Joel H. Bortz
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CT Colonography for Radiographers

A Guide to Performance and Image Interpretation

Foreword by David Burling

Springer

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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 wife, 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 contribute to this book, written by highly experienced radiographers and radiologists, keen to pass on their knowledge and skills to others who would like to perform and interpret CT colonography examinations.

CT colonography has come of age and in many centres complements conventional colonoscopy as a first-line investigation for symptoms suggestive of bowel cancer or for bowel cancer screening. Consistent, accurate CT colonography interpretation demands excellent quality examination technique and patient co-operation. This book informs the reader on how best to prepare a patient for CT colonography and then how to undertake an efficient examination whereby colonic distension and patient experience are optimised, ensuring a high quality, safe technique.

Radiographers are well placed to lead the CT colonography service, particularly in high volume centres where dedicated teams support routine CT colonography lists each day. In this environment, experienced radiographers carefully co-ordinate the entire patient pathway from request form vetting and appointment scheduling through to delivery of high quality examinations and analysis of routine audit data. This book deals with each of the pathway steps in a logical sequence which is easy to follow.

CT colonography interpretation has been undertaken almost exclusively by radiologists since its introduction, with the knowledge and skills aligned to radiology training. However, rapid analysis of CT colonography images by radiographers at the time of examination has become routine in many centres: identifying cancer and facilitating same visit CT staging and endoscopy. It would seem a natural evolution for a subset of dedicated and talented radiographers to hone these skills further and contribute their interpretation more formally to the final report. This book provides guidance on interpretation which will no doubt encourage radiographers to explore this role further.

Whilst the primary target readership for this book are radiographers, its content will also appeal to radiologists and radiology trainees who are learning CT colonography and will likely share leadership of CT colonography services in the future.

Finally, I would like to congratulate the contributing authors and editorial team for providing this valuable addition to the CT colonography literature.

Harrow, UK — David Burling

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.

There are currently no textbooks on CTC performance and image interpretation aimed at supporting radiographers in this extended role, and this text fills the gap in this market. The aim of this text therefore is 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.

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 6000 CTC examinations over the past decade. Collectively the authors have put together these chapters, which serve as both a learning package and a toolkit in CTC performance and image interpretation.

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 key teaching points and authors have focused on the essential elements that pertain to CTC. Each chapter includes a list of references which adds to the learning aspects for readers. The text opens with an introduction which sets the scene, for the

chapters to follow, as a guide which meets the needs of radiographers with regard to role extension.

There are two critical components to achieving a successful CTC examination: an adequately prepared bowel and good distension of the colon with carbon dioxide (CO2). Patients must therefore fully understand their responsibilities for bowel preparation. This requires that oral and written instructions are clear 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 the CTC examination.

It is the responsibility of the radiographer performing CTC examinations to ensure that patients have been provided with the necessary information, including related risks, to enable informed consent to be established. The chapter on informed consent discusses duty of care and the role and responsibilities of the radiographer in the information-giving and consent-gaining process.

A chapter on the principles of computed tomography and types of scanners is included for knowledge and understanding of the technology behind the face of computed tomography imaging. Student radiographers would study this subject as part of their undergraduate course of study and may be familiar with the concepts discussed. Radiographers with years of experience would be gently reminded about the science behind the technology. Keeping radiation dose as low as reasonably achievable (ALARA) forms the basis of radiographic practice, and it is therefore essential for radiographers to be mindful of the application of the three principles of the International Commission on Radiological Protection (ICRP), viz, justification, optimisation and dose limitation, as well as be cognisant with the latest publications of the International Atomic Energy Agency (IAEA), among others. Chapter 5 introduces the concepts of effective dose and dose reference levels in computed tomography imaging, and Chapter 6 describes various options for dose optimisation in CTC.

Evidence-based practice requires that any new technique introduced into clinical practice be audited and reviewed leading to the development of guidelines for future implementation. Chapter 7 reviews the development of CTC as a diagnostic tool, evaluates current guidance and discusses the future of CTC. As CTC is an interventional 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 Chapter 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 pitfalls and artefacts are discussed in Chapter 12.

An extensive range of images demonstrating pathologies can be seen in Chapters 13, 14, 15, 16, 17 and 18 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; lipomas and extracolonic findings.

Chapter 19 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. Chapter 20 evaluates the role of ultrasound, magnetic resonance imaging and positron emission tomography in the management of colorectal pathology.

Chapter 21 explores the responsibility and accountability of the radiographer within a practice framework and the possible consequences of failing to provide a duty of care, and practice, at the required standard.

In keeping with the ethos of learning and applying knowledge and understanding of the information presented within the text, Chapter 22 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 text a helpful and useful resource in your learning and practice.

Los Angeles, CA, USA — Joel H. Bortz
Hertfordshire, UK — Aarthi Ramlaul
Durban, South Africa — Leonie Munro
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Abbreviations

2D	2-Dimensional
3D	3-Dimensional
AAA	Abdominal aortic aneurysm
AC	Adaptive child
ACG	American College of Gastroenterologists
AGA	American Gastroenterological Association
AIDR	Adaptive iterative dose reconstruction
ALARA	As low as reasonably achievable
Apps	Applications (software)
ASIR	Adaptive statistical iterative reconstruction
BE	Barium enema
BI-RADS	Breast imaging reporting and data system
BLMRC	Bright lumen magnetic resonance colonography
BSGAR	British Society of Gastrointestinal and Abdominal Radiology
CAD	Computer-aided diagnosis
CCE	Colon capsule endoscopy
CEA	Carcinoembryonic antigen
ceCT	Contrast-enhanced computed tomography
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
DCBE	Double contrast barium enema
DLMRC	Dark lumen magnetic resonance colonography
DLP	Dose-length-product
DNA	Deoxyribonucleic acid
DVD	Digital versatile disc
EBCT	Electron beam computerized tomography
ECF	Extracolonic findings
eGFR	Estimated glomerular filtration rate
ESGAR	The European Society of Gastrointestinal and Abdominal Radiology

ESGE	Society of Gastrointestinal Endoscopy
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
gFOBt	Guaiac faecal occult blood test
GIT	Gastrointestinal tract
GRE	Gradient echo
HASTE	Half-Fourier acquisition single-shot turbo spin-echo
HCPC	Health and Care Professions Council
HU	Hounsfield units
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
ICV	Ileocaecal valve
i.v.	Intravenous
IVC	Inferior vena cava
keV	Kiloelectronvolts
L	Level (window)
LLD	Left lateral decubitus
MDCT	Multi-detector computed tomography
MinIP	Minimum intensity projection
MIP	Maximum intensity projection
MPR	Multiplanar reformations/reconstructions
MRC	Magnetic resonance colonography
MRF	Mesorectal fascia
MRI	Magnetic resonance imaging
MSAD	Multiple scan average dose
MSI	Microsatellite instability
NHS	National Health Service
NHSBCSP	National Health Service Bowel Cancer Screening Programme
NICE	National Institute for Health and Clinical Excellence
NP	Nurturing parent
NPSA	National Patient Safety Agency
NSF	Nephrogenic systemic fibrosis
PACS	Picture archiving and communication system
PET	Positron emission tomography
PGD	Patient Group Directive
PPV	Positive predictive value
pVR	Perspective volume rendering
QA	Quality assurance
RCR	Royal College of Radiologists
RLD	Right lateral decubitus

SAFIRE	Sinogram-affirmed iterative reconstruction
SoR	Society of Radiographers
SSCT	Single-slice computed tomography
SSP	Sessile serrated polyp
TA	Transactional analysis
TD	Translucent display
TNM	Tumour node metastases
TRUS	Transrectal ultrasound
UICC	Union for International Cancer Control
US	Ultrasound
USA	United States of America
VC	Virtual colonoscopy
W	Width (window)
WHO	World Health Organization

Introduction

1

Joel H. Bortz

Abstract

The aim of this book is to provide a guide which addresses the needs of radiographers. Computed tomographic colonography (CTC) books are aimed at radiologists. There are none specifically for radiographers and students. 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. CTC is a minimally invasive, fast, safe and accurate screening examination for colorectal cancer screening. It also allows evaluation of structures outside the colon. When compared with optical colonoscopy the risk of perforation at CTC is virtually zero. Screening CTC versus optical colonoscopy is discussed. Some associated risks of optical colonoscopy are discussed. Imaging examples of perforations due to colonoscopy are presented. This introductory chapter serves as a link to the other chapters in this guide.

There were several reasons that led to writing this guide for radiographers on computed tomographic colonography (CTC) performance and image interpretation. Over the past decade, various studies were undertaken to evaluate radiographers' competencies in interpreting CTC images [1–4]. 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 [5], stated that barium enema should be replaced by CTC as the imaging modality of choice for patients with suspected colorectal cancer. According to them, the number of CTC examinations has increased, which has added to an already heavy-laden radiology workload. Hence in many United Kingdom 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. In view of these respective publications, we realised that CTC books are aimed at radiologists and that there are none specifically for radiographers and students. Our aim is to provide a guide which addresses the needs of radiographers in terms of role extension. The basics of CTC are addressed together with images: a range of normal images of

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the colon and images of the most common pathology seen at CTC.

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 [6]. 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 optical colonoscopy (OC). The 2003 groundbreaking publication by Pickhardt et al. [7] resulted in CTC being brought into mainstream colorectal cancer (CRC) screening [8].

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 [9]. Tagging of fluid is accomplished by using 60 mL diatrizoate meglumine (Gastrografin), which tags residual fluid white. This allows for easier observation of any submerged lesions. The use of automated pressure-controlled carbon dioxide (CO_2) 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 [10, 11]. Carbon dioxide 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 [12].

CRC is a leading cause of death worldwide. According to the World Health Organisation, CRC was the fifth most common site of cancer in both men and women in 2012 [13]. An estimated 93,090 cases of colon cancer and 39,610 cases of rectal cancer are expected to be diagnosed in 2015. The latest CRC statistics for new cases in the United States of America (USA) is expected to decrease to 136,830 from the previous estimate of more than 143,000 cases in 2012 [14–16]. The number of deaths in 2015 is expected to decrease to 49,700 from the previous figure of more than 50,000 deaths per year [14–17]. There has been a gradual decline in the incidence of cancer as well as the number of deaths in the United States. These declines have been attributed to CRC screening and removal of potentially harmful polyps [17].

When a new screening test is assessed, the following criteria are used: diagnostic performance, procedural risk, patient acceptability, and cost-effectiveness. Optical colonoscopy (OC) has for many years been considered the gold standard in CRC screening. Recent publications have cast doubt on this statement [18, 19]. For CTC an argument can be made that in terms of these criteria it meets or exceeds OC as a CRC screening test [19]. 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 [19]. The high specificity of CTC has resulted in a high positive predictive value (PPV) [20]. Advanced neoplasia yield is equivalent to primary OC even though less than 10 % of cases are referred to polypectomy [21]. CTC is effective for the diagnosis of relevant flat lesions [22].

Optical colonoscopy 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 [23]. 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 [24]. 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. Figures 1.1a, b are of an OC-related complication.

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 [25]. Perforation of the colon may be intraperitoneal and/or extraperitoneal. Perforation is most common in the sigmoid colon due to acute angulation at the rectosigmoid junction. Figures 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 [26, 27].

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 [27]. Polypectomy may cause haemorrhage in 2.7 % of patients [28]. Bleeding may result from a haematoma in the wall of the colon or haemorrhage into the lumen of the colon.

Polypectomy syndromes may be subdivided into the postpolypectomy distension syndrome and the 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 [29]. This syndrome is only seen in 1 % of cases. Patients develop severe abdominal pain with peritoneal signs and fever, usually 1–5 days after the procedure. Abdominal radiographs are usually negative. This 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 [30] and is probably a lot more common than has been reported [31]. 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 (i.v.) benzodiazepine (midazolam) and an intravenous (i.v.) narcotic

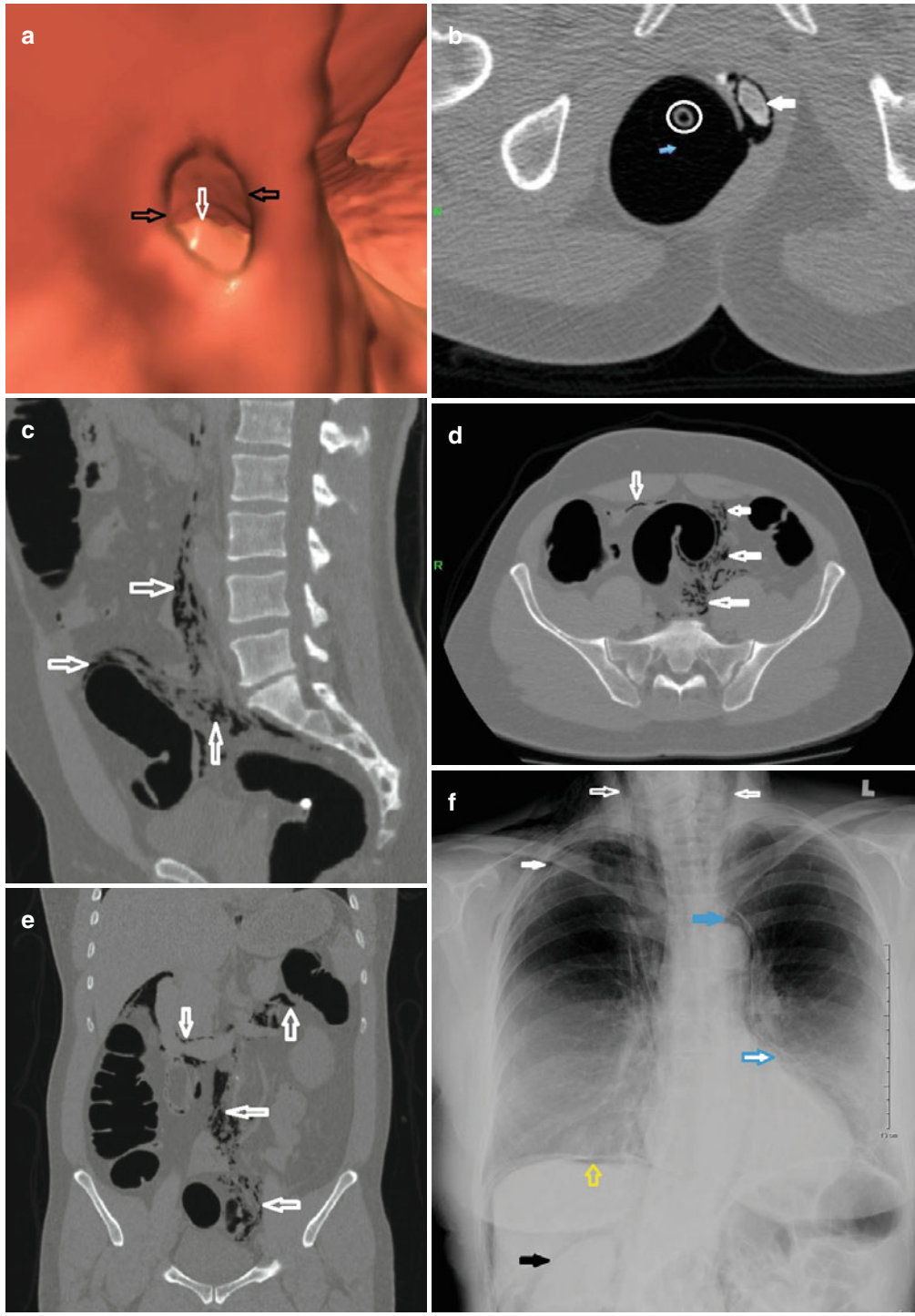

Fig. 1.1 (**a**) 3D view of contained perforation of the rectum (*open black arrows*). Calcified enterolith (*open white arrow*). (**b**) 2D axial view shows contained perforation and calcified faecalith (*white arrow*) and rectal catheter (*white circle*). (**c**–**e**) Unsuspected colonic perforation at incomplete optical colonoscopy diagnosed at same-day diagnostic CTC. Extraluminal gas (*open white arrows*) 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 the 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*), and air around the right kidney (*closed black arrow*)

pain medication (fentanyl) may depress cardiopulmonary movement. Of fairly recent origin is the transmission of infection via incompletely sterilised colonoscopes. Incomplete cleaning and sterilisation of the colonoscope may cause infections, such as hepatitis B and C and HIV [32, 33].

CTC is a minimally invasive, fast, safe, and accurate screening examination for CRC [34]. 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 small 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 are factored in [35]. A paper published in September 2015 underscores that CTC is a cost-effective screening test for CRC compared to OC [36]. According to Pyenson et al. [36], CTC was 29 % less expensive than OC for the Medicare population in the United States in terms of screening for CRC. Another important point pertains to the maximum age for screening. There is general consensus that CRC screening should commence at age 50 years. However, the American College of Gastroenterologists (ACG) recommends screening should commence at age 45 years for African Americans. At what age should CRC screening stop? Pyenson et al. [36] set the start age of CRC screening at 50 years and the stop age at 85 years. The US Preventive Services Task Force recommends screening should be done until the age of 74 years. The American Gastroenterological Association (AGA) and the ACG are silent in terms of maximum screening age, and Medicare sets no upper age limits [37]. 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' [38].

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, extracolonic findings, 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, 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 intravenous contrast media, is discussed in terms of preoperative evaluation of CRC, as well as for tumour, node, and metastases (TNM) staging.

Some readers may question the need for CTC because the barium enema is still performed in a few countries for investigation of colon pathology. 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 fibre-optic colonoscopy had gained ground [39, 40]. The literature on this topic shows that BE could not match the sensitivity of colonoscopy for detection of polyps. Two hundred and seventy-six 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 [41]. 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 the diagnosis of polyps and CRC, the findings were that CTC detected more polyps and cancer than DCBE [42]. 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 [42, 43], 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 [5]. The performance of DCBE is inadequate for the exclusion of CRC. As such it should now be abandoned as a first-line test in patients at risk of CRC: its place to be taken by CTC [44]. In addition, the radiation dose of DCBE is almost double than that of CTC [45].

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 pertinent medicolegal 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. Bodily KD, Fletcher JG, Engelby T, et al. Nonradiologists as second readers 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 Am J Roentgenol. 2007;188(3): W249–55.
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. 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. [cited 2015 August 23]. Available from www.rcr.ac.uk.
6. Vining DJ. Virtual colonoscopy: a storm is brewing. Appl Radiol. 2008;37(11):12–6.
7. 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. http://dx.doi.org/10.1056/NEJMoa031618.
8. ACR practice guidelines for the performance of computed tomography (CT) colonography in adults [cited 2015 August 30]. Available from www.acr.org.
9. 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. http://dx.doi.org/10.1007/s00330-014-3095-z.
10. 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. http://dx.doi.org/10.2214/ajr.04.1506.
11. 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. http://dx.doi.org/10.2214/ajr.05.0416.
12. 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. http://dx.doi.org/10.1148/radiol.2272020293.
13. WHO. Cancer key facts. [cited 2015 June 25]. Available from: http://www.who.int/mediacentre/factsheets/fs297/en/.
14. American Cancer Society. Cancer facts and figures 2015. [cited 2015 June 25]. Available from: http://www.cancer.org/cancer/colonandrectumcancer/detailedguide/colorectal-cancer-key-statistics.
15. 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. http://dx.doi.org/10.7150/jca.5858.
16. Siegel R, Naishadham D, Jemal A. Cancer statistics, 2012. CA Cancer J Clin. 2012;62(1):10–29. http://dx.doi.org/10.3322/caac.20138.
17. Johnson DA. Landmark developments in gastroenterology. Medscape June 19, 2015. [cited 2015 June 25]. Available from: http://www.medscape.com.
18. Atkin W, Dadswell E, Wooldrage K, 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.

19. Pickhardt PJ, Hassan C, Halligan S, et al. Colorectal cancer: CT colonography and colonoscopy for detection – systematic review and meta-analysis. Radiology. 2011;259(2):393–405.
20. Pickhardt PJ, Wise S, Kim DH. Positive predictive value for polyp detected at screening CT colonography. Eur Radiol. 2010;20:1651–6.
21. 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.
22. 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.
23. 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(6):1670–7.
24. Waye JD, Lewis BS, Yessayan S. Optical colonoscopy: a prospective report of complications. J Clin Gastroenterol. 1992;15(4):347–51.
25. Han SY, Tishler JM. Perforation of the colon above the peritoneal reflection during the barium enema examination. Radiology. 1982;144(2):253–5.
26. Kim DH, Park S, Pickhardt JP, et al. Imaging evaluation of complications at optical colonoscopy. Curr Probl Diagn Radiol. 2008;37(4):165–77.
27. Daly B, Lu M, Pickhardt JP, et al. Complications of optical colonoscopy: CT findings. Radiol Clin North Am. 2014;52(5):1087–99.
28. 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(2):132–41.
29. Waye JD, Kahn O, Auerbach M. Complications of optical colonoscopy and flexible sigmoidoscopy. Gastrointest Endosc Clin N Am. 1996;6(2):343–77.
30. Fishback SJ, Pickhardt PJ, Bhalla S, et al. Delayed presentation of splenic rupture following optical colonoscopy: clinical and CT findings. Emerg Radiol. 2011;18:539–44.
31. Saad A, Rex D. Optical colonoscopy-induced splenic injury: report of 3 cases and literature review. Dig Dis Sci. 2008;53:892–8.
32. The Farber Law Group. Improper sterilization procedures prompts letters to Vets who underwent colonoscopies; 31 Mar 2009. Available from: http://www.washingtoninjuryattorneyblog.com.
33. Artavia D. Two hundred colonoscopy patients accidentally exposed to HIV, 22 July 2013. Available from: http://www.hivplusmag.com/case-studies/daily-dose/2013/07/22/two-hundred-colonoscopy-patients-accidentally-exposed-hiv.
34. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Rad. 2014;18(1): Art. #607, 11 pages. http://dx.doi/org/10.4102/sajr.v18i1.607.
35. 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(11):2213–21.
36. Pyenson B, Pickhardt PJ, Sawhney TG, Berrios M. Medicare cost of colorectal screening: CT colonography vs. optical colonoscopy. Abdom Imaging. 2015. doi:10.1007/s00261-015-0538-1. Published online 09 September 2015.
37. Medicare.gov. Your Medicare coverage: is my test, item or service covered? Colorectal cancer screenings. 2015. [cited 2015 Oct 1]. Available from: http://www.medicate.gov/coverage/colorectal-cancer-screnningss.html.
38. Pickhardt PJ. CT colonography: does it satisfy the necessary criteria for a colorectal screening test? Expert Rev Gastroenterol Hepatol. 2014;8(3):211–3.
39. Ott DJ, Gelfand DW. The future of barium radiology. Br J Radiol. 1997;70:S171–6.
40. Winawer SJ, Stewart ET, Zauber AG, et al. A comparison of colonoscopy and double-contrast barium enema for surveillance after polypectomy. N Engl J Med. 2000;324(24):1766–72.
41. 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.
42. 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.
43. von 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(10):2046–55.
44. Shariff MK, Sheikh K, Carroll NR, et al. Colorectal cancer detection: time to abandon barium enema. Frontline Gastroenterol. 2011;2:105–9. http://dx.doi.org/10.1136/fg.2010.003616.
45. Hirofuji Y, Aoyama T, Koyama S, Kawaura C, Fujii K. Evaluation of patient dose for barium enema and CT colonography in Japan. Br J Radiol. 2009;82(975):219–27.

Patient-Centered Communication

2

Leonie Munro

Abstract

A successful CT colonography (CTC) procedure is underpinned by effective communication between healthcare practitioners and patients. Communication should be a straightforward process, but language and culture barriers often present challenges. Patient-centered communication is an interactive process in which patients are treated with respect and dignity. Verbal and nonverbal communications are both important when providing patients with information. Suitable communication material, such as brochures, videos, e-communication, and mobile technology, should be used to ensure that patients understand their role and responsibilities in adhering to patient preparation instructions. A CTC procedure is not limited to the study but includes all factors that may impact on a patient's perception of the entire experience, such as seating, wheelchair access, and being treated as a person and not an object. It is the responsibility of health professionals to create a positive communication climate to ensure patient compliance. The overarching aim of patient-centered communication should be to create a positive experience for patients to ensure they would be willing to return for further imaging studies. It is important to speak slowly and to face patients when providing them with information.

2.1 Introduction

There are three stages in CT colonography (CTC). The first pertains to patient preparation; the second focuses on performing the study; and the third covers 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. Informed consent is essential and is covered in Chap. 3. 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

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entails patient-centered communication [4]. which may be defined as ensuring that each CTC patient, regardless of socioeconomic environments, cultures, and other differences including disabilities, is communicated with and not at [4–6].

