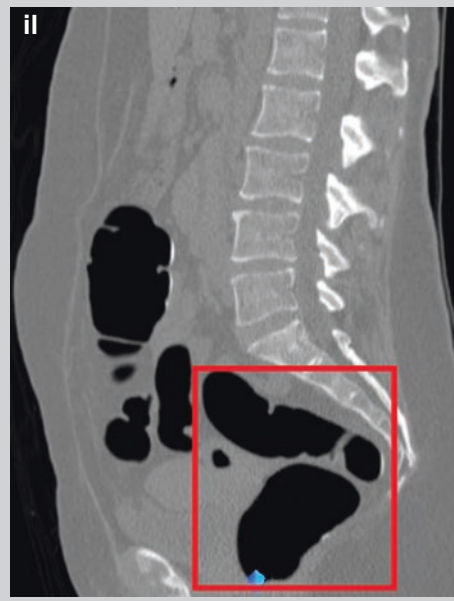




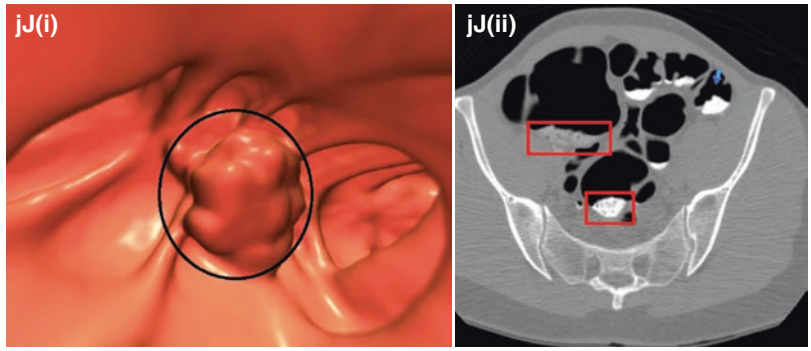


Comment

The rectum as shown in Fig. 28.2il normally lies against the anterior margin of the sacral curve (red square).



Question 27
Lobulated polypoidal lesion (black circle) noted on the 3D image (Fig. 28.2jJ(i)). Excessive stool (red rectangles) noted on the 2D images (Fig. 28.2jJ(ii)). The patient must be rebooked due to poor bowel preparation.



Comment
If a study is non-diagnostic due to poor quality, it is still essential to report on extracolonic findings (ECFs).

Question 28
An anal papilla is an internal skin tag in the anus. It is caused by chronic irritation or anal fissuring.

Comment
There are two kinds of anal papillae: a skin tag with a wide base and triangular shape (see Fig. 13.4) or one with a narrow foot and spherical shape. An anal papilla is usually firm on digital examination compared to a polyp which is usually soft. An anal papilla is also called anal fibroma.

Question 29
A clinical audit should be done to address a problem of poor patient preparation.

Comment
Clinical audit principles are discussed in Chap. 27.

Question 30
The appearance of a lipoma at CT is uniform. It has a fat equivalent density range between −80 and −120 HU.

Comment
A sessile or pedunculated lipoma is the most of the non-epithelial tumours of the GIT. Lipomas are more common in females compared to men. As shown in Table 17.1 in Chap. 17, most are in the right colon.

Glossary

Air insufflations Injection of air into the colon

Anaphylactic An acute, potentially life-threatening allergic reaction

Anthropomorphic phantom A phantom constructed from tissue-equivalent materials having the form and characteristics of a human being

Autonomous To have the freedom to act independently

Barotrauma Injury caused to a part of the body as a result of a change in air pressure

Cathartic Is a purgative drug in the context of CTC as it is used within the text

Confidentiality Not discussing or sharing information about people without their knowledge

Desmoid tumour Is a benign soft tissue tumour that arises from connective tissue

Dyadic An interaction involving a group of two elements, parts or persons

Electrocautery Cautery using an instrument heated by electricity

Extracolonic Situated outside the colon

Extraperitoneal The portion of the abdomen and pelvis which does not lie within the peritoneum

Flatus Gas produced in and expelled from the digestive tract

Herniation Abnormal protrusion of an organ or body structure through a defective or natural opening in the surrounding wall or covering of that area

Hypertonic A solution that has a higher salt concentration than normal body cells resulting in an increase in osmotic pressure

Inflammatory bowel disease A term used to describe conditions that cause chronic inflammation in the intestines

Intracolonic Situated within the colon

Intraperitoneal Within or administered through the peritoneum

Intussusception Is a condition whereby a portion of the intestine invaginates into another portion of the intestine

Melaena The passage of stools which contain decomposing blood giving it a black, tarry appearance

Morphology Having a particular shape, form, or structure

Myasthaenia gravis Is a chronic autoimmune neuromuscular disease which results in muscular weakness

Myochosis Pathological change where muscular thickening of the bowel wall occurs accompanied by a decrease in the width of the taenia coli sometimes seen in patients with diverticular disease

Negligence Failure to discharge one's responsibilities whereby the conduct of the person falls below the expected standards of behaviour

Pancultural Relates to all cultures regardless of race or religion

Pedunculated polyp A mushroom shaped polyp that is attached to the wall of the colon by a thin, long stalk

Perforation A perforation in the colon refers to a tear or hole that develops through the wall of the colon

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Pneumatosis coli The presence of gas within the bowel wall

Pneumomediastinum The presence of air within the mediastinum

Pneumopericardium The presence of air or other gas within the pericardial cavity surrounding the heart

Polyp (colon) Is an abnormal growth of tissue from a mucous membrane and is found on the inner lining of the colon

Polypectomy The removal of a polyp

Prejudicial Relates to bias and prejudice with the intent to cause harm

Serrated polyp A polyp which has an irregular surface with indistinct edges resembling a 'sawtooth'

Sessile polyp A polyp that grows flat against the wall of the colon and doesn't not consist of a stalk

Sigmoidoscopy An examination of the distal portion of the colon (the sigmoid) using a thin, flexible tube

Tagging A means of marking faecal and fluid residue in the colon by the use of oral contrast medium, e.g. barium, thereby enabling a differentiation between the residue and the colonic structures

Tracer A substance, e.g. an element or atom that can be used to follow or identify the course of a process

Topogram Also called a 'scanogram' or 'scout view', e.g. as used in computed tomography

Tort Means a civil wrong and includes negligence, battery, and assault among others

Triadic Refers to a group of three similar or closely related bodies, e.g. persons, units, or items

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