Communication is interactive; it should not be a top-down model [7]. For example, patients are required to adhere to all steps in patient preparation in the first stage, and they must understand the importance of breath hold and not to move during the second stage of the CTC study. We have to communicate with patients in both of these stages. This seems straight forward, but according to Munn and Jordan [8], radiographers need to appreciate patients may experience high levels of anxiety when undergoing high technology imaging, such as CT examinations. They undertook a systematic review of literature pertaining to patients' perceptions of advanced imaging studies. According to them, negative experiences during previous CT examinations can contribute to patients' apprehension when booked for other imaging studies. They found that in many instances patients were objectified, which in turn resulted in lack of patient-centered communication.

Most patients who undergo CTC examinations are 50 years or older. Some may therefore be hard of hearing or visually impaired, and some may have mobility problems. Each of these presents communication challenges. In the United Kingdom (UK), there are over six million people aged 65 years or older who have hearing loss [9]. In the United States of America (US), approximately one in three people between the ages of 65 and 74 years has loss of hearing [10]. Hearing problems are an important communication challenge when performing a CTC. A patient and CTC radiographer cannot participate in face-to-face communication during scanning. There are over two million people in the United Kingdom who have loss of vision; the majority are 65 years or older [11]. It is important that patients with loss of vision are able to identify all items in the bowel preparation kit, for example. These statistics are important in view of the age of CTC patients, i.e, 50 years or older.

Another barrier that can influence patient perception is seating. 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 [12]. 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.

Another communication challenge is language barriers; 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 [13]. 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 [14]. 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 [15].

It is up to healthcare professionals to use different communication media and materials to ensure patient-centered 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 [8], patient perceptions of imaging procedures may be positive or negative. Anecdotal reports in social media may contribute to patients' perceptions of CTC. 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 but include all factors that may impact on a patient's perception of the entire experience. It is the responsibility of diagnostic imaging healthcare practitioners to create a positive communication climate to ensure patient compliance.

2.2 What Is Communication?

There is no agreed universal definition of communication [4]. It has been defined within specific contexts by some authors [16–18]. Discussions of communication frameworks have been presented in terms of communication interaction, people, and the process itself [4]. According to Weissman [19], 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. [20] 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 (i) to solve health problems and (ii) to create a therapeutic relationship, which is necessary to manage health problems and gain a patient's confidence [21].

Several models are used to describe human communication. The simplest is the Shannon and Weaver model: sender→message→channel→noise→receiver [22]. We need to ensure each patient fully understands what is required to achieve a successful CTC study, which means that all bowel preparation instructions, and diet, are followed. Patients need to fully understand that a clean bowel and well-distended colon are necessary in a CTC study. Patients also 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-centered 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 [23]. 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 [24] 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: The free child (FC) and the adaptive child (AD). How do these ego states apply to interactions with patients? A CP interaction is judgmental, critical, and prejudicial, for example, a type of top-down interaction with patients. A NP is supportive and nurturing. Patients are encouraged during imaging procedures. Adult interactions are reality-orientated, organized, 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 interpersonal competence encompasses informing, explaining, instructing, teaching, and being friendly. Such a scenario bodes well if applied in pre-CTC communication with patients, as well as during the study.

2.3 Verbal and Nonverbal Communication

We use verbal and nonverbal communication [25] 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 requires that the rectum must be emptied of any residual fluid. Therefore, before commencing a CTC study, this must be conveyed to a patient. Would all patients understand what a restroom means if instructed to go there? Restroom is used in America, whereas in South Africa, a patient would be instructed to go to the toilet or lavatory. Language is not always verbal and can be also be sign language or written forms of communication. This is important when dealing with patients who are hard of hearing. At times it may be necessary to use mime to communicate with hard of hearing patients [26]. However, this may not be feasible during CT scanning. Other communication methods are needed for patients who remove hearing aids during scanning [6]. Prior to commencing the CTC procedure, an agreed alternate method needs to be practiced 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 [27]. Meaning in communication is a combination of verbal and nonverbal information. What is important to realize is that gestures may be interpreted differently. According to literature, there is controversy whether some gestures are truly pancultural [28] or cultural specific [25, 29] and also whether gestures, for example, are learned or innate behavior [25]. In complex, adult communication, there is much which remains unknown [4]. This is further complicated by any impairment to normal communication, such as deafness, blindness, or mental incapacity [5, 6]. 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 [30].

When communicating with patients, verbal and nonverbal communications are in play. 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 behavior [31]. 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. The 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 two meters to your right." In patient-centered 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" [6]. The height of a chair should also be considered, as many older people experience difficulties attempting to rise from a soft low seat [12]. We need to ensure that chairs of suitable heights are available for elderly CTC patients.

2.4 Sign, Symbols, and Codes

Although some authors do not make a distinction between the meaning of signs and symbols [32], they are usually taken to mean different things [32, 33]. All communication involves using signs. A sign can be anything: a gesture or punctuation mark, for example. A sign does not have meaning because it stands for something else [32, 34]. Let's consider the color 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 color that indicates when a driver must stop; it could be a figure of speech to indicate being angry. According to Danesi [34], 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 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 colors in the visible spectrum are a result of a social process to distinguish each color. The Peircean model, according to Danesi [34], comprises three relationships: a sign; concepts, things, gestures, etc., which refer to 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 [26, 34]. 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 'red,' then according 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 color in the visible spectrum or a figure of speech to represent anger, or on Valentine's day, it may be used as a symbol for love and romance. For some, red may remind them of bleeding. Signs do not function in a vacuum: they require a system to be encoded and decoded. Communication requires encoding; thus, codes are necessary to create and interpret messages. 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 [35] caution that shared meaning is not guaranteed in communication between people with common backgrounds and cultures. Patient-centered communication needs to be unambiguous [36]. Not all messages are understood by all members of a shared social or cultural group even though they share common backgrounds [35] 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 [34]. 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-centered communication.

We also interpret communication subjectively; we ascribe connotative (subjective) meanings, such as feelings, implications, and associations, to a denotative meaning [34]. Each participant attributes denotative and connotative meanings to messages based on life experiences. Patient-centered communication is a dynamic complex process [4], which must be adapted to meet the needs of each patient. The underlying message is that simple, unambiguous language should underpin patient-centered communication [37].

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

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 [38, 39]. Most people have access to smartphones or tablets; thus, information in a range of software options, such as power point presentations, could be used to explain each step in bowel preparation. Mobile phone messaging reminders could be used especially for hard of hearing patients [40, 41].

2.7 Patient Feedback Regarding CTC Examinations

Studies of CTC versus colonoscopy indicate that patients prefer CTC [42]. Conversely, a study by von Wagner et al [43] focused on patients' expectations and experiences of barium enema, colonoscopy, and CT colonography. Their research tool was a semistructured questionnaire. 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. Based on the results of the study, CTC could benefit from patient-centered communication during and immediately after the study. Similar findings were reported by Plumb et al. [44]. Their recommendations include 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.

2.8 Key Messages

- Patient-centered 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 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.

2.9 Summary

Patient-centered communication should cover risks, benefits, and procedural experiences. Different communication material 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. Effective communications are the core of successful CTC studies.

References

1. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Rad. 2014;18(1):11. Art. #607. http://dx.doi/org/10.4102/sajrv18i1.607.
2. Yee J, Weinstein S, Morgan T, et al. Advances in CT colonography for colorectal cancer screening and diagnosis. J of Cancer. 2013;4(3):200–9. http://dx.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. Henwood SA, Munro L. Principles of communication. In: Ramlaul A, Vosper M, editors. Patient centered care in medical imaging and radiotherapy. London: Churchill Livingstone Elsevier; 2013. p. 3–6.
5. Reeves PJ. Communication with specific patients. In: Ramlaul A, Vosper M, editors. Patient centered care in medical imaging and radiotherapy. London: Churchill Livingstone Elsevier; 2013. p. 7–12.
6. 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 Elsevier; 2013. p. 13–9.
7. Booth L. The radiographer-patient relationship: enhancing understanding using a transactional analysis approach. Radiography. 2008;14(4):323–31.
8. 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.
9. Action of hearing loss. [cited 2015 Aug 6]. Available from: http://www.actiononhearingloss.org.uk/your-hearing/about-deafness-and-hearing-loss/statistics.aspx.
10. Hearing Loss Association of America. Basic facts about hearing loss [cited 2015 Aug 5]. Available from: http://www.hearingloss.org/content/basic-facts-about-hearing-loss.
11. John Gill Technology. Blindness and visual impairment [cited 2015 Aug 30]. Available from: http://www.johngilltech.com/guidelines/visual.htm.
12. Alexander NB, Schultz AB, Warwick DN. Rising form a chair: effects of age and functional ability on performance biomechanics. J Gerontol. 1990;46(3):M91–8.
13. 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.
14. Etheredge H. Rethinking responsibility in radiography: some ethical issues in South Africa. S Afr J Radiol. 2011;15(1):10–3.
15. 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.
16. Mowlana H, Wilson LJ. Communication technology and development. Paris: UNESCO;1988. [cited 2015 Aug]. Available from: http://unesdoc.unesco.org/images/0008/000811/081109eo.pdf.
17. Ruxandra R, Filimon S. Improving communication between doctors and patients. Ann Fac Econ. 2010;1(2):1137–40. [cited 2015 Aug 1]. Available from: http://anale.steconomiceuoradea.ro/volume/2010/n2/182.pdf.
18. 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. doi:10.1016/j.eurpsy.2010.07.010.
19. 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.
20. 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.
21. 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.
22. Shannon C, Weaver W. The mathematical theory of communication. Urbana: University of Illinois Press; 1949.
23. 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.
24. Booth LA, Manning DJ. Observations of radiographer communication: an exploratory study using transactional analysis. Radiography. 2006;12(4):276–82.
25. Uko Iniobong I. Verbal and nonverbal communication. Encycl Arts. 2006;3(1):1–5.
26. Watermeyer J, Penn C. Working across language and culture barriers: communication skills for pharmacists. Johannesburg: University of Witwatersrand; 2009.

27. Nash ES. Medical student training in doctor-patient communication. SAMJ. 1979;56:1118–24. [cited 2015 Aug 3]. Available from: 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.
28. Ekman P, Friesen W. The repertoire of nonverbal behavior: categories, origins, usage, and coding. Semiotica. 1969;1(1):49–98. doi:10.151/semi.1969.1.1.49.
29. Jones SE, LeBaron CD. Research on the relationship between verbal and nonverbal communication: emerging interactions. J Commun. 2002;52(3):499–521. [cited 2015 Aug 5]. 10.111/j.1460-2466.2002.tbo2559.x.
30. 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. doi:10.1111/j.1525-1497.2006.00340.x.
31. Mehrabian A. Silent messages. 1st ed. Belmont: Wadsworth; 1971.
32. Ozlem Alp K. A comparison of sign and symbol (their contents and boundaries). Semiotica. 2010;182:1–13. doi:10.1515/semi.2010.048. [cited 2015 August 10].
33. Wiener M, Devoe S, Rubinow S, Geller J. Nonverbal behaviour and non-verbal communication. Psychol Rev. 1972;79(3):185–214.
34. Danesi M. Messages, signs, and meanings. 3rd ed. Toronto: Canadian Scholars' Press Inc; 2004.
35. Littlejohn SW, Foss KA. Theories of human communication. 2008;2–13. [cited 2015 Aug 2]. Available from: http://www.cengagebrain.com/shop/content/littlejohn95877_0495095877_02.01_chapter01.
36. Arora R. Message and framing and credibility: application in dental services. Health Mark Q. 2000;18(10):29–44.
37. Van Sevellen G. Communication skills for the healthcare professional. Concepts, practice and evidence. 2nd ed. Boston: Jones and Bartlett; 2009.
38. Powell AC, Landman AB, Bates DW. In search of a few good apps. JAMA. 2014;311(18):1851–2.
39. West D. How mobile devices are transforming healthcare. Issue Technol Innov. 2012;18:1–14.
40. Gurol-Urganci I, de Jongh T, Vodopivec-Jamsek V, Atun R, Car J. Mobile phone messaging reminders for attendance at healthcare appointments (review). The Cochrane Library. 2013;12:CD007458.
41. Wilcox D. Wireless technology offers providers new communication options for patients. Hear J. 2002;55(6):57.
42. 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.
43. 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.
44. 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. doi:10.1136/gutjnl-2014-307263.293.

Informed Consent

3

Aarthi Ramlaul and Tracey Gregory

Abstract

All medical and 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 the examination, including the risks involved. It is the responsibility of the radiographer performing CTC examinations, therefore, to ensure that patients have been provided with the necessary information, including related risks, to enable informed consent to be established. Radiographers must work within the scope of their practice and the expectations set by the professional and regulatory bodies of the country in which they practise.

3.1 Introduction

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.

The key ethical perspective underpinning consent is the principle of autonomy. The Department of Health (2001) states that 'patients have a fundamental legal and ethical right to determine what happens to their own bodies' [1]. 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, therefore, the autonomous decisions given over to patients with regard to consent to treatment respect patient choice and self-determination. 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

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about the different types of consent and when consent is considered to be valid or 'real'.

Consent can be either expressed 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 the healthcare practitioner (e.g. doctor, radiologist, radiographer, nurse), in a way that the patient understands, enables the patient to make an informed decision about whether or not to receive treatment, that is, whether or not to give informed express consent. Express consent may be either written, whereby a patient signs a consent form following receipt of all necessary information, or oral, whereby the patient verbally confirms his/her willingness to undergo the examination or procedure.

Implied consent also requires an explanation of any examination or procedure to be given. However, it differs from express consent in that written or verbal confirmation does not have to be received by the medical or healthcare practitioner prior to proceeding with the examination or procedure. Instead, the voluntary actions of the 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 the patient is happy to go ahead.

3.2.1 Valid Consent

Consent given by the patient prior to any examination or procedure must be valid. 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 the 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.
- The 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, a patient is assumed to have capacity unless proved otherwise.
- The 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 UK, the role of the GI radiographer has expanded considerably over the last two decades firstly by taking on the double-contrast barium enema (BCBE) examination and now in CTC examinations. CTC is, although minimally so, an invasive procedure. The examination is used both 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 [2].

As radiographers, we cannot assume that our patients know what radiation is and what the risks of radiation are. A false assumption could negatively affect the healthcare decision the 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 experience. 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.

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 the patient actually giving their consent to the examination or procedure. Should any examination or procedure go ahead without the patients giving their consent, then they 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 the patient apprehends a touching of his person) or battery (whereby the patient was actually touched). A patient who has suffered trespass to the 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 him/her. There is no legal obligation for the patient to prove that harm has occurred [3, 4].

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 the 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 the practitioner has been negligent, the patient has to prove a number of key elements; firstly, that he/she was 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 the patient agreeing to the examination or procedure, and that in doing so, the patient suffered harm as a result.

3.5 Patient Information

There are twelve standards that have been approved by the SCoR [5] in liaison with the National Health Service Bowel Cancer Screening Programme (NHSBCSP) and the British Society of Gastrointestinal and Abdominal Radiology (BSGAR). The first standard is 'patient information and consent'. In addition, the guidance makes reference to the National Institute for Health and Clinical Excellence (NICE) guidelines on CTC which radiographers should also refer to. The standard on patient information and consent sets out the following minimum acceptable practice and best practice which are still relevant today [6].

- The process of providing patient information must follow an established pathway.
- If using local information leaflets, they must comply with national standards.
- The writing of information leaflets must be carried out in liaison with patient/service user advisory groups.
- National Patient Safety Guidelines (NPSA) must be followed during the prescribing of laxatives for bowel preparation.
- Written consent provided by the 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 the radiographer, the healthcare professional, in gaining consent from the patient, should be sufficiently knowledgeable and informed to answer routine questions and must be able to call upon the expert advice of either the radiographer or the radiologist prior to the appointment or examination.
  - In signing consent, the 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 him/her.

3.6 Information Giving

Adequate information written in a comprehensive language must include all the important benefits and risks of the examination and whether the examination is being carried out as either 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 [7].

The information provided to the patient should include the following:

- Purpose of the procedure to primarily investigate the presence of bowel cancer or precancerous polyps
- Full description of the examination in detail from start to finish with assurance that dignity will be maintained at all times
- Explanation of the benefits vs the risks of the examination
- Explanation of the risks including the following:
  - Risk of perforation
  - Anaphylactic reaction from the use of contrast agents
  - Risk of harm from ionising radiation explained as a dose equivalent of a CT scan
  - 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 once the examination is being carried out. CTC examinations also demonstrate intra-abdominal and pelvic organs and although relatively small, around 10 % of cases [8] demonstrating significant pathology, e.g. underlying lymphomas or early cancers of the kidney and ovaries may be identified
- Explanation of side effects and discomfort, e.g. bloating arising from the insufflation of air
- Alternative options, if appropriate
- Names and reliable contact details of appropriate persons who can be approached to answer questions

3.7 The Duty of Consent and the Role of the 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 [9] revealed that radiographers were of the opinion that the 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 the patients of the risks of the procedure and explain the benefit of having the examination in lieu 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.

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

The radiographer is responsible for ensuring that the 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 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 [10].

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 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 provided needs to be comprehensive to a lay person and should avoid the use of medical jargon. In addition, radiographers need to ensure that they do not present an overwhelming amount of information that may affect the patient's decision-making ability [2]. The more complex the medical imaging examination and/or the side effects, the greater the risks involved and the more crucial it is to have formal records of patient consent.

Information should be given in advance of the day of examination to enable the patient to take time to read and understand the information and ask questions before the examination. This is one of the key areas that enables consent to be informed [2]. 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 the patient's culture and beliefs and being able to identify when alternate methods of communication may be required, e.g. in cases where English may not be their first language or if the patient has special care considerations, e.g. dementia. (see Chap. 2 communication)

With regard to duty of care, the radiographer must inform the 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 with not having the examination at all, i.e. doing nothing [2].

Patients are naturally concerned about the harmful effects of 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 the patient is able to understand the consequences. A key example of helping patients to understand the extent of the risk is to liken the radiation dose that they are about to receive to other low or acceptable risks in society which they can identify with on a daily basis, e.g. exposure to sunlight. (See Appendix for the NRPB broads levels of risk – permission granted by Christina Freeman of SCoR.)

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.

3.9 Key Messages

- The radiographer has a duty of care to inform the 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 with not having the examination at all.
- 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.
- 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 risk 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 the 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 accessible to a lay person.
- 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.

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 giving information from practitioner to patient. The other is the receiving and processing of information, asking of questions and then signing of a consent form thus providing a written gesture of acceptance of the examination, by the patient. If an examination is conducted in the absence of consent, the 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 procedure. Failure to give sufficient information could result in the 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.

Appendix: Broad Levels of Risk for Common X-Ray Examinations and Isotope Scans

X-Ray examination (*nuclear medicine or isotope scan)*	Equivalent period of natural background radiation	Lifetime additional risk of cancer per examination[a]
Chest Teeth Arms and legs Hands and feet	A few days	*Negligible risk* Less than 1 in 1,000,000
Skull Head Neck	A few weeks	*Minimal risk* 1 in 1,000,000 to 1 in 100,000
Breast (mammography) Hip Spine Abdomen Pelvis CT scan of head (*Lung isotope scan)* *(Kidney isotope scan)*	A few months to a year	*Very low risk* 1 in 100,000 to 1 in 10,000
Kidneys and bladder (IVU) Stomach-barium meal Colon-barium enema CT scan of chest CT scan of abdomen *(Bone isotope scan)*	A few years	*Low risk* 1 in 10,000 to 1 in 1,000

X-Rays how safe are they? NRPB May 2001, reproduced here by kind permission of the Health Protection Agency

[a]*These risk levels represent very small additions to the 1 in 3 chance we all have of getting cancer*

References

1. Department of Health. Good practice in consent implementation guide: consent to examination or treatment. London: Department of Health; 2001.
2. Society and College of Radiographers. Consent to imaging and radiotherapy treatment examinations: an ethical perspective and good practice guide for the radiography workforce. 1st ed. London: The Society and College of Radiographers. Clinical Imaging and Radiotherapy and Oncology; 2007.
3. Dimond BC. Legal aspects of radiography and radiology. Oxford: Blackwell Publishing; 2002.
4. 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 Elsevier; 2013.
5. Society and College of Radiographers. Computed tomographic colonography: guidance on standards. London: Society and College of Radiographers; 2012.
6. National Health Service Bowel Cancer Screening Programme. Guidelines for the use of imaging in the NHS Bowel Cancer Screening Programme. 2nd ed. London: NHSBCSP Publication No 5; 2012.
7. 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. http://dx.doi.org/10.1016/S0140-6736(15)60123-4.
8. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Radiol. 2014;18(1):11. Art. #607. http://dx.doi/org/10.4102/sajr. v18i1.607.
9. Friedrich-Nel H, Munro L. Radiographers' opinions on patients' rights to informed consent: results of an online survey. SAR. 2015;53(1):27–33.
10. Health and Care Professions Council. Standards of conduct, performance and ethics. London: Health and Care Professions Council; 2012.

Additional Reading

Bell L. Medical law and ethics. Essex: Pearson Education Limited; 2013.

Carr C. Beginning medical law. Oxon: Routledge; 2015.

Cowardly ML, Drew M. Basic law for the Allied Health Professions. 2nd ed. London: Jones and Bartlett Publishers; 1995.

Samantha J, Samantha A. Medical law. 2nd ed. London: Palgrave; 2015.

Principles of CT

4

Martin Vosper

Abstract

This chapter summarises the basic technical principles which underpin computed tomography (CT). The key advantage of CT over conventional radiography is its ability to obtain 2D sections and 3D volume representations of the human body, with greatly improved contrast discrimination between tissues. This is enabled by a rotating X-ray tube and detector array which obtain multiple image projections during scanning. Much CT development occurred via a series of scanner generations, especially spiral (helical) scanning and multi-detector row designs. Imaging is based on the conversion of X-ray linear attenuation values to Hounsfield units which can be transformed to an extended greyscale of signal intensities. Windowing is a means of improving the visualisation of image contrast. Image resolution is determined by factors such as the slice width and pixel matrix. The effect of exposure factors such as kilovoltage peak (kVp) and milliampere seconds (mAs) is considered. Modern methods for CT image formation from raw data include back projection and iterative reconstruction.

4.1 Introduction

From our twenty-first century perspective, it is hard to imagine a diagnostic imaging world without computed tomography (CT). The technique has truly revolutionised the two-dimensional (sectional) and three-dimensional (volume) depiction of internal human anatomy, to the extent that there is no hidden corner of the living body which cannot now be explored by it. This includes the colon and adjacent structures. Prior to the introduction of CT in the early 1970s, internal anatomy could only be explored fully by the surgeon's knife or partly portrayed by ultrasound and radionuclide imaging. Conventional X-ray imaging had long been in existence, but could only display structures and organs in a superimposed state, without much discrimination between different soft tissues. Although magnetic resonance imaging (MRI) would later surpass the soft tissue discrimination capabilities of CT it still

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suffers to this day from longer scan times, poorer spatial resolution and a weaker ability to depict air-filled structures or tissue calcifications.

4.2 CT Principles

Computed tomography uses mathematical computation to obtain imaging sections or 'slices' of the human body. Indeed its name is derived from the Greek word *tomos* meaning a cut or section. It allows the content of discrete body sections to be seen with clarity and detail, avoiding the superimposition of structures which is such a disadvantage in conventional or 'plain' radiography. Sections are obtained by allowing the X-ray tube to rotate around the body within the axial plane during a procedure, thereby obtaining projections from many different positions rather than from just a single perspective. By mathematical computation, the huge amounts of projection data are transformed into an image. Often CT is described as a CAT scan, which stands for computed axial tomography. Although the mathematical principles of obtaining a 2D slice image from a large number of projections were described by Radon in 1917, the practical realisation of the technique was delayed until the arrival of improved computers in the 1970s. Only then could the large amounts of projection data be transformed into a viable image.

Both CT and plain radiography use X-rays emitted by X-ray tubes and received by X-ray detectors. Both imaging modalities are affected by the properties of X-rays. The useful properties of X-rays include the ability to penetrate through the body in straight lines and cast a shadow projection of internal structures, recordable by detectors. This can provide a 'true' representation of these structures unless the X-rays become scattered from their straight line path or if there is 'noise' in the imaging system. Noise refers to random fluctuations in received signal which degrade an image. Another useful property of X-rays is their 'differential absorption' in body tissues. This means that some tissues, namely, those that are of high density and atomic number, will absorb more X-rays than those that are not. When a lot of X-ray absorption takes place, such as in metal, bone or contrast media, there is a bright white appearance in the CT image. When very little absorption takes place, such as in bowel gas, there is a resultant black appearance in the CT image. Soft tissues tend to show up as intermediate shades of grey. It should be remembered that CT gives us images based on a single physical property – the absorption of X-rays. Different tissues will appear the same on CT imaging if they have the same X-ray absorption characteristics. This can be regarded as a relative disadvantage of CT compared to MRI, since the latter has more ways of depicting tissue properties and also has better functional imaging capabilities. However, CT provides shorter scan times and finer image resolution than MRI, properties which are of particular benefit when imaging the moving structures of the colon.

4.2.1 CT Fundamentals

The key features of a modern CT scanner are as follows and are depicted in Fig. 4.1.

- An X-ray tube which acts as the source of an X-ray beam, rotating in a continuous 360° arc in the axial plane around a patient's body
- Filters which modify and improve the X-ray beam
- Collimators which reduce the size of the X-ray beam, thereby reducing patient dose and improving image quality
- X-ray detectors, arranged in rows, rotating in a continuous arc and located directly opposite the X-ray tube
- A moving X-ray couch, on which a patient lies

As the X-ray tube and detectors rotate in a circular fashion around a patient's body, a large number of X-ray projections are obtained. These can be considered as consisting of many 'ray' traces, with each ray encountering different tissues during its linear course through the body. It is the presence of these multiple traces that makes CT fundamentally different from conventional radiography and enables a complete two-dimensional section to be obtained through the patient. The X-rays within each trace will experience attenuation, according to

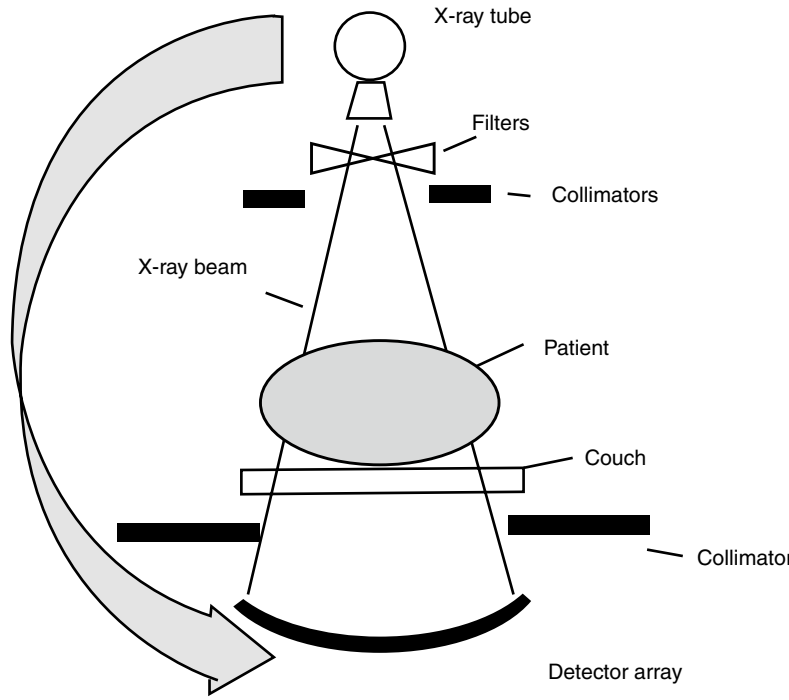

Fig. 4.1 CT scanner components

the total amount of tissue encountered along their path. The amount of X-rays received in the detector array after the X-rays have passed through the patient will depend on the body thickness in that particular direction as well as the combined density and atomic number of the tissues present. Thus, a ray tracing through the body in a particular direction will encounter a superimposed stack or column of tissues. In CT and other forms of digital imaging, the body tissues are considered and depicted as two-dimensional squares (pixels or 'picture elements') or three-dimensional cubes (voxels or 'volume elements'). The total X-ray attenuation in a particular direction will depend on the combined attenuations of the individual pixels or voxels in the column, as shown in Fig. 4.2. The diagram shows a two-dimensional slice through the patient, consisting of a number of pixels (picture elements). Each pixel has an X-ray attenuation value related to its atomic number and density. The total attenuation experienced by each ray will depend upon the combined attenuation of the pixels it encounters within its trace. In the

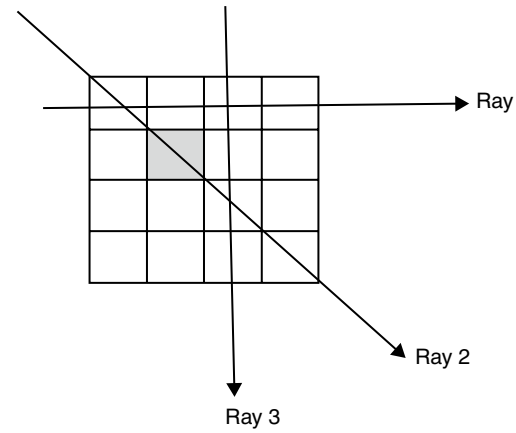

Fig. 4.2 Rays in CT. The diagram shows a two-dimensional slice through the patient, consisting of a number of pixels (picture elements)

example shown here, ray 2 will be the most attenuated (since it passes through a dense pixel) and ray 3 the least. Each ray here corresponds to an X-ray projection. The X-ray beam experiences attenuation (a reduction in intensity) as it passes through a patient's body, in a way that is

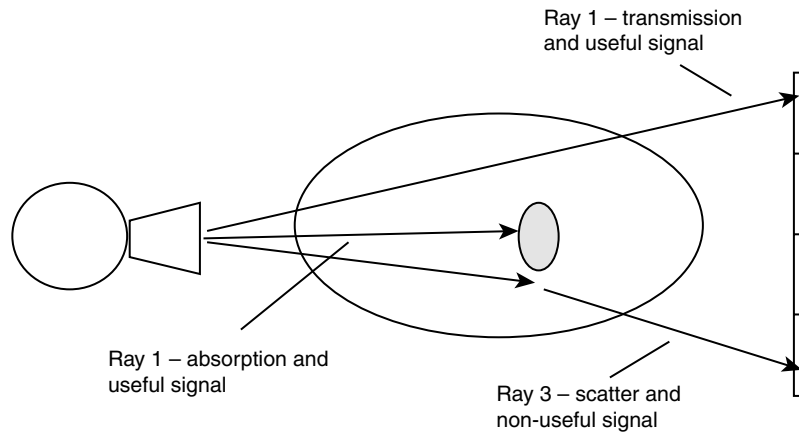

Fig. 4.3 The possible paths of an X-ray photon in CT

determined by the tissues encountered along its path. This process is essential to us in CT, since it produces a signal pattern in the X-ray detectors. There are three things that can happen to an X-ray in CT, as shown in Fig. 4.3.

1. The X-ray may pass right through the body in a straight line (linearly), producing a useful signal in the X-ray detector array.
2. The X-ray may be absorbed in the body. This is also useful, since it produces an 'absence of signal' in the detector array, enabling an absorption pattern to be obtained. This 'shadow projection' results in an image. The X-ray absorption is directly proportional to body tissue atomic number and density as well as the body thickness.
3. The X-ray may be scattered in the body and possibly received by a detector some distance away from the X-ray's original straight line path. This is definitely not useful, since it produces a signal in the detector array that does not correspond to the body anatomy. The X-ray scatter is directly proportional to body tissue electron density (which roughly relates to tissue density) and body thickness.

In CT, we want to obtain both process 1 (signal) and process 2 (absorption) to some extent, whilst minimising process 3 (scatter). The relative amounts of these processes are very much affected by the X-ray exposure factors used.

4.2.2 CT Exposure Factors and the CT Image

There are two principal exposure factors that can be adjusted by the operator during CT scanning.

- Milliampere seconds (mAs)
  This is the amount of electrical current passing through the X-ray tube during an exposure. It has a simple direct effect on the number of X-rays produced, so that a doubling in mAs results in a doubling of X-rays. We should note that mAs does not affect the penetration or energy of X-ray photons, only their number. An increase in the number of X-rays will increase the signal received in a detector array and improve the amount of signal relative to noise. Noise manifests itself as a random fluctuation in image signal, giving what is often termed a 'salt-and-pepper' appearance on the image. X-ray detectors tend to work best when they are receiving sufficient amounts of X-rays, giving an image of high contrast and resolution, without appreciable noise. But of course this comes with an unwelcome increase in patient radiation dose, since dose is directly proportional to mAs. A balance needs to be struck, wherein there is both acceptable image quality and dose.
- Kilovoltage peak (kVp)
  This is the peak voltage in kilovolts applied across the X-ray tube during an exposure. Values used in CT may range from about 80 to 140 kVp. An increase in kVp has a dual effect,

increasing both the energy of the X-ray beam and the number of X-rays produced. In fact the number of X-rays produced is proportional to the square of the kVp. So a simple increase in kVp has the effect of increasing patient radiation dose if other exposure factors remain unchanged. It also has the effect of improving signal in the detectors and reducing noise and also has an impact on image contrast. At this point we should note that a high contrast image is one in which there are large differences in signal between different tissues or structures – in other words it is an image which provides good tissue discrimination. In general, high image contrast is provided by low kVp. This is because X-ray absorption (photoelectric absorption is the physics term) occurs more at low kVp and this absorption process emphasises atomic number differences between tissues. As a result, the signal difference between iodine-containing contrast media (high atomic number) and soft tissue in the bowel (low atomic number) will be maximised at low kVp. At high kVp values, it is X-ray scatter (Compton scatter) which predominates, and thus, the contrast between structures of different atomic number will be reduced. Importantly however, we should note that the X-ray beam must always be of sufficient energy to penetrate through a patient, or else no image will result. Also noise in the X-ray detectors will increase if insufficient rays are able to penetrate through the body and reach those detectors.

There are some other technical factors which affect the CT image; however, not all of them are within the direct control of the operator during a scan: focal spot, geometry, beam filtration, slice thickness, image matrix, detector dimensions, pitch and scan time.

- Focal spot. This is the source of X-rays within the X-ray tube. A small ('fine') focal spot improves the spatial resolution (sharpness) of the image, but also reduces the heat capacity of the X-ray tube. This is an example of the geometric unsharpness (penumbra) effect which is also seen in conventional radiography.
- Geometry. The spatial resolution of the image will be maximised by a small distance between the patient and the detector array, together with a large distance between the X-ray tube and the patient. This is dependent on the scanner design and is another aspect of the penumbra effect.
- Beam filtration. Metal filters, placed between the X-ray tube and the patient, are designed to remove low-energy X-rays ('soft' X-rays) and improve the penetrating capability of the beam. They may also be used to even out the intensity of the X-ray beam across the patient anatomy.
- Slice thickness. A thicker slice contains more signal and thus suffers less from image noise. But a thinner slice provides improved spatial resolution and better ability to depict small objects.
- Image matrix. An axial section in CT consists of a two-dimensional grid of square-shaped pixels (picture elements). A typical value for the matrix is 512 × 512 (i.e. 512 pixels in each of the two dimensions). For a given scan field of view, the size of individual pixels is inversely proportional to the matrix. A matrix of 1024 × 1024 will provide pixels that are half as large in each of the two dimensions and thus four times smaller in area. This 1024 × 1024 matrix will allow better spatial resolution than the 512 × 512 matrix, but each pixel will contain less signal and thus will be more liable to image noise.
- Detector dimensions. The spatial resolution of the image will be improved when using small detector elements but may suffer from reduced signal and thus worse noise [1].
- Pitch. This adjustable technical factor describes the relative speed of the CT couch movement through the scanner during a single X-ray tube rotation, divided by the total width of any simultaneously acquired slices. A large pitch factor (faster couch movement) results in reduced signal and image quality as well as reduced patient radiation dose.
- Scan time. A reduced scan time provides improved temporal resolution, thereby reducing the adverse effects of patient motion on image quality and also permitting dynamic studies of the body in real time. Scan time is affected by a number of factors, including pitch, X-ray tube rotation speed, scan volume and the number of image slices.

4.2.3 CT Image Contrast

Compared to conventional radiography, CT is able to amplify the image contrast that can be seen between different tissues [1]. Image contrast means the amount of signal difference that exists between tissues – so an image containing white and black shades is regarded as higher contrast than one consisting of intermediate shades of grey. How can CT amplify image contrast? There are four ways in which it achieves this.

1. Removal of overlying structures. Conventional radiographic images are compromised by the fact that all anatomy is seen superimposed. This reduces image contrast. In CT, only tissues within a thin section or 'slice' are visible, and this tends to increase the available contrast between them by removing overlying image 'clutter'.
2. Reduction of X-ray scatter. In CT the X-ray beam is tightly collimated ('coned down'), not only before it reaches the patient but also before it reaches the detector array. The overall effect is to lower the amount of scatter reaching the detectors. Scattered X-rays reduce image contrast by raising the amount of background signal and consequently give an unwelcome image 'greyness' which reduces tissue discrimination.
3. X-ray attenuation calculation. CT is able to detect very subtle differences between the X-ray attenuation values of different tissues. This is because it obtains large amounts of X-ray attenuation data, using multiple projection angles. The attenuation values are converted to a range of signal intensities on the CT image, using a scale known as the Hounsfield scale [2], as shown in Table 4.1. This is named after Sir Godfrey Hounsfield, whose pioneering work resulted in the first clinical CT scanner at the Atkinson Morley Hospital in London in 1971. The Hounsfield scale is derived from the relative sizes of the X-ray attenuation coefficients of tissues compared to water. Water is assigned a value of zero Hounsfield units (HU) on the scale, with air having a value of −1000 HU and dense bone a value of +1000 HU. It is interesting to note that fatty tissue has a value of about −100 HU and other soft tissues are in the range of +20 to +80 HU. Hounsfield values are converted to a greyscale of image intensities in CT. In practice a scale of CT numbers is often used. This is based on the Hounsfield scale but extended to about +3000 to allow for the high X-ray attenuation values of metal implants which may be present in the patient.
   The Hounsfield equation below indicates that tissue Hounsfield unit values are based on the relative linear X-ray attenuation coefficients μ of the tissue and water, multiplied by 1000. A Hounsfield unit difference of 5 between two tissues corresponds to a linear attenuation difference of 0.5 %:

$$\text{HU value} = \left(\mu_{\text{tissue}} - \mu_{\text{water}}\right) / \mu_{\text{water}} \times 1000$$

4. Windowing. In CT, tissues are displayed using pixels or voxels, each having a given signal intensity value. The tissues are depicted using a greyscale, whose extremes are white (high X-ray attenuation tissues such as bone or

Table 4.1 The Hounsfield scale

Tissue or substance type	Typical Hounsfield unit values
Air	−1000
Lung	−1000 to −500
Adipose (fatty) tissue	−100 to −50
Water	0
Soft tissues	+20 to +50
Liver	+40 to +70
Acute haemorrhage	+50 to +100
Cancellous (marrow) bone	+50 to +200
Contrast media enhancement	+100 to +300
Cortical (hard) bone	+250 to +1000

haemorrhage) and black (low X-ray attenuation tissues such as lung or bowel gas). Soft tissues present as intermediate shades of grey. There are too many shades (too many different signal intensity values) contained within the extensive data of a CT image to be visible to the human eye 'all at once'. In fact the human eye can only visualise about 30–40 distinct shades of grey within a single image. Thus, the data is post-processed using 'windowing'. A window enables only a particular range of tissue attenuation values to be seen on the image, thereby increasing the contrast between them. For example, it is possible to use a bone window, a lung window or a soft tissue window. The user selects a window level corresponding to the midpoint of the range of tissue X-ray attenuation values and a window width which prescribes the range of X-ray attenuation values to be visualised in the image. A narrow window width results in a high contrast image. The process of windowing is shown in Fig. 4.4.

A CT image contains a wide range of X-ray attenuation values, converted into Hounsfield units. But the eye cannot visualise so many grades of signal within the associated greyscale. Thus, the range of tissue attenuations to be visualised on a CT image is narrowed down to a window width of values, centred around an attenuation value which is called the window level. Typical window levels used in practice might be about +50 for soft tissues, −500 for the lungs and +250 for the bone. Windowing is especially important for soft tissue imaging as it amplifies the image contrast between tissues which have small attenuation differences between them and would otherwise not be visible as distinct entities. Tissue attenuation values above and below the window width cannot be visualised as greyscale intensities and show as very low contrast structures – bright white or pitch black, respectively.

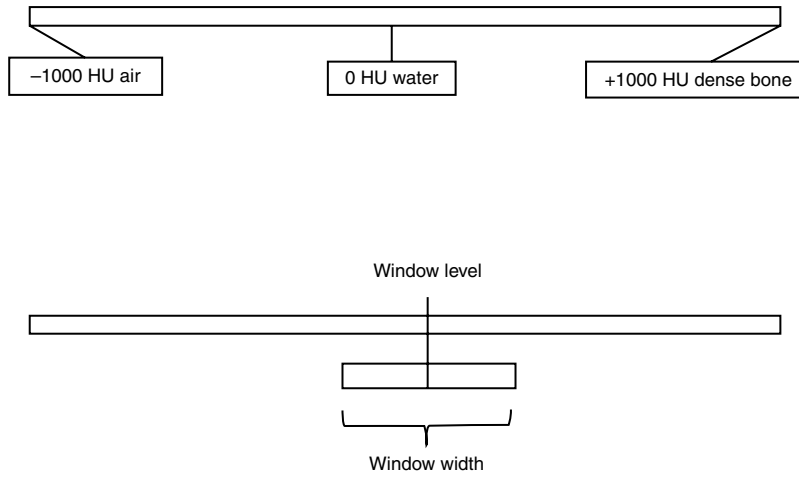

Fig. 4.4 Windowing in CT image processing

4.3 CT Scanner Development

There have been tremendous developments in CT scanner technology and capabilities since the advent of the first system in 1971. Initially CT was restricted to the study of small and relatively motion-free body areas such as the head, but can now image all body contents, including the colon. The benefits of advances in CT include:

- Greatly reduced scan times
- Improved spatial and temporal resolution
- Volume (3D) acquisition
- Slice reconstruction in the sagittal and coronal planes from original axial scan data
- Enlarged scan volume coverage
- Real-time (dynamic) imaging
- Improved signal-to-noise ratios
- More accurate quantification of tissue X-ray attenuation
- Ability to provide some functional information in addition to anatomical depiction
- Advanced image reconstruction techniques
- Image artefact reduction
- Radiation dose optimisation

From its inception, CT provided improved tissue discrimination relative to conventional radiography, due to its improved image contrast and sectional imaging capability, providing anatomical slices free from overlying information. However, even modern CT cannot compete with the spatial resolution capabilities of conventional radiography. A typical CT image matrix of 512 × 512 pixels compares poorly with the 4096 × 4096 pixel matrix of a digital chest radiograph. The real strength of CT lies in its ability to display structures which can be separated on the basis of their X-ray attenuation characteristics, such as bone, calcification, fresh haemorrhage, fat, air and tissue enhanced by contrast media.

CT scan times have shortened from about 5 min for a single slice in 1971 to less than a second for multiple slices in 2015. Volume imaging has been permitted by the introduction of continually rotating X-ray tubes and moving patient couches. X-ray detectors have progressed from single elements and single image slices to arrays of over 300 rows of detectors, permitting the simultaneous acquisition of data from multiple slices. New techniques for CT data acquisition and computation have improved image signal and reduced patient radiation dose. The real milestones in CT have been the introduction of spiral (helical) scanners in 1989 and multi-slice scanners in circa 1998.

4.3.1 CT Scanner Generations

There have been several generations or phases in CT scanner development since 1971 [2]. All modern CT units have many parallel rows of X-ray detectors, enabling them to acquire data from multiple imaging slices simultaneously. This technology is termed multi-detector CT (MDCT). However, the key elements of CT are still based on earlier third-generation designs, consisting of a rotating X-ray tube and a rotating array of X-ray detectors.

4.3.1.1 First-Generation (Translate-Rotate) CT

Hounsfield's original CT scanner involved a thin 'pencil' X-ray beam of parallel rays, which rotated around a patient into 180 projection positions and then translated sideways across the patient within each position. Hence, the scanner was termed a 'translate-rotate' design. Scan time was exceptionally slow by modern standards, at 5 min per slice, and the pixel matrix was coarse, consisting of 128 × 128 pixels in each two-dimensional axial slice.

4.3.1.2 Second-Generation CT

This design was based on a translate-rotate X-ray beam movement but introduced a diverging 'fan-shaped' X-ray beam. This enabled about 30 detectors to receive X-rays simultaneously and helped to shorten the scan time.

4.3.1.3 Third-Generation (Rotate-Rotate) CT

This development was introduced in circa 1977 and laid the foundations for modern CT scanners, which still use its rotate-rotate configuration.

This consisted of a rotating X-ray tube, linked to a rotating arc-shaped detector array which was located on the opposite side of the patient from the X-ray tube. The detector array contained up to 960 elements. The X-ray tube rotated 360° clockwise or anticlockwise and then had to reverse its motion, to avoid twisting the attached high voltage X-ray cables. This was still a single slice CT (SSCT) technology. The CT couch and patient were moved in increments through the X-ray beam as each slice was acquired in turn. Scan time was about 5 sec per slice.

4.3.1.4 Fourth-Generation CT

This design from circa 1980 proved to be a dead end in terms of development and did not lead to subsequent derivatives. Here the rotating X-ray tube was enclosed in a fixed circular array of detector elements, about 4800 in total. The intention was to avoid some circular image artefacts which could be associated with a rotating detector array. The X-ray tube still had to rotate in one direction then reverse its motion, and the design was still single-slice CT. Disadvantages inherent in the design included high cost, increased radiation dose and increased geometric unsharpness.

4.3.1.5 Fifth-Generation CT

In 1983 a specialist and non-mainstream CT scanner was introduced, designed to assess coronary artery calcification. This was a design based on electron beam CT (EBCT). It had a very original configuration in which an electron beam was rapidly swept by electromagnetic fields around the patient in a circular motion. X-rays were produced when the rotating electron beam struck a circular target track which surrounded the patient. The commercial name for the system was the Imatron, and its main advantage was very short scan times, permitting the freezing of coronary artery motion.

4.3.1.6 Sixth-Generation (Spiral) CT

A revolutionary improvement in CT technology was pioneered in 1989 by Willi Kalender and his team within Siemens. This was termed spiral or helical CT, so-called because the X-ray beam now prescribed a helical (corkscrew) pattern during the scan whilst the patient couch moved continuously through the scanner gantry. The speed of couch movement was referred to as the pitch factor. A major advantage was the possibility of volume scanning, enabling high-quality 3D images and superior scan reconstructions in other imaging planes from the axial scan data. This was enabled by the production of isotropic voxels (cubic voxels with sides of equal lengths in all three dimensions). Spiral CT required that the X-ray tube should be capable of continuous rotation in the same direction during scanning. Slip ring technology was the key development which allowed this, replacing high voltage X-ray tube cables by rotating rings connected electrically by conductive brushes. The X-ray tube and detector array were still rotate-rotate in design, with a rotating single row of detectors aligned opposite the X-ray tube. The single detector row meant that this was still a single slice design, as in previous generations of scanners. Scan times were about 3 sec per slice.

4.3.1.7 Seventh-Generation (Multi-slice) CT

Scan times could be further reduced if the spiral CT technology was coupled with multiple parallel rows of detectors, enabling data for several image slices to be acquired simultaneously. A four-slice design was launched in 1998 and was termed multi-slice or multi-detector CT (MDCT). Scanners with 64 slices were available by 2004, and the latest units may have over 300 slices. It is possible to combine detector elements in various ways to achieve different effective slice widths [3]. The broadening of volume coverage means that X-ray beams in such scanners are now cone shaped rather than fan shaped. It should be noted that the cone beam should not be confused with cone beam CT, which uses a rotating flat panel detector and is a different type of scanner. Minimum scan time per slice using MDCT is now about 0.1 s. There has also been a reduction in X-ray tube rotation time, from about 2 sec per 360° rotation in sixth-generation CT to less than 0.3 s per rotation in modern designs.

It should be noted that modern CT scanners are based on a rotate-rotate X-ray tube and detector array geometry, spiral scanning and multi-slice detector arrays [4]. The latest units utilise the incremental improvements that have occurred in previous scanner generations.

4.3.1.8 Dual-Energy CT

Many of the latest CT scanners are able to produce scans based on two distinct X-ray beam energies [5]. The advantage of this is that very precise information can be obtained about pixel and voxel X-ray attenuation (and hence Hounsfield unit values). This can enable more effective subtraction of unwanted tissues as well as functional studies based on the perfusion rates of contrast media into tissues. The subtraction technique can be useful for removing unwanted tissue such as faeces and image artefacts from CT colonography studies. There are a number of solutions for achieving dual-energy CT.

- Dual source. This technology uses two X-rays tubes, each operating at a different kVp, as well as two separate detector arrays. The X-ray tube kVp determines the peak and mean X-ray beam energy.
- KVp switching. Here a single X-ray tube is used, with rapid switching between two different kVs applied across it.
- Dual detector arrays. This solution uses a single X-ray tube and two superimposed layers of detectors, each absorbing X-rays of a different energy range.

4.4 Image Construction

In CT, a two-dimensional image matrix is obtained in the axial plane, typically consisting of 512 × 512 (which totals 262,144) pixels (picture elements). The X-ray attenuation value of each individual pixel must be calculated and then converted to a Hounsfield unit in order that a signal intensity can be assigned to it within the slice image. The mathematical calculations involved are huge and complex, because each pixel is contained in a column of other pixels. Individual pixel image intensities must be extrapolated from total X-ray linear attenuation values obtained from X-ray tracings [6]. This is only possible with a large amount of attenuation data obtained from multiple directions, each direction being an individual X-ray beam projection as the tube rotates circularly around a patient. A simple representation of this problem is shown in Fig. 4.5.

Let's look at a very simple situation based on only four pixels, which highlights the mathematical problems faced in producing a CT image. Let's say that we are trying to find the attenuation value for pixel A. Ray 1 provides a total attenuation value of four for pixels A and B combined. There could be many solutions to this – for example, $A=3$, $B=1$, $A=2$, $B=2$, $A=1$, $B=3$ and so on. We cannot assign a unique correct attenuation value to A on the basis of this one ray. Now let's add ray 2 data, based on another projection angle, which gives at total attenuation value of ten. Once again there are many possible solutions based on this data – for example, $A=1$, $C=9$, $A=2$, $C=8$, $A=3$, $C=7$ and so on. Let's add a third ray which gives a total attenuation value of six. Even with data from three rays, the attenuation value of pixel A is still unknown – it could be either 0, 1, 2, 3 or 4. Try inserting possible values yourself. Adding a further three rays, passing through pixels C-D, B-D and B-C would give enough data to solve the value of pixel A. This example is only illustrative, but it gives an idea of the difficulties involved in calculating pixel values using algebra. Imagine how much data would be needed for a 512 × 512 matrix.

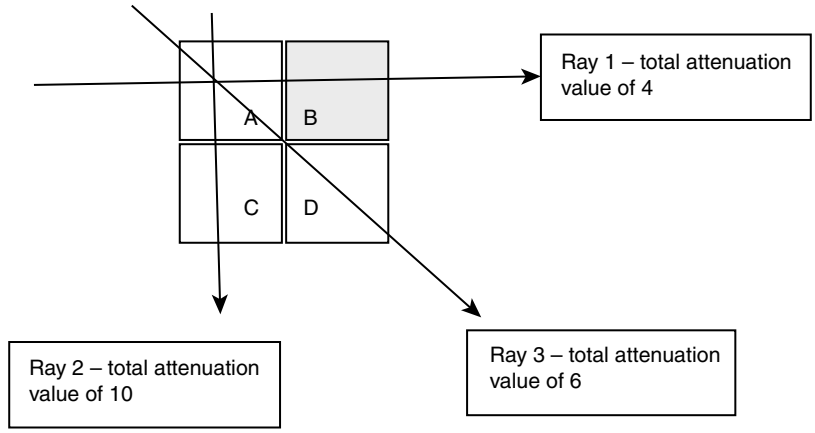

Fig. 4.5 The pixel attenuation calculation problem

A single X-ray transmission measurement through a patient's body made by an individual detector at a given point in time is called a ray or line. A series of rays that pass through a patient from the same X-ray perspective or orientation is called a projection. Modern CT scanners might use 600–1200 rays taken at 800–1500 projection angles. This is likely to give about 1,000,000 transmission measurements. This is a type of forward projection technique for image construction, since real X-ray attenuation data is linearly projected onto the detector array. In practice the algebraic calculation of pixel attenuation values is not feasible for large matrices, especially when random noise is present due to X-ray scatter, low X-ray intensity and electrical fluctuations in detectors.

4.4.1 Back Projection Methods

Back projection is a faster means of constructing the CT image from X-ray attenuation data. Attenuation values obtained in detectors are projected back along the ray paths into the image as shown schematically in Fig. 4.6. Each back-projected ray tracing uses the average value of the X-ray attenuation encountered along its linear path. The values are combined to produce summated signal where there is anatomical detail in the projection data. A disadvantage of the approach is image blurring. Attenuation information from the detectors is projected back into the patient to produce image signal. Note that this signal is summated where the projections overlap, thus indicating an X-ray attenuating object in the patient.

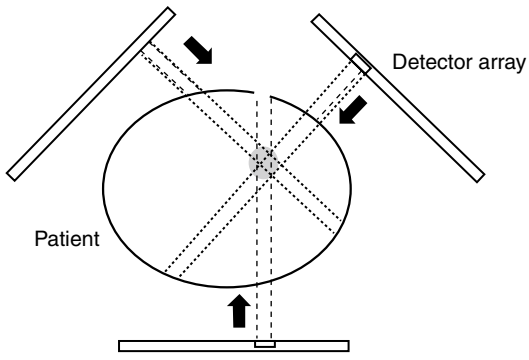

Fig. 4.6 Back projection in image construction. Attenuation information from the detectors is projected back into the patient to produce image signal

A process of filtration is applied to the back-projected image data in order to reduce blurring effects. This process is not the same as X-ray beam filtration. It involves a mathematical process known as convolution which tidies up the image and enhances the edges of objects. The mathematical filter applied is called a kernel. Soft and hard filters may be applied to CT data – soft filtration tends to be applied when soft tissue information is important and hard filtration when edge information is required. A hard filter improves image sharpness but may result in an increase in image noise.

4.4.2 Iterative Image Reconstruction

Iterative techniques are mathematical calculations that first make an assumption that all pixels have the same linear attenuation value and then repeatedly compare the real data situation with that assumption, making corrections. Mathematical recycling refines the image solution during the process. Back projection data is compared with a correct data model based on a forward projection through the patient. The mathematics is constantly refined through iteration until the two models agree, producing a less noisy image. The techniques have a lot of advantages, since iteration not only reduces image noise but also therefore permits lower exposure factors to be used whilst maintaining an acceptable noise level [7]. CT manufacturers have adopted slightly different techniques to achieve this, such as Adaptive Statistical Iterative Reconstruction (ASIR) by GE, iDose by Philips, Sinogram Affirmed Iterative Reconstruction (SAFIRE) by Siemens and Adaptive Iterative Dose Reconstruction (AIDR) by Toshiba.

4.4.3 Volume Rendering Techniques

Spiral CT brought about true volume imaging, since it enabled the production of isotropic voxels which are equal in size in all three dimensions. This permitted 3D datasets which achieve image reconstructions in any plane, since image resolution is the same in any plane. There are a number of techniques for rendering volume images from CT data, all of which can be rotated for viewing from multiple angles as follows.

- *Maximum intensity projection (MIP)*
  Anatomical structures are projected using ray paths from all directions. Image projection is based on the highest X-ray attenuation value that the ray encounters within its linear path. This is converted to an image signal intensity. The technique may be used when a contrast medium is introduced, since this will generally be the most attenuating material. Data are generally excluded from soft tissues which lie below a set cutoff value measured in Hounsfield units. However, high-density material such as tissue calcification may still show up and may obscure detail. Overlying high attenuation structures such as other vessels may interfere with vessel visualisation. The MIP approach produces a series of 2D images from multiple projection angles, and the 3D relationship between structures may be difficult to visualise. A variant of MIP is termed minimum intensity projection (MinIP) and can be useful for the visualisation of air or gas.
- *Surface shaded display*
  In this technique, the surface contours of structures such as vessels are displayed as if illuminated by an external simulated light source. Upper and lower Hounsfield unit threshold values are chosen, so that only tissues within these threshold limits are visualised. Each tissue type is allocated to a colour or transparency within the image, and surfaces are defined which represent boundaries between different tissues. The technique is limited by the fact that voxels with a mixed tissue composition cannot be properly represented since their Hounsfield value is averaged out. This can cause faulty representation of tissue boundaries. The technique is also vulnerable to image noise and variable contrast media enhancement.
- *Volume rendering*
  This approach provides a more accurate anatomical depiction since it can allow voxels to be displayed in terms of their true percentage composition of different tissue types rather than a false 'all or nothing' composition. Each voxel is given a colour or transparency within the 3D image, so that intermediate tissue compositions can be assigned values of hue or opacity. Simulated light rays are passed through the model so that it can be viewed. It is possible to view multiple tissue types such as bone, soft tissue and contrast-filled vessels within a single rendering. Also unwanted tissue types can be 'peeled away' if required.
- *Perspective volume rendering (pVR)*
  This is a novel way of displaying volume data and enables a virtual fly-through to be obtained within the hollow cavities such as the bowel and vessels. Internal structures and walls are assigned colours or transparencies for better visualisation, using perspective images which simulate the presence of the observer within the structure. There are applications for virtual colonoscopy (also called CT colonography).

4.5 CT Image Resolution

Resolution can be thought of as the ability to resolve small objects or detail. It is affected by a number of factors. It should be noted that many of the factors which lead to increased resolution may also result in increased image noise. Here are some of the factors.

- *Slice thickness*
  In single-detector row CT, the slice thickness was principally determined by the X-ray beam collimator aperture. But in multi-detector row CT, the slice thickness is affected by combining detector elements in the z direction (along the long axis of a supine patient). Effective slice thickness can be measured using the slice sensitivity profile, which is the measured slice width taken at 50 % of the maximum signal value across the slice using a quality assurance phantom. Pitch factor affects the slice sensitivity profile (and thus the slice width) by widening it in the z-direction during table movement. It should be noted that a perfect slice sensitivity profile would be rectangular, but factors such as pitch and X-ray beam geometry tend to convert it to a bell-shaped curve as shown in Fig. 4.7. Small slice thicknesses provide a high spatial resolution and suffer less from 'partial voluming'. This means that they are more able to accurately depict small objects which might otherwise become averaged out within thicker slices.
- *Detector size*
  This is often a limiting factor with regard to resolution. It is affected by the detector element aperture as well as the spacing between the detector elements. In multi-detector row CT, there tends to be increased X-ray scatter due to the width of the cone-shaped X-ray beam. Thus, there needs to be thicker septa (dividers) between the detector elements in order to prevent stray scatter from entering. The smallest detector elements tend to be about 0.5 mm in aperture. Detector rows may be combined in multi-detector row CT in order to provide a range of possible slice thicknesses.
- *Geometric effects (penumbra)*
  These are due to the diverging nature of the X-ray beam. Resolution is increased by a small X-ray tube focal spot size, large X-ray tube to patient distance and a small patient to detector distance. In addition penumbra effects can cause a drop off in the received X-ray intensity at the beam edges. This is less of a problem in multi-detector row CT that uses more than 16 detector rows.
- *Scan field of view and pixel matrix*
  Pixels of smaller physical dimensions will provide increased spatial resolution. This can be achieved via a 'finer' pixel matrix, such as a 512 × 512 array rather than 256 × 256, as well as a small scan field of view.

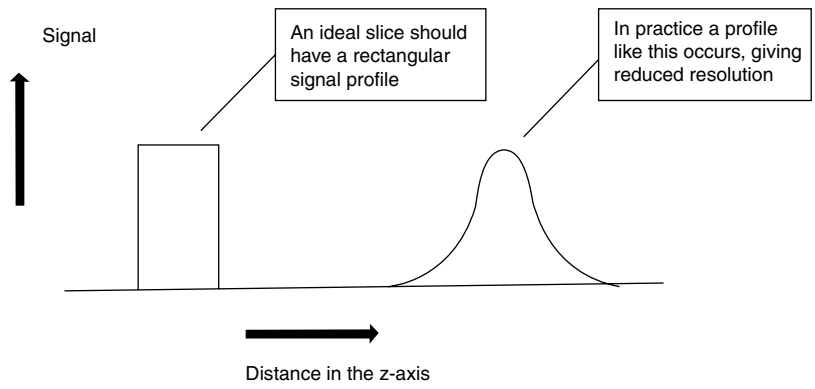

Fig. 4.7 Slice sensitivity profiles

4.6 Key Messages

- Computed tomography (CT) utilises the attenuation of X-ray photons to produce sectional information about human body structures. X-ray absorption results in a useful pattern of information in the X-ray detector array. X-ray scatter results in non-useful information and increases image noise.
- A sectional image in CT is based on many X-ray attenuation measurements based on multiple projections and many ray tracings obtained during a rotation of the X-ray tube around the patient's body. This presents a complex mathematical problem which is solved via back projection and iterative image reconstruction.
- Signal intensity (brightness) values within individual voxel elements are obtained via the conversion of X-ray attenuation data to Hounsfield units or CT numbers. Zero on the Hounsfield scale corresponds to the X-ray attenuation value for water.
- The main advantage of CT relative to conventional X-ray imaging is its ability to amplify image contrast between tissues. This is achieved via removal of overlying anatomy, X-ray scatter reduction and the use of an extended scale in which the small X-ray attenuation differences between anatomical features are amplified.
- Relative to MRI, CT provides improved spatial resolution, faster scan times, poorer soft tissue discrimination and reduced functional imaging capability. Other advantages of CT include its ability to depict cortical bone, calcification, fresh bleed and air.
- Progressive technological developments in CT have resulted in shorter scan times, improved spatial resolution, volume imaging, multiplanar reconstructions, improved soft tissue characterisation and some functional imaging capability. This has enabled CT colonography and many other examinations which would not have been possible in the early days of CT.
- Modern CT scanners use a helical (spiral) rotation of the X-ray tube relative to a moving X-ray couch, together with multi-slice imaging based on the presence of many parallel rows of X-ray detectors.
- Increase in the kVp (kilovoltage peak) setting results in increased X-ray photon energy and an increased number of photons, increased signal-to-noise ratio, reduced soft tissue contrast and increased radiation dose.
- Increase in the mAs (milliampere seconds) setting results in an increased number of X-ray photons, increased signal-to-noise ratio and increased radiation dose.

4.7 Summary

Computed tomography (CT) is a powerful technique for providing sectional 'slices' of the human body, free from the obscuring presence of overlying structures. The physical principles of CT enable improved image contrast, by accentuating the differential X-ray attenuation that occurs within different body tissues and translating this into the Hounsfield scale of signal intensities. Progressive technical developments since the early 1970s have resulted in sub-second scan times, 'freezing' of involuntary patient motion, improved spatial resolution, volume acquisition and 3D display. These assets have greatly advanced the non-invasive radiological examination of the colon.

References

1. Seeram E. Computed tomography: physical principles, clinical applications and quality control. St. Louis: Saunders; 2009.
2. Kalendar W. Computed tomography: fundamentals, system technology, image quality, applications. Erlangen: Publicis; 2011.
3. Prokop M. General principles of MDCT. Eur J Radiol. 2003;45:S4–10.
4. Salni S. Multi-detector row CT: principles and practice for abdominal applications. Radiology. 2004; 233:323–7.
5. Petersilka M, Bruder H, Krauss B, et al. Technical principles of dual source CT. Eur J Radiol. 2008;68:362–8.
6. Goldman L. Principles of CT and CT technology. J Nucl Med Technol. 2007;35:115–28.
7. Lee T-Y, Chemm R. Impact of new technologies on dose reduction in CT. Eur J Radiol. 2010;76:28–35.

5 Principles of Radiation Dose in Computed Tomography and Computed Tomography Colonography

Christoph Trauernicht

Abstract

Radiation dose in X-ray computed tomography (CT) has become a topic of high interest due to the increasing numbers of CT examinations performed worldwide. Computed tomography has its own dose quantities, including the computed tomography dose index (CTDI) and its variations, as well as the dose-length product (DLP). The measurement and use of these quantities is described in this chapter. The CTDI is often substituted as the patient dose, but in reality it is only the dose to a particular phantom and not the patient dose. In addition, the latest CT scanners have scan widths that are wider than the scan widths that the scanners had when the CTDI was introduced; this potentially makes the CTDI an inaccurate dose measure and correction factors have to be applied. The concepts of effective dose and diagnostic reference levels (DRLs) are introduced.

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].

In CT the dose is deposited from all directions, while the X-ray tube is switched on, which means that the dose is deposited more evenly in the 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 CT 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 inte-

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gral 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* (kinetic energy released in matter) 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 gray [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 (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 profile indicating the scattered dose deposited outside of the nominal slice width, while Fig. 5.1 (ii) shows the penumbra of an X-ray beam. The penumbra 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

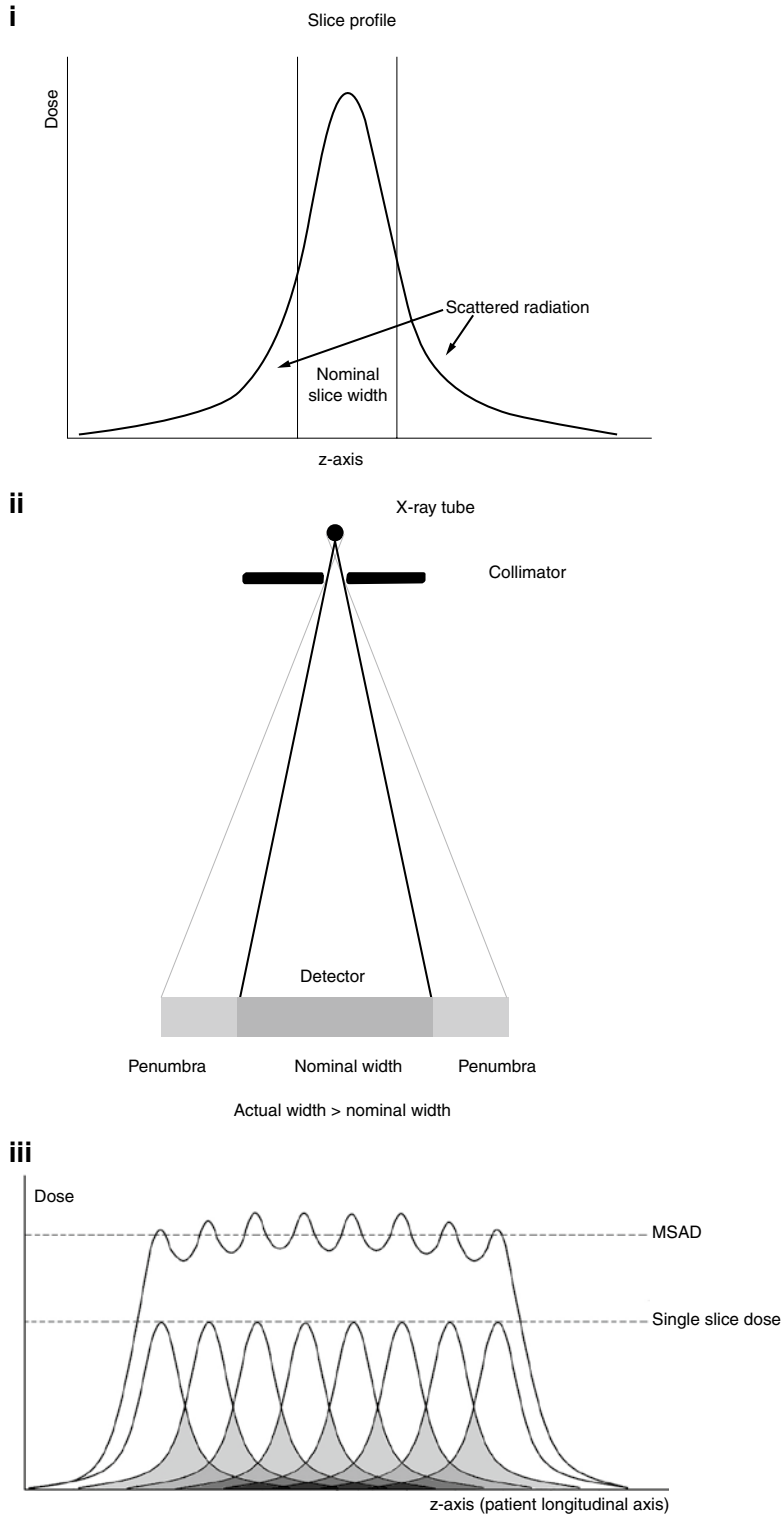

Fig. 5.1 (**i**) Image of a slice profile. (**ii**) Image of the X-ray penumbra. (**iii**) Summation of eight slice profiles and the resultant MSAD

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). The CTDI 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. The ionisation chamber (Fig. 5.2 (i)) 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, which for most CT scanners will not happen in a single gantry rotation, because the nominal beam width for most scanners is less than 100 mm. Therefore the nominal beam width (see Fig. 5.2 (ii)) is used to correct the chamber reading for the partial exposure, so that the cor-

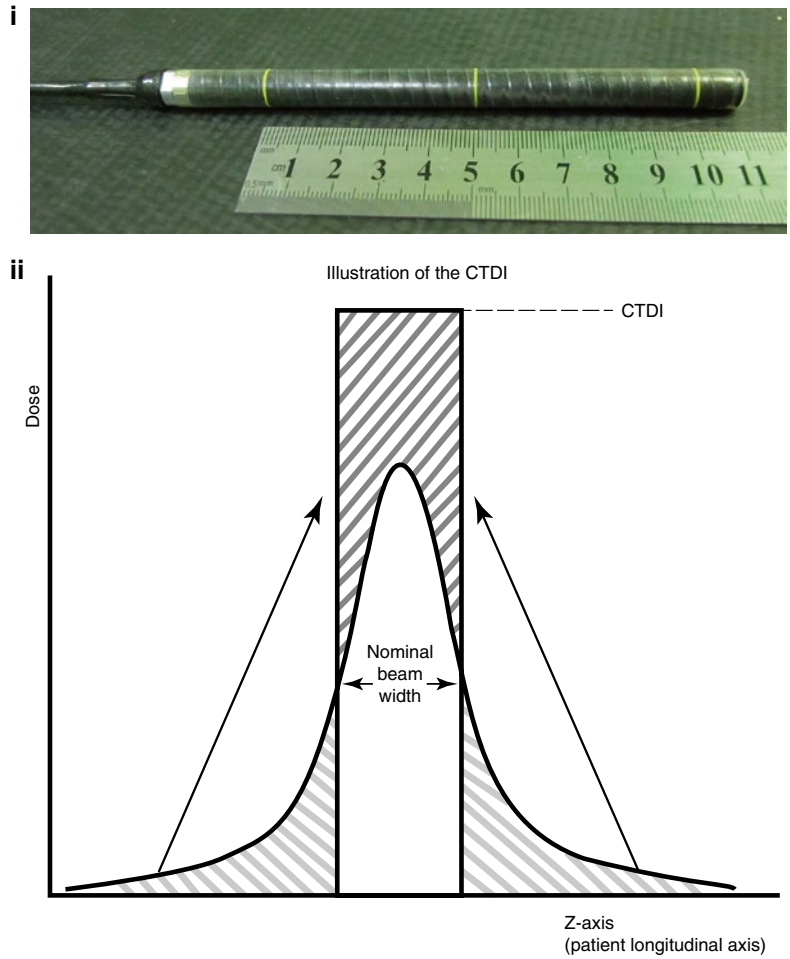

Fig. 5.2 (**i**) A typical CT ionisation chamber. (**ii**) Illustration of the CTDI

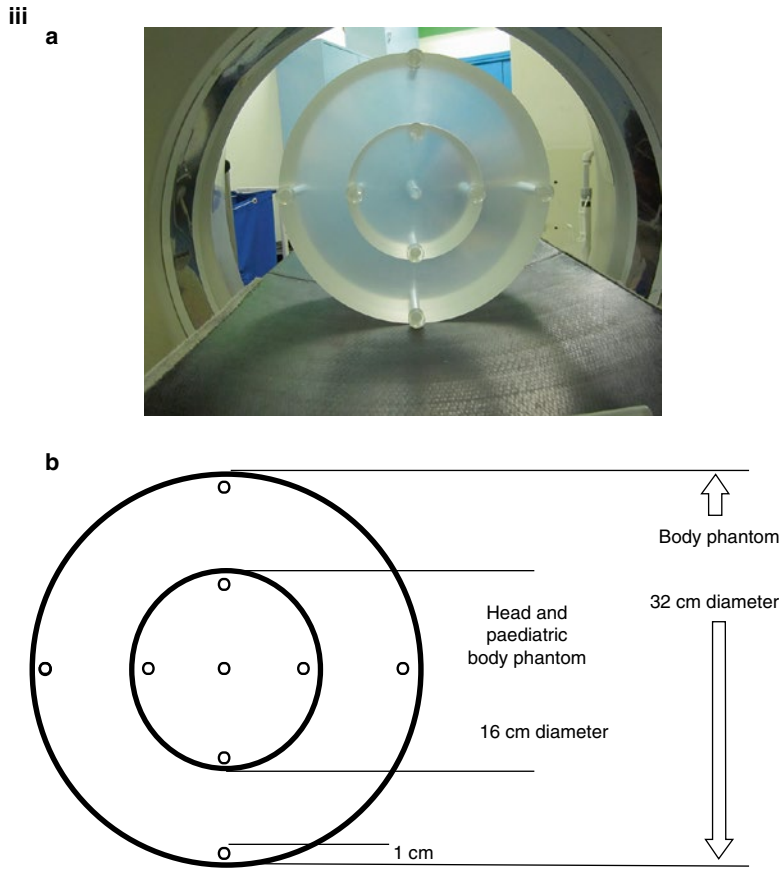

Fig. 5.2 (**iii**) (**a**, **b**) Photo of a PMMA CTDI phantom (**a**) and sketch of the phantom with dimensions (**b**)

rected 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 nonoverlapping slices x slice width [8] or by the width of an individual CT detector x 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 was 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].

However, 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 ($CTDI_{100,centre}$) 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 overranging (discussed in the next chapter on dose optimisation). 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 $mGy \cdot cm$ 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, but the $CTDI_{vol}$ 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 and 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 radiosensitivity 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. They have been adjusted over time [16, 17] as new evidence became available.

The measurement of effective doses in or on the 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, but has its 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 the 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] and 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 [20].

It is quite evident that there is a considerable variance in effective doses, but that 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 the next chapter.

5.6 Diagnostic Reference Levels

Diagnostic reference levels (DRLs) are dose levels for typical examinations of groups of standard-sized patients [25]. The ICRP states in Publication 105 [26] 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 can then be set using this data, and local practice can be improved by comparing the institution's data with appropriate DRLs. Radiology departments should set local DRLs by taking into account appropriate national or international DRLs [25].

There are ongoing efforts to tally the CT dose metrics, in particular the $CTDI_{vol}$ and DLP, for various studies for the purpose of comparing dose levels. In the European Union, DRLs are required by law [25]. 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 [25].

Various dose optimisation tools and possible approaches are discussed in the following chapter.

5.7 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 the patient dose, but is a reasonable indicator of the dose to the patient.
- The effective dose is the common denominator between different imaging modalities using ionising radiation. Comparing the DLP with, e.g. 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.
- Dose reference levels are not a dose-limiting tool in any given patient examination, but provide a good indication that if the radiological practice is operating at reasonable dose levels.

5.8 Summary

All through the 1980s and 1990s, there were no major debates or controversies regarding the topic of dose in CT [6], but there have been some discussions and debates on the continued appropriateness of the CTDI [27, 28]. 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.

References

1. Pernička F, McLean ID. Dosimetry in diagnostic radiology: an international code of practice. Vienna, Austria: 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. New York: American Association of Physicists in Medicine by the American Institute of Physics; 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 of AAPM Task Group. 2010; 111:20740–3846.
6. Kalender WA. Dose in x-ray computed tomography. Phys Med Biol. 2014;59(3):R129.
7. McNitt-Gray MF. AAPM/RSNA physics tutorial for residents: topics in CT: radiation dose in CT 1. Radiographics. 2002;22(6):1541–53.
8. Tack D, Gevenois PA, Abada HT. Radiation dose from adult and pediatric multidetector computed tomography. Berlin Heidelberg: 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. Directorate-General Environment, 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. Br J Radiol. 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. In: McLean ID, editor. Vienna, Austria: 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. 3.1 ed. IEC; 2012.
16. ICRP. 1990 recommendations of the international commission on radiological protection – ICRP Publication 60; 1991.
17. ICRP. The 2007 recommendations of the international commission on radiological protection – 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. Br J Radiol. 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 Dosimetry. 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. IAEA. Diagnostic radiology physics – a handbook for teachers and students. In: Dance DR, Christofides S, Maidment ADA, McLean ID, Ng KH, editors. Vienna, Austria: IAEA; 2014.
26. ICRP. Radiological protection in medicine. ICRP Publication 105. 2007.
27. Brenner DJ. Is it time to retire the CTDI for CT quality assurance and dose optimization? Med Phys. 2005;32(10):3225–6.
28. 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.

Dose Optimisation in CT Colonography

6

Christoph Trauernicht

Abstract

There is a growing awareness that radiation dose originating from medical diagnostic procedures in radiology is contributing an increasing proportion of the total population dose, especially for examinations using computed tomography (CT). In response to the heightened awareness of the importance of patient dose contributed by radiology procedures, there has been a general trend to optimise CT examinations to obtain the required diagnostic outcome while minimising the dose to the patient. This chapter describes various options for dose optimisation in CT colonography (CTC). These techniques are not necessarily unique to CTC and can be applied for optimisation of CT-scan protocols for other sites as well. Dose-reduction tools discussed include tube current reduction and automatic tube current modulation, tube voltage, iterative reconstruction, filtration, active collimation, CT detectors, shielding and other factors such as pitch and slice thickness.

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 cosponsored by the World Health Organization (WHO) and 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 ben-

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efit 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 and 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]. At the most general level, the use of radiation in medicine 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 the radiologist, 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 come 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; even so some argue that the risks of medical radiation should form part of an informed consent process [10]. 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 50–80 showed that the benefits from CTC screening outweigh 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

There are a number of controllable and built-in factors influencing patient dose in CT.

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; however, decreasing mAs will 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 AP (anterior-posterior) 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. This means that the tube current can be 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 preprogrammed, implemented in near real time using a feedback mechanism or achieved using a combination of preprogramming with a feedback loop [22]. Figure 6.1 indicates that the smaller patient thickness in the AP direction (and thus less attenuation of the X-ray beam) allows for a reduction in the tube current for those projections.

Automatic dose modulation can occur in the X-Y axis as described above, but 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

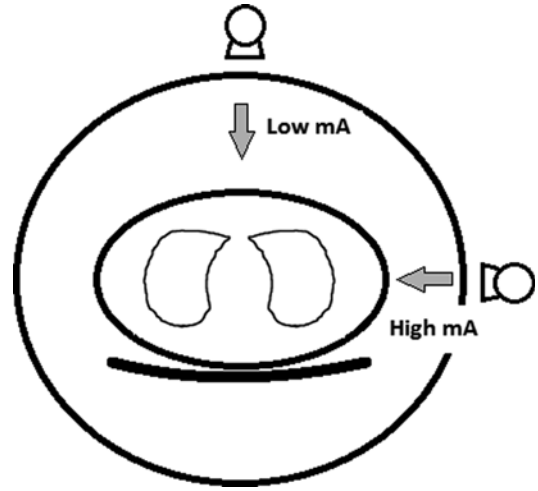

Fig. 6.1 Tube current modulation

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, such as the lens of the eye, thyroid and breast. This is done by decreasing the tube current when the tube passes closest to these organs, but 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 kVp 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's weight from 10 kg (kilogramme) 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 the patient's weight [16], whereas another approach takes into account the patient's 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's 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 and 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, with the first CT vendor introducing iterative reconstruction in 2008 [33].

All iterative reconstruction methods consist of three major steps, which are repeated iteratively. In the first step, a set of projections from an estimated volumetric object is generated to create artificial raw data. This data are 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 are 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 decreases of 25.1 % in another study [41] when compared to filtered back-projection image reconstruction [42], while another pilot study showed that the radiation dose during CTC can be reduced 50 % below currently accepted low-dose techniques without significantly affecting the image quality when an adaptive statistical iterative reconstruction technique was

used for image reconstruction [43]. While there is some variation in the amount of dose saving, there is a significant dose reduction in all cases.

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 [44] to reduce the radiation dose to the patient, especially the skin dose [45].

6.4.6 Active Collimators: Overranging

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 [46]. This overranging 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-overranging depends on slice width and pitch [47]. Z-overranging increases with increasing cone angle of large Z-axis coverage multi-detector CT scanners [48]. 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 for pitch values [49]. Figure 6.2 (i) shows the concept of overranging, 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 overranging. Active collimation (Fig. 6.2 (iii)) reduces the dose outside of the planned scan length by opening and closing the collimator asymmetrically.

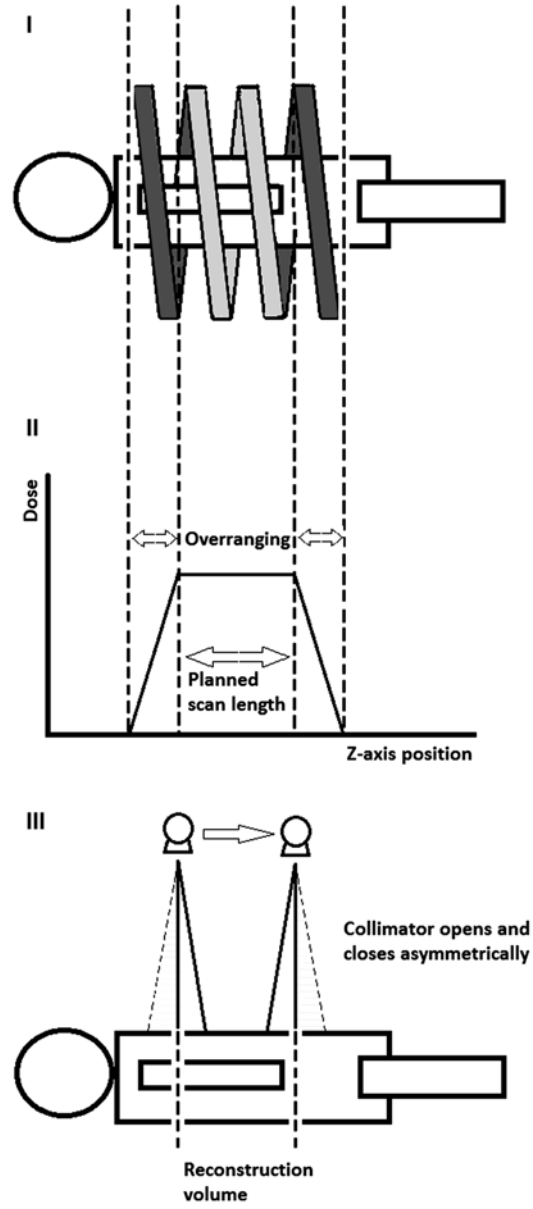

Fig. 6.2 (**i**) & (**ii**) Overranging – the deposition of dose outside of the planned scan length. (**iii**) Active collimation to block parts of the beam that are not used for image reconstruction at the beginning and end of each spiral scan

6.4.7 Detector Material

The X-ray detector is a very important determinant of the dose performance of a CT system [45]. 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 [50]. 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 [51].

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 [52]. The use of shielding for radiation sensitive tissues and organs in the examination field is generally not recommended [53] because of an increase in noise and beam-hardening artefacts.

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 [54]. 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, the patient dose is less, but data must be interpolated to preserve spatial resolution along the Z-axis (like in Fig. 6.3 (ii)) [55]. By increasing the pitch with a fixed scan length and mAs, the radiation dose is reduced. The detectability of small lesions may be reduced due to a lower dose and an increase in image noise.

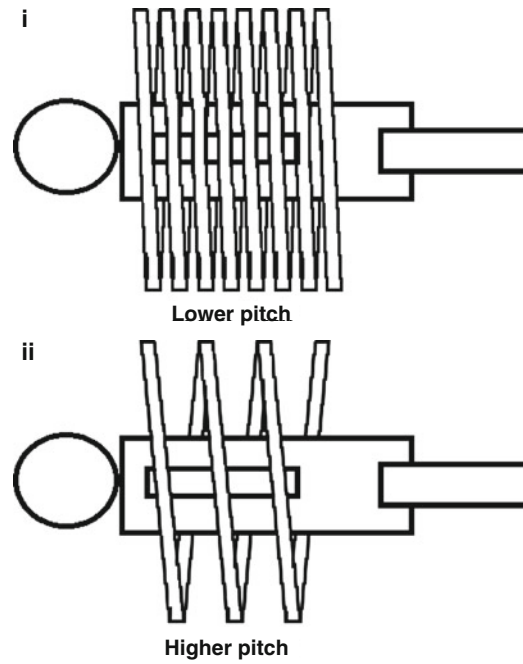

Fig. 6.3 (**i**) & (**ii**) Explanation of pitch

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 [55]. A decrease in slice thickness by 50 % will necessitate a dose increase by a factor of 2 to fully compensate.

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 minimise 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 isocenter. 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 [56].

6.6 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 e.g. 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 the 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.

6.7 Summary

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. A good measure for optimisation is the use of dose reference levels as discussed in the previous chapter. 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, the 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. ICRP Publication 103; 2007.
2. ICRP. Radiological protection in medicine. ICRP Publication 105; 2007.
3. Organization WH. 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 Am J Roentgenol. 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. 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 Jr J, 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 Am J Roentgenol. 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. Feasibility of MDCT colonography in ultra-low-dose technique in the detection of colorectal lesions: comparison with high-resolution video colonoscopy. AJR Am J Roentgenol. 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. Br J Radiol. 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 Jr JM. 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 Am J Roentgenol. 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 Am J Roentgenol. 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 CTDIvol. Radiat Prot Dosimetry. 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 thoracoabdominal computed tomography angiography: improved dose effectiveness. Invest 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. Phys Med Biol. 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. arXiv preprint arXiv:09044495. 2009.
38. Irwan R, Nakanishi S, Blum A. AIDR 3D–reduces dose and simultaneously improves image quality. Toshiba Medical Systems Whitepaper available via 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 Am J Roentgenol. 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. Invest 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. Br J Radiol. 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 Am J Roentgenol. 2010;195(1):126–31.
44. Toth TL, Cesmeli E, Ikhlef A, Horiuchi T, editors. Image quality and dose optimization using novel x-ray source filters tailored to patient size. Medical Imaging; 2005: International Society for Optics and Photonics.
45. 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.
46. Nicholson R, Fetherston S. Primary radiation outside the imaged volume of a multislice helical CT scan. Br J Radiol. 2002;75(894):518–22.
47. 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.
48. 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.
49. 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 Am J Roentgenol. 2010;194(1):W49–55.
50. Von der Haar T, Klingenbeck-Regn K, Hupke R. Improvement of CT performance by UFC detector technology. Advances in CT IV: Springer; 1998. p. 9–15. Springer Berlin Heidelberg.
51. 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.
52. 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.
53. McCollough CH, Primak AN, Braun N, Kofler J, Yu L, Christner J. Strategies for reducing radiation dose in CT. Radiol Clin North Am. 2009;47(1):27–40.
54. Hendee WR, Ritenour ER. Medical imaging physics. New York: John Wiley & Sons; 2002.
55. Bushberg JT, Boone JM. The essential physics of medical imaging. Philadelphia: Lippincott Williams & Wilkins; 2011.
56. Li J, Udayasankar UK, Toth TL, Seamans J, Small WC, Kalra MK. Automatic patient centering for MDCT: effect on radiation dose. AJR Am J Roentgenol. 2007;188(2):547–52.

Overview of CTC in Imaging the Colon

7

Rachel Baldwin-Cleland and Janice Muckian

Abstract

The transition of a new technique into clinical practice involves review of the practice, audit and the development of standards and guidelines to support the introduction of the technique. CTC has been developed by gastrointestinal-focused radiologists throughout the globe, with guidelines issued to aid implementation and to establish best practice for centres performing CTC. This chapter reviews the development of CTC and discusses current guidance and where CTC may be heading in the future.

7.1 Introduction

Colorectal cancer (CRC) is the third most common cancer worldwide, equating to 1.4 million people diagnosed in 2012 [1], and the third leading cause of cancer-related death in the 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] and 92 % [7] to 100 % [8] is possible if the cancer is diagnosed early at T1 stage; however, it can drop to 8 % 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 colonoscopy, either for pathological reasons, such as stenosing cancer, or technical reasons such as a fixed sigmoid. These patients would have traditionally been sent for a barium enema but instead were diverted to CTC. Therefore it was extremely important during the development of CTC that the accuracy and sensitivity for cancer were higher than barium enema, which has been

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reported with a sensitivity of 86 % [9], and comparable to optical colonoscopy at 94.7 % [10]. Published CTC sensitivity for CRC ranges from 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].

Due to CTC's higher sensitivity, better patient tolerance and published guidance recommending CTC, most countries have now phased out the use of barium enemas for the detection of CRC [14]. Therefore patients may now present directly to a CTC service, as they would have done with direct barium enema referrals, with symptoms such as altered bowel habit, abdominal pain, weight loss and anaemia [15]. 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) [16], once-only flexible sigmoidoscopy (bowel scope) [5] and multitarget stool DNA tests such as Cologuard [17] or faecal immunochemical tests (FITs) [18]. 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 pilot CRC bowel screening programmes [19] 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, 20, 21]. 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 are reported as 82.9 % and 91.4 %, respectively [22], and adenomas >10 mm 87.9 and 97.6 %. However, there are huge variations seen across the meta-analysis data [22] with some published findings ranging from 59 to 86 % for sensitivity of polyps 6–9 mm in size [23–26]. The SIGGAR study [9, 27] was a large UK multicentre randomised study that compared CTC with barium enema and colonoscopy, respectively. It showed that the detection rate of cancer and polyps >10 mm was significantly higher in CTC than barium enema [9] but lower than the gold standard for comparison-colonoscopy's 100 % detection rate [27]. However, most studies have shown a link in accuracy with the experience of the reporting radiologists and the CTC technique used.

7.3 Development of CTC

Traditionally barium enema was the radiology choice for imaging the large bowel, but, as demonstrated, a poor comparator to colonoscopy in its sensitivity and specificity of pathology [28]. It was thought of as physically taxing for both operator (radiologist or barium enema trained radiographer) as well as the patient [29]. Evidence has shown barium enema to be highly operator dependent [29], with a 4.4–5 % technical failure rate [9, 30]. Although the rate of perforation was less than 1 in 24,000 [31], the rate of mortality for barium-related perforated peritonitis patients was 10 % [31]. Therefore the search for a less-invasive, better tolerated, quicker and more accurate test began.

CTC was first described in the 1980s [32], though most attribute Vining et al. [33] who described it as 'interactive 3D medical imaging'. It has been known as virtual endoscopy [34], virtual colonoscopy (VC) [35] 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 [34]. Optimisation of data acquisition and display was the focus of some original research studies, with techniques, preparation and interpretation following suit.

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 [36]. However, with further CT technology development, multi-detector scanners can now scan isotropic submillimetres slices within seconds and then process and display them almost as fast [37]. 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 [6].

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 minutes 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 minutes; on average it is however recommended a 30-minutes appointment slot is required for each CTC [38].

Crucially, modern scanners have the opportunity to reduce the radiation dose received by patients by up to 50 % during the test [14, 39], 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 (CAD) 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 [40]. Software and processing features such as these were originally acquired separately to the CT scanner but now may come as a standard feature when a CT scanner is purchased.

7.3.2 Interpretation Methods

Accurate interpretation of CTC requires additional focussed training [41] and involves the use of specific dedicated CTC software [14, 15, 38, 42].

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 [43]. It is accepted that accurate interpretation must include a combination of 2D and 3D review [14, 44, 45].

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 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 [46]. Technical developments have improved CAD over the years

[46, 47]; however its performance can be dependent on the quality of scan data obtained [48]. Regardless it has been shown to significantly alter polyp identification in 3D review with the greatest positive effect seen in inexperienced CTC readers [49, 50]. However, poor bowel preparation can produce false-positive CAD findings, causing some experienced readers choosing not to use it [51].

Radiographers with comparable experience to radiologists have been shown to display similar ability to detect polyps [52, 53]. Currently in the UK, there is no established algorithm for radiographer interpretation, with most centres that have experienced reporting CTC radiographers offering a preliminary read with a radiologist reviewing the CTC as a second reader and providing an extracolonic report [38].

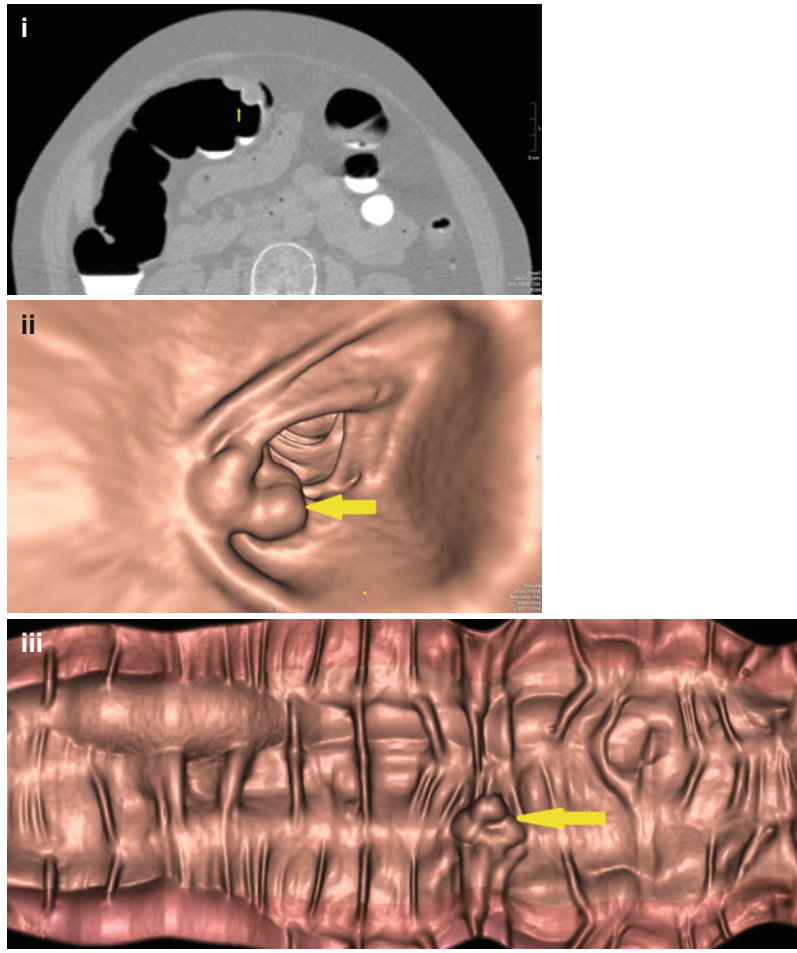

Fig. 7.1 (**a**) (**i**) A supine 2D axial CTC scan visualised in a colon window, on which faecal tagging is seen as white pools of fluid. A centrally depressed 'jelly bean'-shaped cancer is demonstrated in the transverse colon (*yellow arrow*). (**a**) (**ii**) The same supine CTC scan is now presented 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. (**a**) (**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

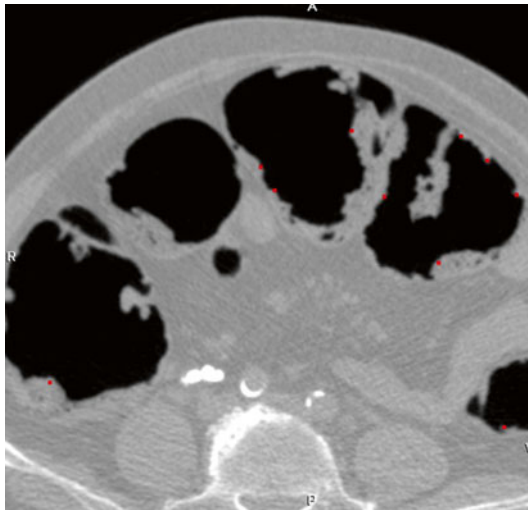

Fig. 7.2 2D axial image of a CTC performed in a poorly prepared bowel without faecal tagging. The CAD findings are shown as *red dots*. The inadequate bowel preparation resulted in a high number of CAD findings. In a well-prepared bowel, far fewer CAD findings would be expected

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 barium enemas, for example, polyethylene glycol or sodium picosulphate (Picolax®) [54]. Whilst these generally resulted in an 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 which had the potential to hide pathology [37, 55]. As the cohort of patients referred to CTC are often frailer and more comorbid, a less vigorous bowel cleansing regime is preferable [56].

The aim of bowel cleansing is to balance patient acceptability with diagnostic accuracy, achieving adequate cleansing and faecal tagging [55]. There is a range of bowel preparation regimes utilised in UK institutions [51], 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 which were deemed inadequate predominately due to bowel preparation, crucially, the absence of faecal tagging in the cohort of patients having Picolax® alone as their preparation regime [55]. 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 [15, 38, 44, 57, 58], 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) [42]. The choice of tagging product is however dependent on local experience

and no clear guideline on preference has been published [14]. 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, which was a common technique used to insufflate the colon during barium enema [59]. 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 [60]. Other manufactures have also developed automated insufflators, and automated insufflation is now the recommended way to insufflate the colon [14, 47, 58]. The use of an automated pressure-controlled insufflator is described in detail in Chaps. 9 and 10.

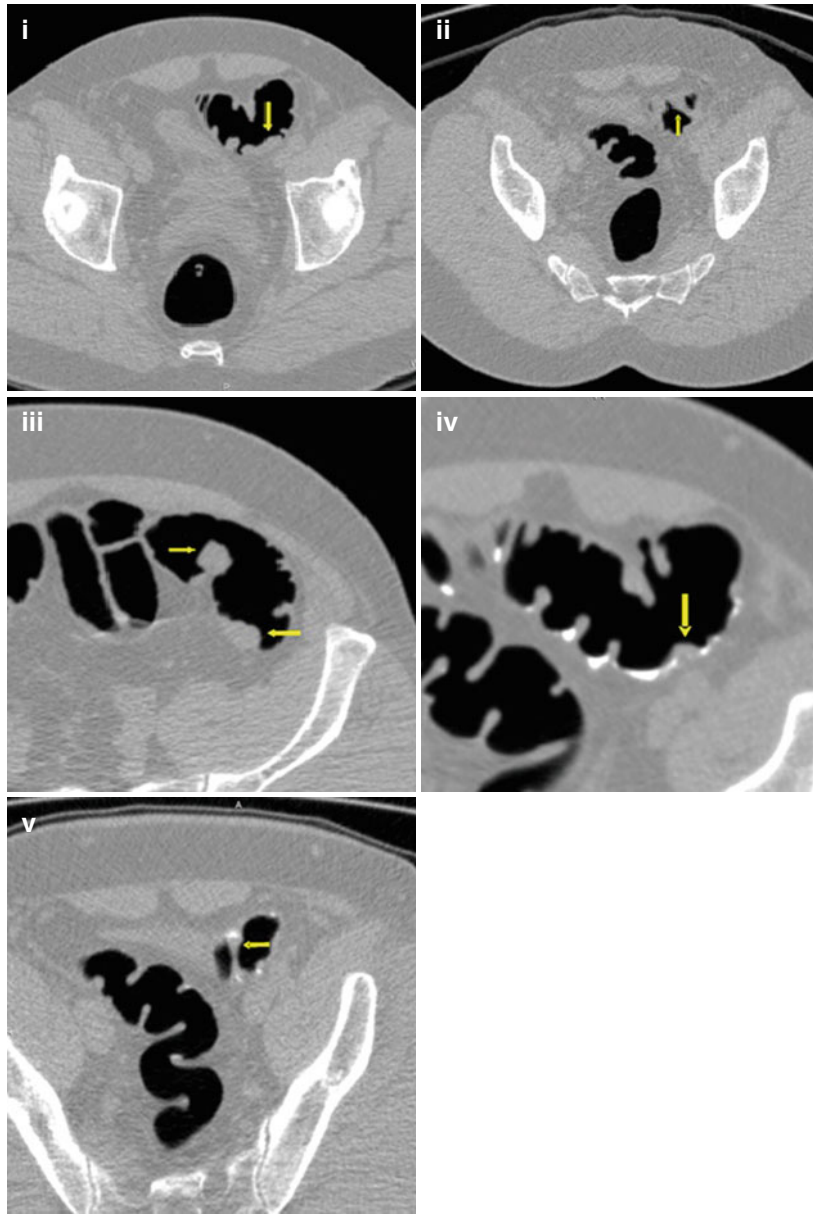

Fig. 7.3 (**a**) (**i**) 2D axial supine image of a CTC performed with cathartic regime only (Picolax®). The *yellow arrow* indicates a soft tissue density within the sigmoid colon which could possibly represent a polyp or may simply be untagged residue. (**a**) (**ii**) 2D axial prone image of the same 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. (**a**) (**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. (**a**) (**iv**) and (**v**) supine and prone images of the repeated examination undertaken in Fig. 7.3 **(a) (i), (a) (ii), (a) (iii)**. This was performed with combination of catharsis (Picolax®) and faecal tagging (Gastrografin®). (**a**) (**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). (**a**) (**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 [59] commented that there was a lack of standards for CTC training, technical performance, interpretation methods and the management of extra-colonic findings. This document also highlighted that CTC had further limitations, namely:

- Polyps cannot be removed during the CTC.
- Inadequate data on flat adenoma detection rates at 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 [59] 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, e.g. subsequent endoscopy or further evaluation of extra-colonic findings or due to incident extra-colonic findings. More recent literature published [61] shows that CTC is 29 % less expensive than optical colonoscopy in the American Medicare population. The complexity of the CTC test will affect the cost in comparison to a barium enema. In the UK there is currently no national specific tariff, and the price of the CTC is often locally negotiated [38]. America now recognises CTC as part of the screening algorithm [15] with reimbursement being subject to insurance company tariffs.

Metal artefacts can now be reduced by products such as MAR (Smart Metal Artefact Reduction – GE®) [62] and O-MAR (Metal Artefact Reduction for Orthopaedic Implants – Philips®) [63] by using projection-based and iterative methods to reduce streak artefacts, beam hardening, edge artefacts and photon starvation [62, 63]. Figure 7.4a (i) and (ii) demonstrates the effect of using metal artefact reduction software.

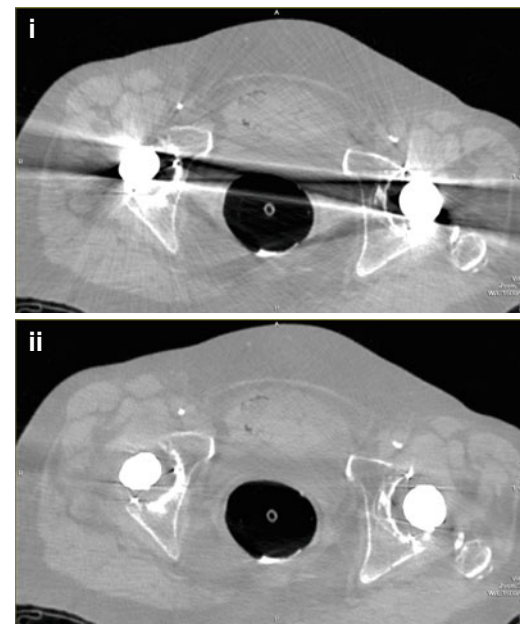

Fig. 7.4 (**a**) (**i**) 2D axial supine image of a patient with bilateral metal hip prosthesis. (**a**) (**ii**) 2D axial supine image with Philips O-MAR® applied to the original image data

7.6 Team Approach and Training

To deliver a CTC service, a team approach is vital [38, 47], with UK published CTC standards recommending local development of department protocols, which clearly define skills and competencies for all team members [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 [38]. 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 [38].

Training combined with structured competencies can help reduce the performance gaps between different institutions [64]. It has been shown that radiographers, having been provided with the appropriate training, can acquire a level of interpretation expertise which enables them to accurately evaluate the acquired images at the time of examination [52, 64]. 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) [38, 64]. This optimises efficiency and helps to ensure patients receive the best possible experience and outcome [38].

Radiographers should be provided with information and training with regard to all aspects of CTC including how to consent, which is covered in Chap. 3, and 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 (i.v.) contrast or to perform a decubitus scan when the two initial scans are deemed inadequate. 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 [65–67]. These range from 'hands-on' courses covering the practical aspects of image acquisition to those which are more targeted at image interpretation. The availability of appropriate radiographer training elsewhere is limited, and, when not available, training in some centres may be provided by the lead CTC radiologist as a minimal standard.

7.7 Published Documentation which has Influenced CTC

The international collaboration by the UK, Europe, Australia and New Zealand resulted in the CT colonography standards [47] published in 2010. This paved the way for NHS national bowel cancer screening programme (BCSP) guidelines to be published in England in 2012 [42], which are due to be updated in early 2016. The European Society of Gastrointestinal and Abdominal Radiology (ESGAR) published a second consensus statement on CTC in 2013, with a further publication by the European Society of Gastrointestinal Endoscopy (ESGE) and ESGAR in 2014, which will be reviewed in 2019 [58]. The UK Royal College of Radiologists, in conjunction with the British Society of Gastrointestinal and Abdominal Radiology (BSGAR), published their own in 2014 [38]. The American Cancer Society did not recommend CTC in 2003 as a screening tool [59] but did state they would relook at CTC as additional data became available, and, in 2008 they included CTC, every 5 years, as an alternative CRC prevention test, and colonoscopy every 10 years [68]. Further guidance for America by the American College of Radiology on performance parameters was published in 2014 [15].

7.8 CTC in the Future

The ionising radiation risk and inconsistency in sensitivity and specificity results mean CTC at present has only been integrated into the screening programmes as an alternative test to current algorithms but not as a primary option in Europe [69]. America has seen falling incidence and mortality which are 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 America in 2008 recommend full assessment of the colon by either optical colonoscopy or by radiology, as the preferred choice over the faecal tests such as gFOBt or FIT [6]; later documentation clarifies the radiology as CTC, with promotion of screening every 5 years [15, 37].

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 America [15, 70]. Europe has not yet adopted these algorithms and they are the current hot topic in research literature, and the authors feel it will be the new developing area for CTC. Some studies have already proposed CTC as a primary screening test to look for adenomas and CRC directly as they believe that in competent hands CTC has shown similar detection rates comparable to colonoscopy [16, 35, 71, 72]. CTC's performance, sensitivity and specificity rates and cost and patients' acceptance will need to be comparable for clinicians and governments to accept it as part of a primary screening pathway.

The English BCSP radiologists are in favour of accreditation for CTC interpretation [51], and the BCSP quality assurance committee are looking into accreditation schemes for English BCSP practices. The accreditation process would be for centres performing CTC and for individual radiographers and radiologists in order to perform and report CTC. However, to date this has not been formally published, but is due to be outlined in the updated BCSP imaging guidelines early 2016.

7.9 Key Messages

- CTC is a more accurate test than barium enema and, therefore, has replaced the barium enema as the choice for radiological imaging of the large bowel in the diagnosis of CRC.
- Sensitivity and specificity of CTC are variable.
- 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 and the use of CTC in screening algorithms are hot topics for the future development of CTC.

7.10 Summary

CTC has evolved considerably since its inception in the 1980s, with its sensitivity and specificity higher than barium enema, but the 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. Until the variation in CTC outcomes improves, CTC will have a tough time becoming a direct pathway in bowel screening algorithms or as a primary tool for surveillance. 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.

References

1. Ferlay J, Soerjomataram I, Ervik M, Dikshit R, Eser S, Mathers C, Rebelo M, Parkin DM, Forman D, Bray F. GLOBOCAN 2012 v1.0, cancer incidence and mortality worldwide: IARC Cancer Base No. 11 [Internet]. Lyon: International Agency for Research on Cancer; 2013. http://globocan.iarc.fr. Accessed 05 July 2015.
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 13 Oct 2015.
3. World Health Organisation: International Agency for research on Cancer. World Cancer fact sheet: world cancer burden 2012; 2014. http://publications.cancerresearchuk.org/downloads/product/CS_REPORT_WORLD.pdf. Accessed 05 Aug 2015.
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. doi:10.1007/s10900-010-9348-0.
5. Atkin WS, Edwards R, Kralj-Hans I, Wooldrage K, Hart AR, Northover JM, et al. 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.
6. Levin B, Lieberman DA, McFarland B, et al. 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.
7. American Cancer Society. Colorectal cancer: early detection, diagnosis and staging topics. Revised 13th August 2015. http://www.cancer.org/cancer/colonandrectumcancer/detailedguide/colorectal-cancer-survival-rates. Accessed 13 Oct 2015.
8. Cancer Research UK. Bowel cancer survival statistics: bowel cancer survival by stage at diagnosis. http://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/bowel-cancer/survival#heading-Three. Accessed 13 Oct 2015.
9. Halligan S, Wooldrage K, Dadswell E, Kralj-Han I, von Wagner C, Edwards R, Atkin W. Computed tomographic colonography versus barium enema for diagnosis of colorectal cancer or large polyps in symptomatic patients (SIGGAR): a multicentre randomised trial. Lancet. 2013;381:1185–93.
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.
11. Hara AK, Johnson CD, Reed JE, et al. Detection of colorectal polyps with CT colonography: Initial assessment of sensitivity and specificity. Radiology. 1997;205:59–65.
12. Royster AP, Fenlon HM, Clarke PD, et al. CT colonoscopy of colorectal neoplasms: Two-dimensional and three-dimensional virtual-reality techniques with colonoscopic correlation. AJR Am J Roentgenol. 1997;169:1237–42.
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. http://www.ncbi.nlm.nih.gov/pubmed/24519111. Accessed 01 July 2015.
14. Laghi A. Computed tomography colonography in 2014: an update on technique and indications. World J Gastroenterol. 2014;20:16858–67. doi:10.3748/wjg.v20.i45.16858.
15. ACR-SAR-SCBT-MR Practice parameter for the performance of computed tomography (CT) colonography in adults – revised 2014. http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/CT_Colonography.pdf. Accessed 03 June 2015.
16. Guittet L, Bouvier V, Mariotte N, et al. 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.
17. Imperiale TF, Ransohoff DF, Itzkowitz SH, Levin TR, Lavin P, Lidgard GP, et al. Multitarget stool DNA testing for colorectal-cancer screening. N Engl J Med. 2014;370:1287–97.
18. 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. doi:10.5009/gnl.2014.8.2.117.
19. 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. http://onlinelibrary.wiley.com/doi/10.1002/ijc.23273/pdf. Accessed 01 July 2015.
20. Sewitch MJ, Fournier C, Ciampi A, Dyachenko A. Adherence to colorectal cancer screening guidelines in Canada. BMC Ggastroenterol. 2007;7:39–48.
21. Center MM, Jemal A, Smith RA, Ward E. Worldwide variations in colorectal cancer. CA Cancer J Clin. 2009;59:366–78. http://onlinelibrary.wiley.com/doi/10.3322/caac.20038/full#bib32. Accessed 01 July 2015.
22. de Haan MC, van Gelder RE, Graser A, Bipat S, Stoker J. Diagnostic value of CT-colonography as compared to colonoscopy in an asymptomatic screen-

ing population: a meta-analysis. Eur Radiol. 2011;21:1747–63.
23. 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.
24. Mulhall BP, Veerappan GR, Jackson JL. Meta-analysis: computed tomographic colonography. Ann Intern Med. 2005;142:635–50.
25. 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.
26. 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.
27. 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.
28. 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.
29. Levine MS, Rubesin SE, Laufer I. Barium studies in modern radiology: do they have a role? Radiology. 2009;250:18–22.
30. 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.
31. Blakeborough A, Sheridan MB, Chapman AH. Complications of barium enema examinations: a survey of consultant radiologists 1992–1994. Clin Radiol. 1997;52:142–8.
32. Coin CG, Wollett FC, Coin JT, et al. Computerized radiology of the colon: a potential screening technique. Comput Radiol. 1987;7:215–21.
33. 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.
34. Vining DJ. Virtual endoscopy: is it reality? Radiology. 1996;200:30–1.
35. 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;349:2191–200.
36. Halligan S, Fenlon HM. Virtual colonoscopy. BMJ. 1999;319:1249–52.
37. 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. doi:10.7150/jca.5858.
38. British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiologists. BFCR (14)9. Guidance on the use of CT colonography for suspected colorectal cancer. London: The Royal College of Radiologists; 2014. https://www.rcr.ac.uk/sites/default/files/publication/BFCR[14]9_COLON.pdf. Accessed 13 Sept 2015.
39. 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.
40. Bortz JH. An approach for performing a successful computed tomography colonography. S Afr J Rad. 2014;18(1):Art. #607, 11. http://www.sajr.org.za/index.php/sajr/article/viewFile/607/pdf. Accessed 13 Oct 2015.
41. 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.
42. NHS Bowel Cancer Screening Imaging guidelines. No 5: guidelines for the use of imaging in the NHS Bowel Cancer Screening Programme. 2nd ed. Sheffield: NHS Cancer Screening Programmes; 2012. http://www.cancerscreening.nhs.uk/bowel/publications/. Accessed 01 June 2015.
43. 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.
44. Burling D. International collaboration for CT colonography standards. CT colonography standards. Clin Radiol. 2010;65:474–80. doi:10.1016/j.crad.2009.12.003.
45. 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.
46. Bielen D, Kiss G. Computer-aided detection for CT colonography: update 2007. Abdom Imaging. 2007;32:571–81.
47. Yoshida H, Dachman AH. CAD techniques, challenges, and controversies in computed tomographic colonography. Abdom Imaging. 2004;30:26–41.
48. 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 9412, Medical Imaging 2015: Physics of Medical Imaging. 2015;9412. doi:10.1117/12.2081982. http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=2210265. Accessed 01 Aug 2015.
49. Burling D, Moore A, Marshall M, et al. Virtual colonoscopy: effect of computer-assisted detection (CAD) on radiographer performance. Clin Radiol. 2008;63:549–56.
50. 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.

51. 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.
52. 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.
53. 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.
54. 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.
55. 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.
56. 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.
57. 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. doi:10.3348/kjr.2007.8.4.264.
58. 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. European Radiology. 2015;25:331–45. http://doi.org/10.1007/s00330-014-3435-z. Accessed 01 Oct 2015.
59. 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 markers. CA Cancer J Clin. 2003;53:44–55.
60. Yee J. CT colonography: techniques and applications. Radiol Clin North Am. 2009;47:133–45.
61. 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. doi:10.1007/s00261-015-0538-1.
62. GE Healthcare – Smart Metal Artifact Reduction (AMR) Date of publication: 8/21/2014 – Document ID: DOC1381483; JB23002XX http://www3.gehealthcare.com/en/products/categories/computed_tomography/radiation_therapy_planning/metal_artifact_reduction. Accessed 13 Oct 2015.
63. Philips NetForum community – Metal Artifact Reduction for Orthopedic Implants (O-MA) 8th January 2012 http://clinical.netforum.healthcare.philips.com/us_en/Explore/White-Papers/CT/Metal-Artifact-Reduction-for-Orthopedic-Implants-(O-MAR). Accessed 13 Oct 2015.
64. 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.
65. St Marks – CTC courses for radiographers. https://www.stmarkshospital.org.uk/shop/courses/st-marks-hands-on-ct-colonography-ctc-training-course-for-radiographers. Accessed 09 Sept 2015.
66. British Abdominal Imaging – The CTC Northern School -Leeds – CTC courses for radiographers and radiologists http://www.britishabdominalimaging.co.uk/. Accessed 09 Sept 2015.
67. Keele University. Key Facts: NUR-40036: advance practice in computed tomographic colonography. http://www.keele.ac.uk/health/postgraduate/individualmodules/advancedpracticeincomputedtomography-colonography/. Accessed 13 Oct 2015.
68. 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.
69. 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. doi:10.1136/gut.2008.156448.
70. Levine MS, Yee J. History, evolution, and current status of radiologic imaging tests for colorectal cancer screening. Radiology. 2014;273:S160–80. doi:10.1148/radiol.14140531.
71. Brenner DJ, Georgsson MA. Mass screening with CT colonography: should the radiation exposure be of concern? Gastroenterology. 2005;129:328–37.
72. Kim DH, Pickhardt PJ, Taylor AJ, Leung WK, Winter TC, Hinshaw JL, et al. CT colonography versus colonoscopy for the detection of advanced neoplasia. N Engl J Med. 2007;357:1403–12.

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

Rachel Baldwin-Cleland and Stephen Wilson

Abstract

It must be remembered that CT colonography (CTC) is an interventional procedure, and there are many stages to produce the best results for both the patients and the medical teams: the referral, bowel preparation, CTC training and technique, patient aftercare and the final report. Throughout these stages, patient safety must be considered by the radiographer, advanced practitioner and radiologist. A CTC radiographer should consider whether the procedure is appropriate and will the patients cope with the oral medications to cleanse and tag their bowel. Consideration should also be given to whether the department has the correct documentation for the administration of carbon dioxide (CO_2,) for colonic distension, intravenous contrast and antispasmolytic injections.

8.1 Introduction

Although CT colonography (CTC) has been described as safer than colonoscopy [1, 2], it still has the potential for adverse events [2], and departments must have appropriate training and procedure guidelines to cover events such as colonic perforation and vasovagal reactions. Images should be reviewed during and after the procedure for perforation and staff must be fully trained in recognising the appearance of perforation at CT. 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.

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

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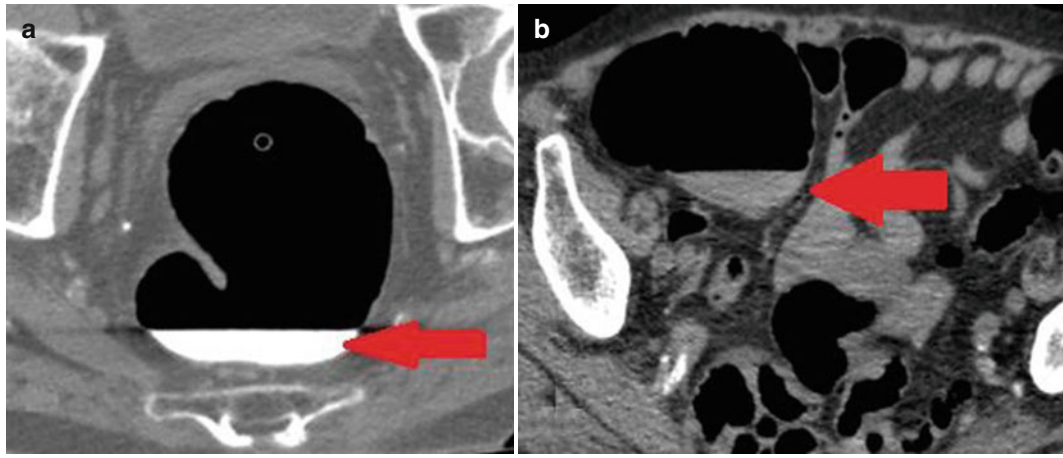

Fig. 8.1 (**a**) Residual high-density 'tagged' fluid (*red arrow*) is seen as bright white on the supine CTC image. (**b**) Untagged fluid (*red arrow*) will be seen as much darker, with an almost soft tissue density

optical colonoscopy [4]. There still 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, but recent research has shown that the use of sodium amidotrizoate 100 mgs/meglumine amidotrizoate 660 mg (Gastrografin®) as both a laxative and faecal tagging agent combined with an effective 24 h low residue diet can result in highly diagnostic images [5]. The high osmolality of Gastrografin® draws fluid into the colonic lumen and increases the density of the residual fluid [6]. Figure 8.1a, b shows CTC images of tagged and untagged bowel preparation.

The use of oral contrast to provide faecal tagging enables the 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, 7–10]. As well as increasing the sensitivity of CTC, faecal tagging decreases the necessity of a residual dry bowel, as required in endoscopy procedures [11]. 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.

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 (i.v.) 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 [8].

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 medical procedures [12]. 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 [12]. The supply of the medicine must be authorised by a clinical professional, and each patient must receive written information

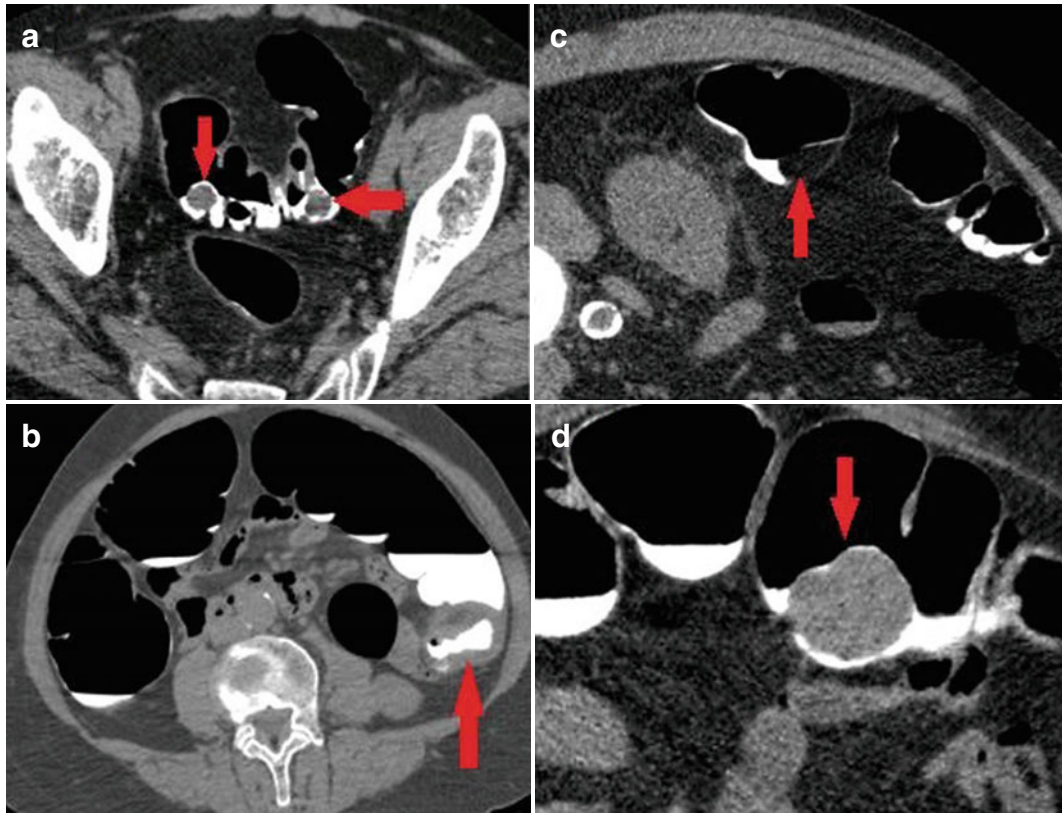

Fig. 8.2 (**a**) Supine image of a patient who was administered oral tagging as part of bowel preparation shows two polyps (*red arrows*) in the sigmoid colon surrounded by faecal tagging. (**b**) Supine image of a patient who was administered oral tagging as part of bowel preparation shows an annular 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*)

(including named contact) and an explanation on the safe use of the product [12]. This is now a compulsory practice in the UK for distribution of these bowel preparation products. Gastrografin® is not listed in the alert, but it is still best practice to adhere to ensure the same safety standards.

Patient bowel preparation instructions should advise patients to remain hydrated and continue consuming approximately 250 mLs of non-diuretic fluids per hour whilst awake [13]. If this is not followed, there is a risk of hypokalaemia (low potassium) which requires prompt medical attention to restore the fluid/electrolyte imbalance. If left unresolved hypokalaemia can be serious in the frail and debilitated patients [13]. 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 [14].

The delivery of pharmaceuticals to patients by 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 and the inclusion of the appropriate literature with the 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 shell fish or strawberry allergy must not be confused with a specific iodine allergy, and there remains no link between high sensitivity and iodine-based oral/intravenous (i.v.) contrast agents [14]. If a patient has a documented i.v. contrast allergy, then an untagged CTC or a catharsis regime with barium tagging may be discussed with your clinicians depending on your individual department's protocols [15]. The drawback with untagged studies is residual faecal matter, which may mimic or obscure pathology, especially within areas of poor distension [11]. Some institutions routinely use barium-based tagging, but a change in diet and bowel cleansing must be used in conjunction [16]. 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 [17].

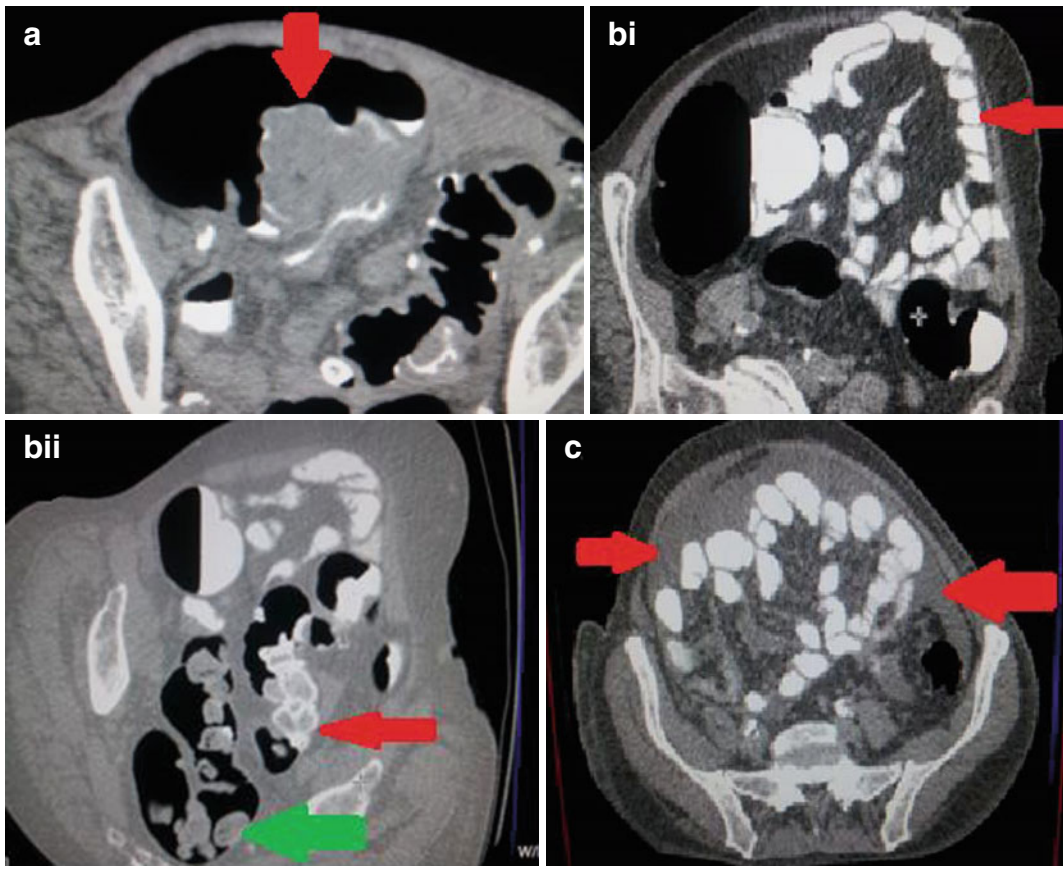

Fig. 8.3 (**a**) Large polypoidal mass within the caecum (*red arrow*) including the ileocaecal valve. This mass is not obstructing as the small bowel and large bowel contain very little faecal matter and there is tagging seen throughout. The patient is still a priority but does not require emergency admission. (**b**) (**i**) and (**ii**). CTC images of the same patient. 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**) 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 is consistent with the bowel preparation being ingested later than instructed. Such patients do not need emergency admission. (**c**) 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

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 [5, 18, 19]. 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, 18, 20, 21]. 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 [22]. 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 [23]. If this occurs stop insufflation immediately and deflate the colon by releasing the tube from the automated insufflator. Medical help should 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 [23]. 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 [24]. Figure 8.4a (i–iv) shows a perforation in a patient who was referred for a CTC with

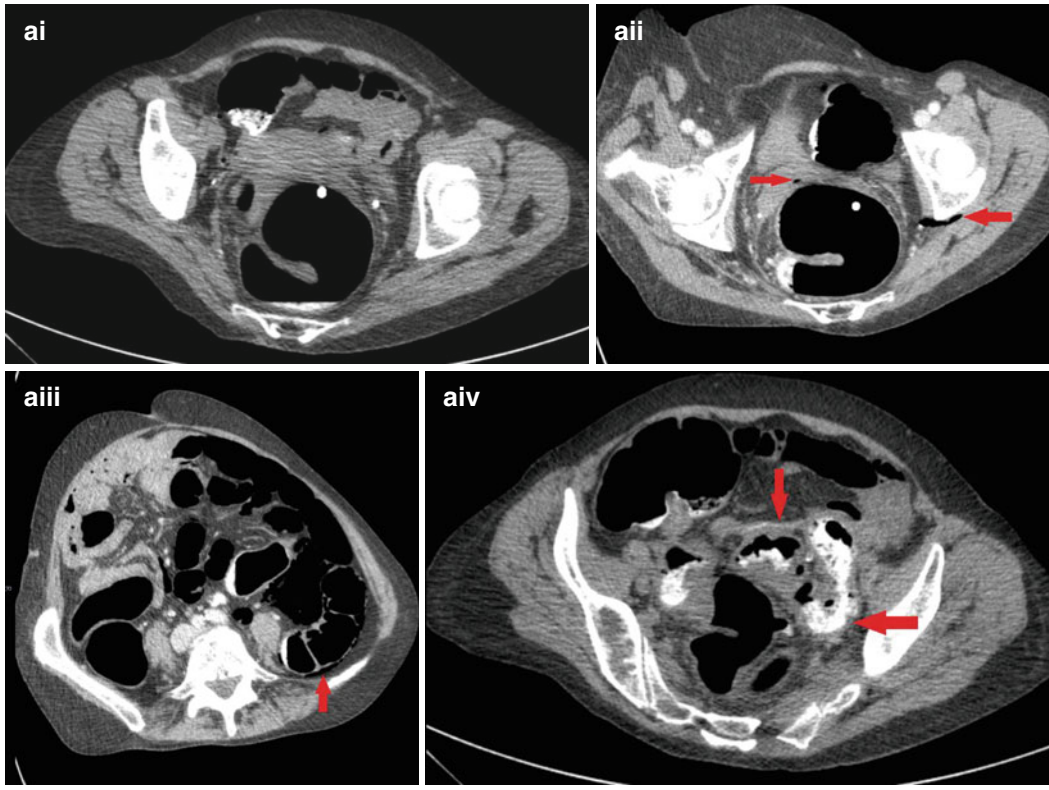

Fig. 8.4 (**a**) (**i**) Supine position, during the CTC the patient experienced some abdominal pain similar to the pain with which she had been referred. (**a**) (**ii**) The patient was then moved into the right lateral decubitus position. The patient felt a sudden 'release' feeling and then felt slightly better. A thin strip of air can be seen outside of the colon in the retroperitoneal area (*red arrows*). (**a**) (**iii**) *Red arrow* air outside of the colon in the retroperitoneal area. (**a**) (**iv**) Thickened sigmoid colon (*red arrows*), which was the likely site of perforation. The patient was monitored in hospital for 48 h and given i.v. 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

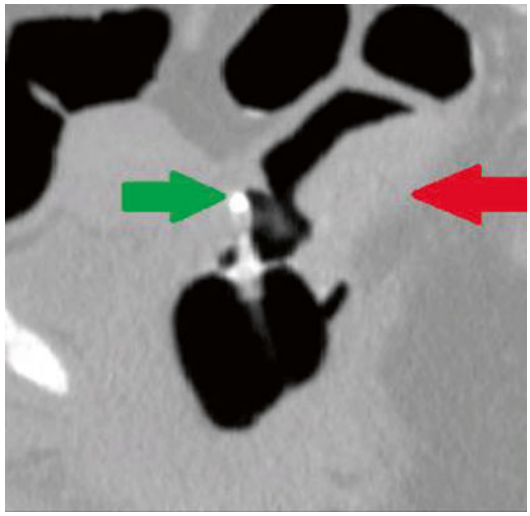

Fig. 8.5 A large rectal tumour (*red arrow*) is seen adjacent to the rectal catheter (*green arrow*). Trauma to distal pathology can be caused by the insertion of the rectal catheter. If there is resistance when placing the rectal catheter or it cannot be inserted, refer to a senior CTC radiographer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

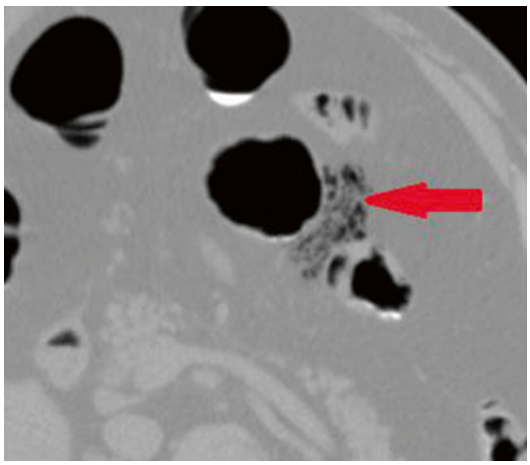

Fig. 8.6 This supine image (shown using lung window levels) reveals a small localised perforation in the sigmoid colon (*red arrow*) which occurred during the CTC examination

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 technique and the possibility of perforating distal pathology. Figure 8.6 shows a small perforation. A large perforation is

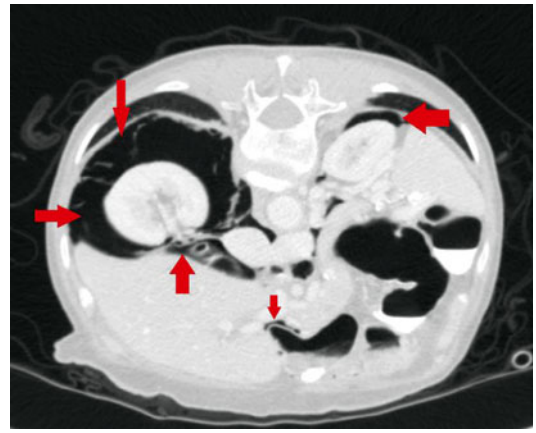

Fig. 8.7 This prone image (shown using lung window levels) reveals a perforation at CTC. A large amount of retroperitoneal gas shown behind the right kidney, but with a small amount also seen behind the left kidney (*red arrows*)

shown in Fig. 8.7. Figure 8.8a (i and ii) is also an example of a large perforation. Studies in colonoscopy and barium enema patients [25–27] 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 [27] as the air contributes to the volume and expansion of the colon but has little effect on the pressure [28]. 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 [28]. The upper limit of most CO_2 automated insufflators is 30 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.

Sosna et al. [29, 30] believe that the lower recorded pressure at CTC compared to conventional nontherapeutic colonoscopy may explain why the incidence of perforation at CTC is lower. The incidence of perforation at CTC is in the range of 0.005–0.9 % [24, 31] compared to diagnostic colonoscopies' rate of 0.1 % [24] or 1 in 1000 [32]. There have been no known patient deaths at CTC [18, 31]. Pickhardt's [18] review of the published data on colonic perforation during

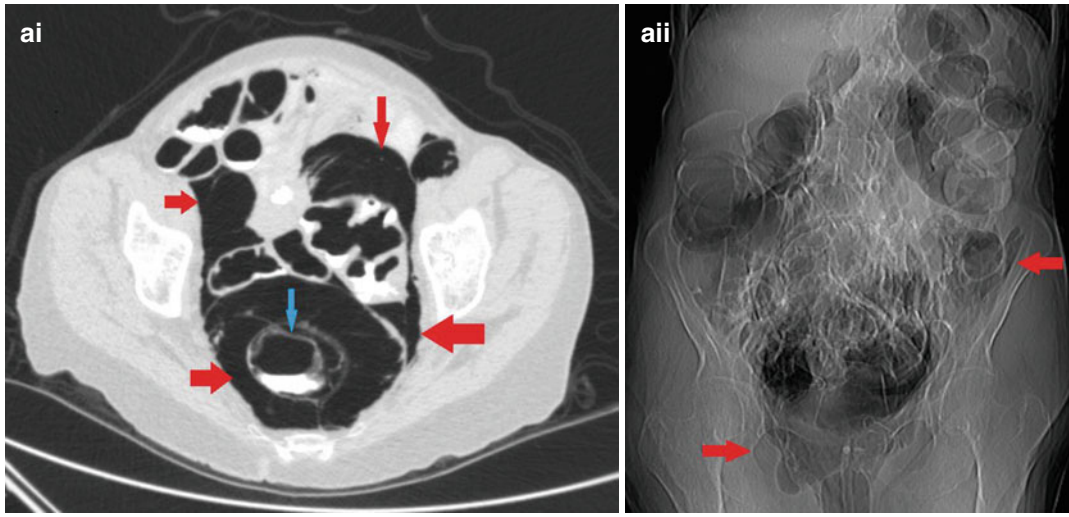

Fig. 8.8 (**a**) (**i**) A supine CTC with faecal tagging. A large amount of mesorectal and retroperitoneal gas can be seen (*red arrows*) and the rectosigmoid wall can be seen clearly (*blue arrow*). (**a**) (**ii**) Scout taken prior to the scan. On review, the free gas can already be seen on this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

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 [18]. The use of a soft, flexible rectal tube has also decreased the likelihood of colonic perforation due to rectal trauma [18] as discussed in Chaps. 9 and 10.

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 [18], and therefore the 1 in 1000 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. Intravenous (i.v.) access must be established if not already present. A member of staff should remain with the patient whilst another confirms the perforation with a consultant radiologist. The radiologist will then make a referral to an appropriate gastrointestinal (GI) team for further management. 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 [33] with follow-up and treatment adjusted according to the patient's clinical status.

A review by Pickhardt [18] 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, all images must be checked for adequate distension and colonic perforation. This review should be performed by an adequately trained member of staff, which may be a radiologist or an experienced CTC radiographer. 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 guidance (either verbal or written) should be given to CTC patients before they leave the scan room regarding symptoms of perforation (severe abdominal pain, increasingly painful abdominal discomfort, sweating and nau-

sea 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 in the appropriate management of patients should perforation be identified.

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 licenced in several countries including the United States of America (USA). The latter previously used Glucagon® as an alternative [34], but due to its cost and side effects, it is now rarely used [35]. Drotaverine® has been reported as comparable to Buscopan® in Bulgaria [36]. Double-contrast barium enemas identified the benefit of the use of Glucagon®, but its use in CTC has not shown the same effect [37]. In 2001, the Joint Formulary Committee [38] found that Buscopan® was safer and cheaper than Glucagon. However, its efficacy in CTC examinations has not been conclusively proven [34]. Some research has shown it does not routinely improve distension when compared to patients with no antispasmolytic [21] but does aid distension in patients with sigmoid diverticular disease [39]. Others have shown improved adequacy rates of CTC when Buscopan® is used [5] and that significant colonic distension is better in patients who had received antispasmodics compared to those without [40]. 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 [38]. 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 ischemia [38].

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 i.v. or intramuscular), know the contraindications to administration (untreated narrow angle glaucoma, myasthaenia gravis, tachycardia, prostatic enlargement with urinary retention or paralytic ileus) [41] and maintain a regular audit of administration.

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 [42]. European consensus statement in 2013 by ESGAR [43] 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 i.v. contrast to asymptomatic individuals [19] or screening programme patients (imaged within the NHS Bowel Cancer programme), unless there is a specific indication or evidence (such as cancer) on the first CTC position scanned [3].

Table 8.1 ESGAR statements on intravenous contrast use in CTC [43]

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

Research by Morrin et al. [44] showed the use of i.v. 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 i.v. contrast being used, very flat lesions can still be missed. Yau et al. [45] believe that the use of i.v. contrast does not increase the detection rate of clinically significant findings within symptomatic patients. The use of i.v. contrast for symptomatic patients can increase the detection of incidental findings, e.g. 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 i.v. 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 who did not receive i.v. contrast (a renal cancer) would have benefitted from its use. Their conclusion was that i.v. contrast should be 'judicious, rather than routine', as its small benefit might be offset by the associated risks [5]. Gross extracolonic findings can be visible even without i.v. contrast. Subtle pathology with and without contrast may be visualised as shown in Fig. 8.9a (i and ii). Figure 8.9a (iii) shows the findings. However, patients suspected of having colorectal cancer on CTC images should have i.v. 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, 44]. Figures 8.10, 8.11, 8.12, 8.13 and 8.14a (ii) demonstrate colonic and extracolonic findings (ECFs) with and without i.v. contrast.

Nonionic i.v. contrast is thought to be almost completely excreted (97 %) by the kidneys within 24 h of administration [46] and has been shown to have a minimal effect on renal function with some diabetic patients showing a small rise in creatinine levels postinjection [46]. Adequate hydration should be advised both pre and post-test. Manufacturers advise special consideration in the use of i.v. contrast in patients with pre-existing renal impairment, diabetes mellitus, Waldenström macroglobulinemia or myelomatosis [46]. The incidence of notable i.v. contrast reactions occurs in 0.5 % of patients [47, 48], but some have reported 3–4 % [44]. 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 45 min [46]. 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 i.v. contrast and therefore may warrant premedication with corticosteroids prior to the CTC study. CT departments that make use of i.v. contrast should have adequate medication, equipment and a

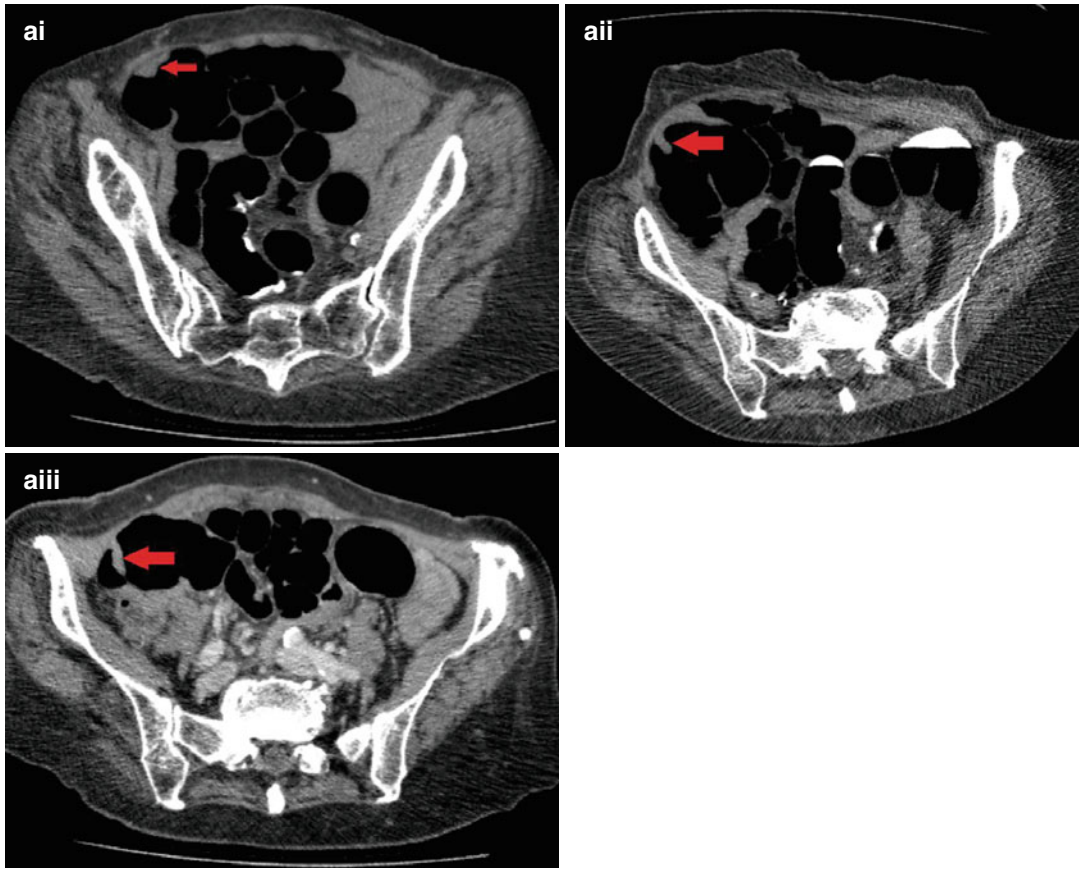

Fig. 8.9 (**a**) (**i**) A supine scan was acquired. A small amount of faecal tagging can be seen in the sigmoid colon. (**a**) (**ii**) On review of the prone sequence by the radiographer, the subtle thickening (*red arrow*) in the caecum opposite the ileocaecal valve raised a red flag, which was then identified on the previous supine image (**a**) (**i**) (*red arrow*). (**a**) (**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 (**a**) (**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*)

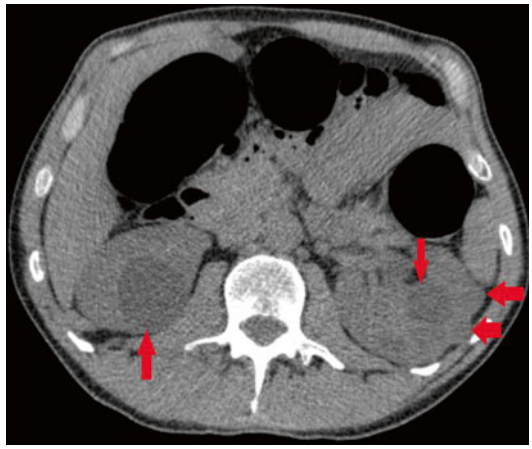

Fig. 8.10 A normal well-prepared and distended colon. Incidental finding of multiple cysts (*red arrows*) in the kidneys meant that the patient was referred for a kidney ultrasound which confirmed these to be benign cysts

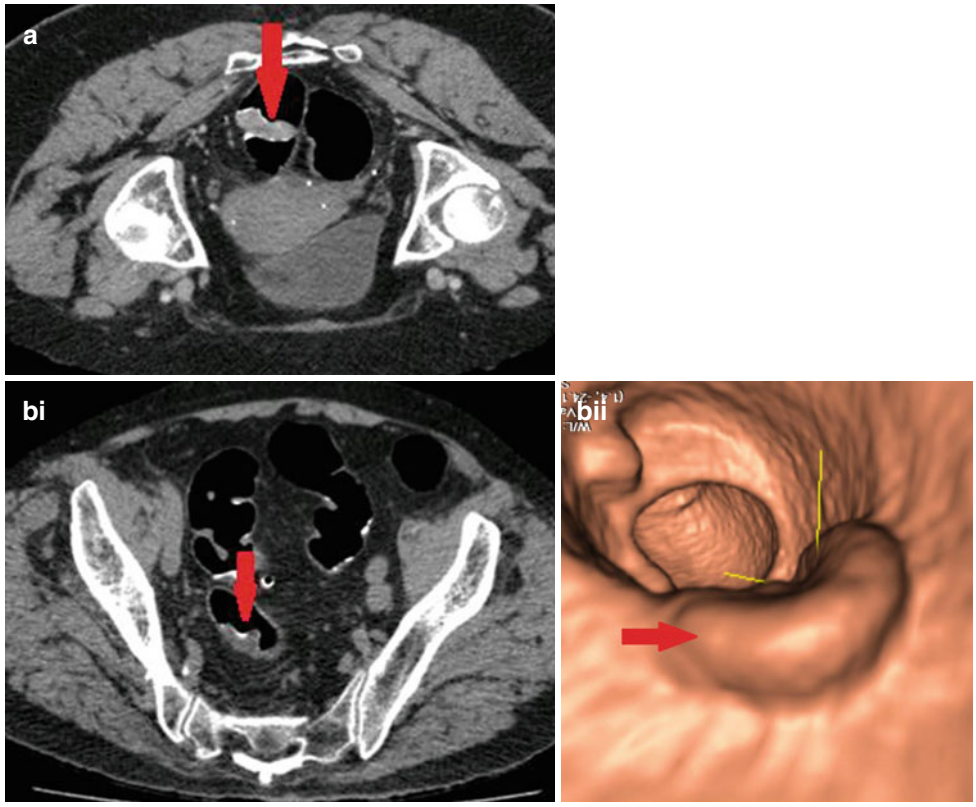

Fig. 8.11 (**a**) Prone scan. Patient #1 had faecal tagging and i.v. contrast. A saddle-shaped lesion with central depression can be seen in the sigmoid colon (*red arrow*). (**b**) (**i**) Supine scan. Patient #2 had faecal tagging and no i.v. contrast due to poor renal function. A centrally depressed lesion (*red arrow*) can also be seen in the sigmoid colon even without i.v. 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

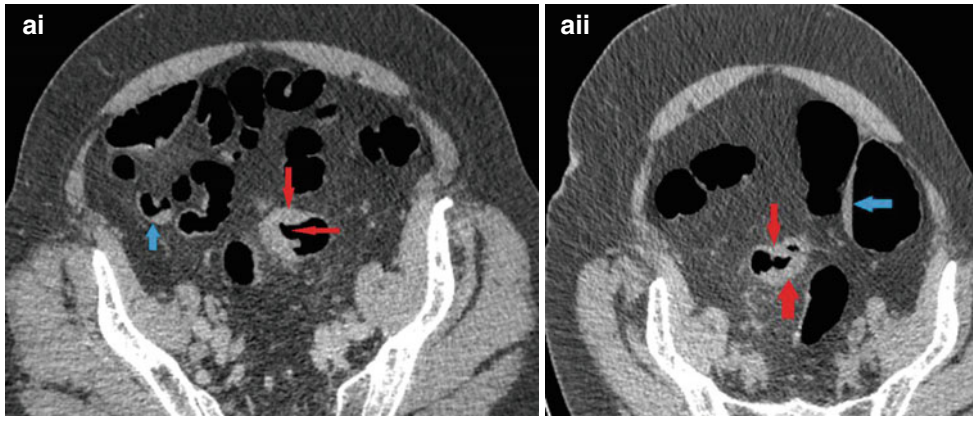

Fig. 8.12 (**a**) (**i**) Supine image with i.v. contrast after a failed colonoscopy. A patient, with a known sigmoid cancer identified at colonoscopy which could not be passed with the scope, was sent for a staging CTC to enable visualisation of the rest of the colon. *Red arrows* show the location the endoscopist could not pass. (**a**) (**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 (**a**) (**i**) is with i.v. contrast, there is only a small amount of vascular enhancement, and the cancer does not look dissimilar in density to (**a**) (**ii**)

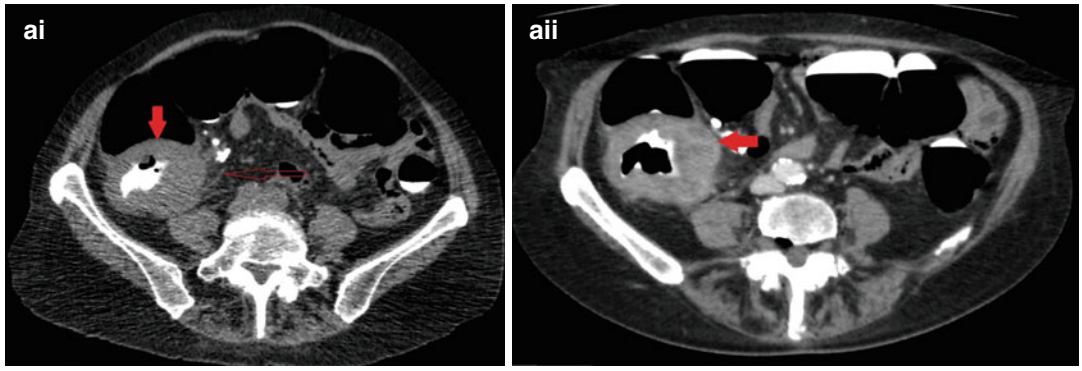

Fig. 8.13 (**a**) (**i**) Supine image of a patient presented with a right-sided mass and anaemia. The patient was given Gastrografin® tagging to take at home the day before. A large circumferential mass in the caecum is shown. The cancer can be seen clearly even without i.v. contrast (*solid red arrow*).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

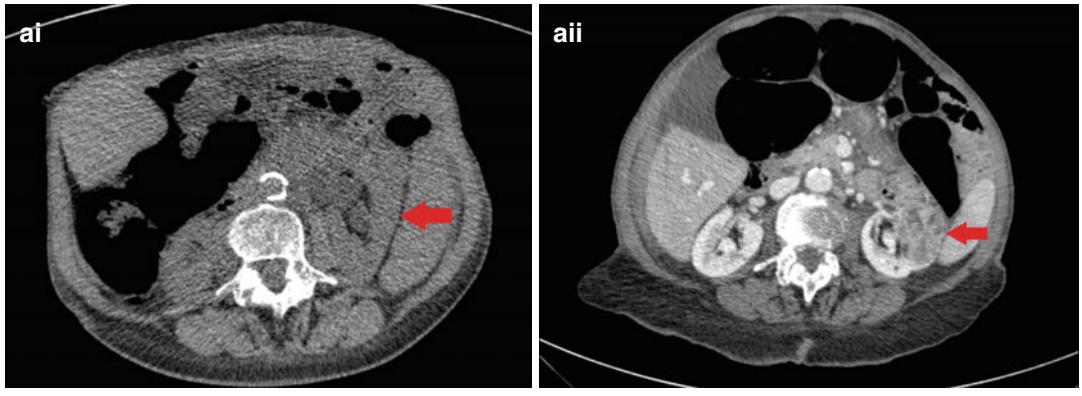

Fig. 8.14 (**a**) (**i**) Patient with anaemia, weight loss and change in bowel habit referred for a CTC. The image was acquired as a very low dose-prone sequence as the patient was to have i.v. contrast on second sequence due to anaemia. The left kidney (*red arrow*) looks larger than the right, but at a very low dose, the pathology is very hard to see. (**a**) (**ii**) Supine image with i.v. 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

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

Institutions vary in the volume of i.v. 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. When deciding on the use of i.v. 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.

8.6 Key Messages

- Faecal tagging is proven to increase the sensitivity and specificity of the CTC examination and is recommended by the UK Bowel Cancer Screening Programme (BCSP), BSGAR (British Society of Gastrointestinal and Abdominal 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 guidelines must be agreed and in place for a safe service.
- The use of an antispasmolytic (for example 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.

8.7 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 i.v. 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 i.v. 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. doi:10.1148/radiol.2392051101.
3. NHS Bowel Cancer Screening Imaging Guidelines. No 5: guidelines for the use of imaging in the NHS Bowel Cancer Screening Programme. 2nd ed. Sheffield: NHS Cancer Screening Programmes; 2012. (Cited 1 June 2015). Available from: http://www.cancerscreening.nhs.uk/bowel/publications/.
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. Bayer plc. Gastrografin® Gastroenteral solution summary of product characteristics, Revised April 2015. Available from: http://www.mhra.gov.uk/home/groups/spcpil/documents/spcpil/con1440738619790.pdf.
7. British Society of Gastrointestinal and Abdominal Radiology (BSGAR) and The Royal College of Radiologists. BFCR (14)9. Guidance on the use of CT colonography for suspected colorectal cancer. London: The Royal College of Radiologists; 2014.
8. 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. doi:10.3348/kjr.2007.8.4.264.
9. ACR-SAR-SCBT-MR practice parameter for the performance of computed tomography (CT) colonography in adults – revised 2014. (Cited 3 June 2015). Available from http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/CT_Colonography.pdf.
10. Spada C, Stoker J, Alarcon O, et al. Clinical indications for computed tomographic colonography: ESGE and ESGAR Guideline. Endoscopy. 2014;46:897–908. (Cited 28 May 2015). Available from: http://www.

esge.com/assets/downloads/pdfs/guidelines/042_10-1055-s-0034-1378092.pdf. (Accessed 28 May 2015).
11. 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. doi:10.1148/radiol.2241011222.
12. NHS National Patient Safety Agency: Rapid Response Report NPSA/2009/RRR012: Reducing risk of harm from oral Bowel cleansing solutions. 2009. (Cited 15 May 2015). Available from: http://www.nrls.npsa.nhs.uk/resources/?entryid45=59869.
13. EMC. Picolax. (Cited 1 June 2015). Available from: https://www.medicines.org.uk/emc/medicine/670.
14. The Royal College of Radiologists. Standards for intravascular contrast agent administration to adult patients. 3rd ed. London: The Royal College of Radiologists; 2015. BFCR(15)1. (Cited 10 June 2015). Available from: https://www.rcr.ac.uk/sites/default/files/Intravasc_contrast_web.pdf.
15. 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.
16. 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. doi:10.3348/kjr.2009.10.1.25.
17. Blakeborough A, Sheridan MB, Chapman AH. Complications of barium enema examinations: a survey of UK Consultant Radiologists 1992 to 1994. Clin Radiol. 1997;52:142–8.
18. 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.
19. Burling D. International collaboration for CT colonography standards. CT colonography Standards. Clin Radiol. 2010;65:474–80. doi:10.1016/j.crad.2009.12.003.
20. 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.
21. 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. doi:10.2214/AJR.14.12772.
22. Fenton AM, Hammill SC, Rea RF, Low PA, Shen WK. Vasovagal syncope. Ann Intern Med. 2000;133:714–25.
23. Neri E, Caramella D, Vannozzi F, Turini F, Cerri F, Bartolozzi C. Vasovagal reactions in CT colonography. Abdom Imaging. 2007;32:552–5.
24. De Gonzalez AB, Kim KP, Yee J. CT colonography: perforation rates and potential radiation risks. Gastrointest Endosc Clin N Am. 2010;20:279–91. doi:10.1016/j.giec.2010.02.003.
25. 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.
26. Kozarek RA, Earnest DI, Silverstein ME, Smith RG. Air-pressure-induced colon injury during diagnostic colonoscopy. Gastroenterology. 1980;78:7–14.
27. Tzelepis GE, Nasiff L, McCooL FD, Hammond J. Transmission of pressure within the abdomen. J Appl Physiol. 1996;81:1111–4.
28. Woltjen JA. A retrospective analysis of cecal barotrauma caused by colonoscope air flow and pressure. Gastrointest Endosc. 2005;61:37–45.
29. 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.
30. Sosna J, Bar-Ziv J, Libson E, Eligulashvili M, Blachar A. CT colonography: positioning order and intracolonic pressure. AJR. 2008;191:175–80. doi:10.2214/AJR.07.3303.
31. 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. doi:10.1007/s00330-014-3190-1.
32. NHS Bowel Cancer Screening Imaging Guidelines. No 6: quality assurance guidelines for colonoscopy. Sheffield: NHS Cancer Screening Programmes; 2011. (Cited 1 June 2015). Available from: http://www.cancerscreening.nhs.uk/bowel/publications/nhsbcsp06.pdf.
33. Baccaro LM, Markelov A, Wilhelm J, Bloch R. Pneumoperitoneum after virtual colonoscopy: causes, risk factors, and management. Am Surg. 2014;80:549–54.
34. 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; 229:1. http://dx.doi.org/10.1148/radiol.2291021151.
35. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Rad 2014;18(1); Art. #607, 11 pages. http://dx.doi/org/10.4102/sajr. v18i1.607 SAJR 2014.
36. 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.
37. 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.

38. 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.
39. 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.
40. 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
41. Ingelheim B. Professional leaflet: buscopan® ampoules 20 mg/ml solution for injection. Last revised Aug 2008.
42. Amin Z, Boulos PB, Lees WR. Technical report: spiral CT pneumocolon for suspected colonic neoplasms. Clin Radiol. 1996;51:56–61.
43. 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. doi:10.1007/s00330-012-2632-x.
44. 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.
45. 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.
46. GE Healthcare. Professional leaflet: Visipaque ® Iodixanol. Last revised Feb 2013.
47. 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.
48. Yasuda R, Munechika H. Delayed adverse reactions to nonionic monomeric contrast-enhanced media. Invest Radiol. 1998;33:1–5.

9 Patient Preparation Including Bowel Preparation, the Role of Tagging and Methods of Colonic Insufflation

Joel H. Bortz

Abstract

Cathartic bowel preparation and tagging agents are pivotal in CT colonography. For a successful study, it is important that a clean bowel is well distended and that residual fluid is tagged. Although perforation is rare, it is important to use a small-gauge rectal catheter and an automated pressure-controlled insufflator to prevent risk of perforation. Patients must be informed of their responsibilities before and during the study. It essential that they adhere to a liquid diet and take the bowel preparation medication at the correct times. CTC images are presented of poor bowel preparation and tagging of residual fluid.

9.1 Introduction

There are two critical components to achieve a successful CTC: an adequately prepared bowel and good distension of the colon [1]. To achieve these two components requires patient co-operation. 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 will require insertion of a rectal catheter to allow for distension of the colon. 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. Patients 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.

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9.2 Bowel Preparation

An adequately cleansed bowel and good distension of the colon with CO_2 are essential 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 [2]. 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 [3, 4]. A primary barrier, to achieving optimal colorectal cancer (CRC) screening with either CT colonography (CTC) or optical colonography (OC), is many patients' aversion to bowel cleansing [5, 6]. 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 and 60 mL diatrizoate (Gastrografin/Gastroview), are used [1]. The barium tags stool in the colon; the Gastrografin/Gastroview (hereafter Gastrografin) tags the residual fluid in the bowel.

Cathartic bowel preparation is still required for both CTC and optical colonoscopy (OC) with same-day polypectomy [7]. There are many different bowel preparations available, and most work well. A standard protocol is not available as opinions vary as to which is 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 or 45 mL sodium phosphate [8]. There were reports that its usage could have contributed to isolated cases of acute phosphate nephropathy [9]. 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 [10]. Furthermore, 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 [11]. Magnesium citrate thus remains the front-line CTC cathartic agent (see Fig. 9.1c). 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. Dehydration must be avoided; thus, fluid intake is essential [12].

There are two types of preparation: 'dry' preparation, and 'wet' preparation [12]. A 'dry'

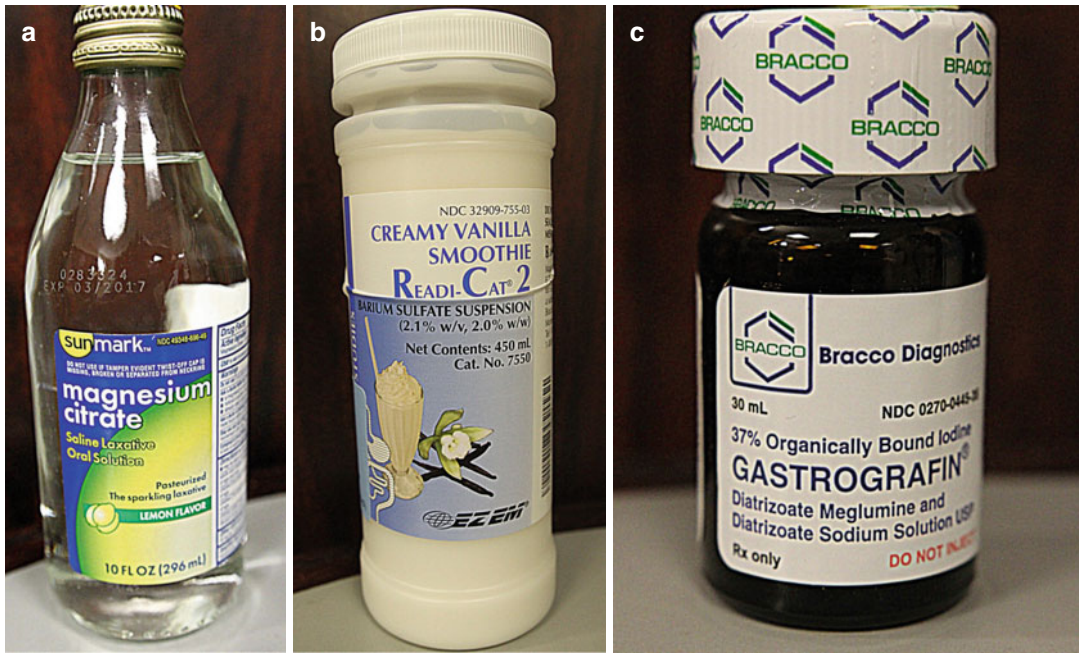

Fig. 9.1 (**a**) Magnesium citrate for bowel preparation. 2 × 296 mL bottles are required. (**b**) Readi-Cat 2 to tag stool. Only 250 mL is required. Remaining 200 mL is to be discarded by the patient. (**c**) Gastrografin to tag residual fluid. 2 × 30 mL bottles are required

preparation for CTC means that less residual fluid is present hence better visualisation of the colon wall [12]. 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®) [13]. PEG is a 'wet' preparation; hence, it is an electrolyte lavage preparation. It functions as an osmolar agent by increasing the water content of stool and inducing elimination [12]. Since many patients are adverse to the available agents for bowel cleansing, there is continual research being undertaken to find a cathartic agent that can (i) reduce residual fluid in the bowel and (ii) be positively accepted by patients.

A new formulation, called Suprep (OSS®), has been introduced into the OC market [14]. 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 [14]. Sulphate is a poorly absorbed anion, and OSS does not alter electrolyte balance [15]. The recommended OC regimen consists of 2 × 177 mL bottles in a split dose. This provides an adequately cleansed colon for OC examinations. Bannas et al. [16] 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 diatrizoate/meglumine diatrizoate (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 of 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 of Readi-Cat 2 and 60 mL of Gastrografin the evening before the CTC examination.

The authors used an automated QA software tool to determine volume and attenuation of residual colonic fluid. The findings were that OSS Suprep regime is 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.

9.4 Recommended Bowel Preparation

For a successful examination, bowel preparation should consist of a well-established CTC standard protocol [17]. The author's recommended protocol 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). Nil per mouth from midnight. Note that if a patient has had breakfast in error, another CTC appointment must be arranged. It is important for a patient to

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 on the 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 one hour before or one hour 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 Diatrizoate meglumine (Gastrografin) (60 mL) to tag remaining fluid	*Step 1* At 11:00: Bisacodyl (Dulcolax) tablets to be taken with one 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 four to six 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: 60 mL of undiluted diatrizoate (Gastrografin) to be swallowed OR can be mixed with one 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.

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). Patients should be warned of the unpleasant taste of Gastrografin; diluting it in a flavoured drink lessens the unpleasant taste.

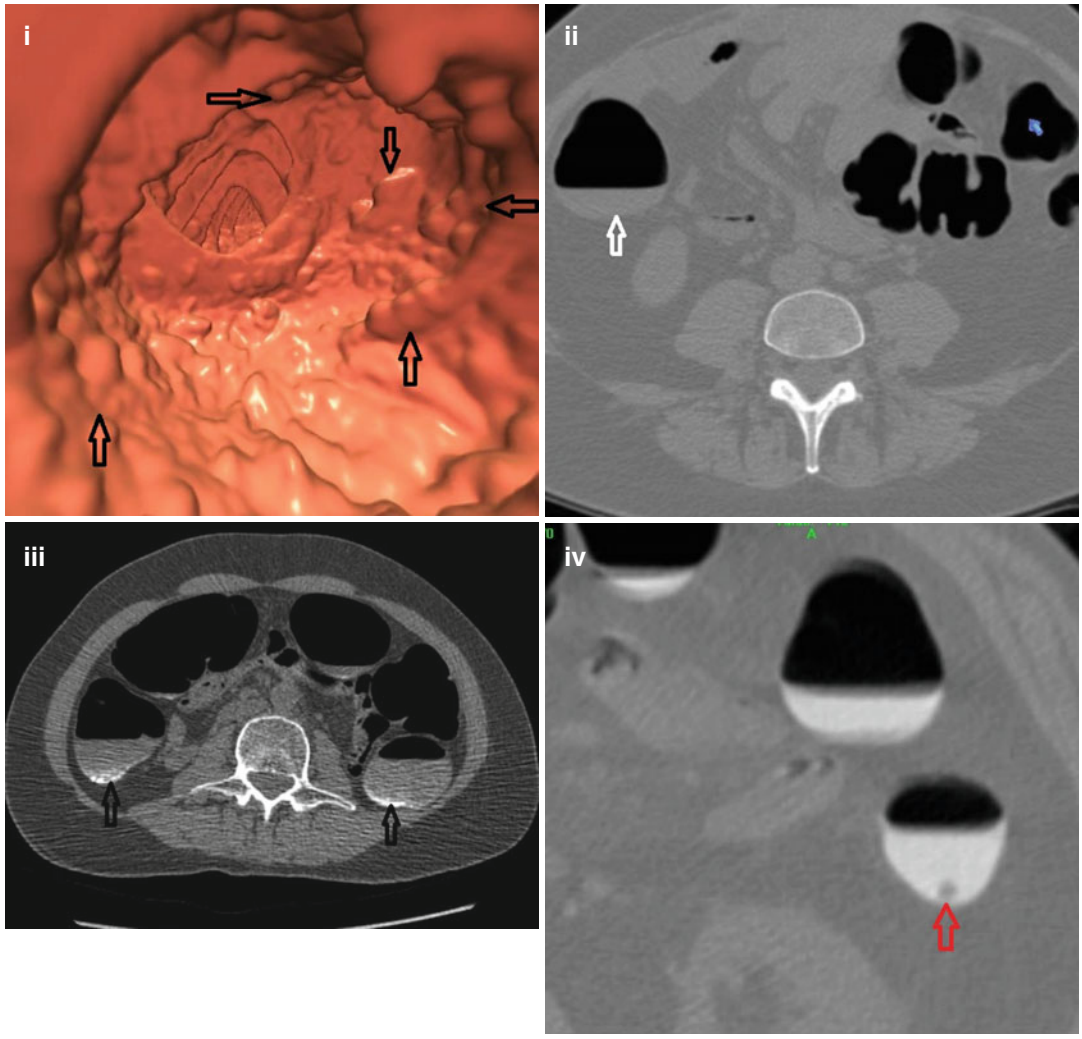

Fig. 9.2 (**i**) 3D view shows excessive stool (*open black arrows*) in the caecum due to poorly prepared bowel as patient ate snacks in the evening before the study. (**ii**) 2D axial view showing unopacified fluid (*open white arrow*) due to lack of Gastrografin as a tagging agent. (**iii**) 2D axial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

Gastrografin is a hypertonic oral contrast medium that has been used for decades in gastrointestinal radiology [18]. 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 [1]. 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 [19]. 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 [18]. 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.

An interesting fact is that barium does not adhere to the colonic wall; it coats the surfaces of polyps making them more conspicuous and easier to diagnose [17]. This may reduce the false-positive rate on CTC. Gastrografin has a dual action. It stains 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 [17]. 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 [1].

9.4.1 Non-cathartic Options for CTC

Patient adherence may improve with a non-cathartic preparation, but there are trade-offs [20]. 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 [21]. Patient preparation comprised of a low-fibre diet and barium and diatrizoate for stool and fluid tagging. The study employed electronic cleansing as well as CTC computed-aided detection (CAD) software, respectively. Electronic cleansing may cause significant artefacts (see Chap. 12), and 2D 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 optical colonoscopy cannot be performed if the CTC findings reveal an adenoma ≥10 mm [21]. 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 [7], 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 carbon dioxide (CO_2) can be insufflated using either a handheld device (manual insufflation) or an automated pressure-controlled insufflator [1, 22]. The benefits and risks of both methods should be included in informed consent forms. It is also important to consider the use of room air versus CO_2 and potential risks of perforation in CTC studies.

9.5.1 Carbon Dioxide Versus Room Air for Colonic Insufflation

There is an advantage of using CO_2 compared with room air. Carbon dioxide is rapidly absorbed from the colon by normal breathing. It is absorbed across the intestinal mucosa 160 times more rapidly than nitrogen and 13 times more rapidly than oxygen [23]. Both nitrogen and oxygen are the principal gas components of air [23]. Patients therefore experience less cramps during and after the CTC study [1]. This holds true for patients during and post-colonoscopy [24]. Pain during CTC is less of a feature with CO_2 than room air because the former is rapidly resorbed following the procedure resulting in much reduced post-procedure distension and pain [25, 26]. Carbon dioxide may cause bloating for a short period [1].

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, but 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 [27]. Introducing room air or CO_2 into the colon requires many puffs of a handheld device. According to Sosna et al. [28] 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 [28]. 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 [29]. An intracolonic pressure above 140 mmHg can lead to perforation of the caecum [28]. During manual insufflation, perforation can be caused by the use of either room air or CO_2. The medicolegal 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 [25]. 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 [1]. Several vendors supply automated CTC insufflators. Training is often necessary to operate an insufflator and to understand pressure and volume readings on the dials. Furthermore, it is essential to check that there is sufficient CO_2 in the cylinder before commencing a CTC study.

The intracolonic pressure is constantly monitored; the pressure is indicated on the dial of an automated CO_2 insufflator (see Fig. 9.3 a(i), b(i)). 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 [30]. Kim et al. [30] 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 [31]. Unlike a handheld device, an automated insufflator can be switched on and off to control insufflation. The amount of CO_2

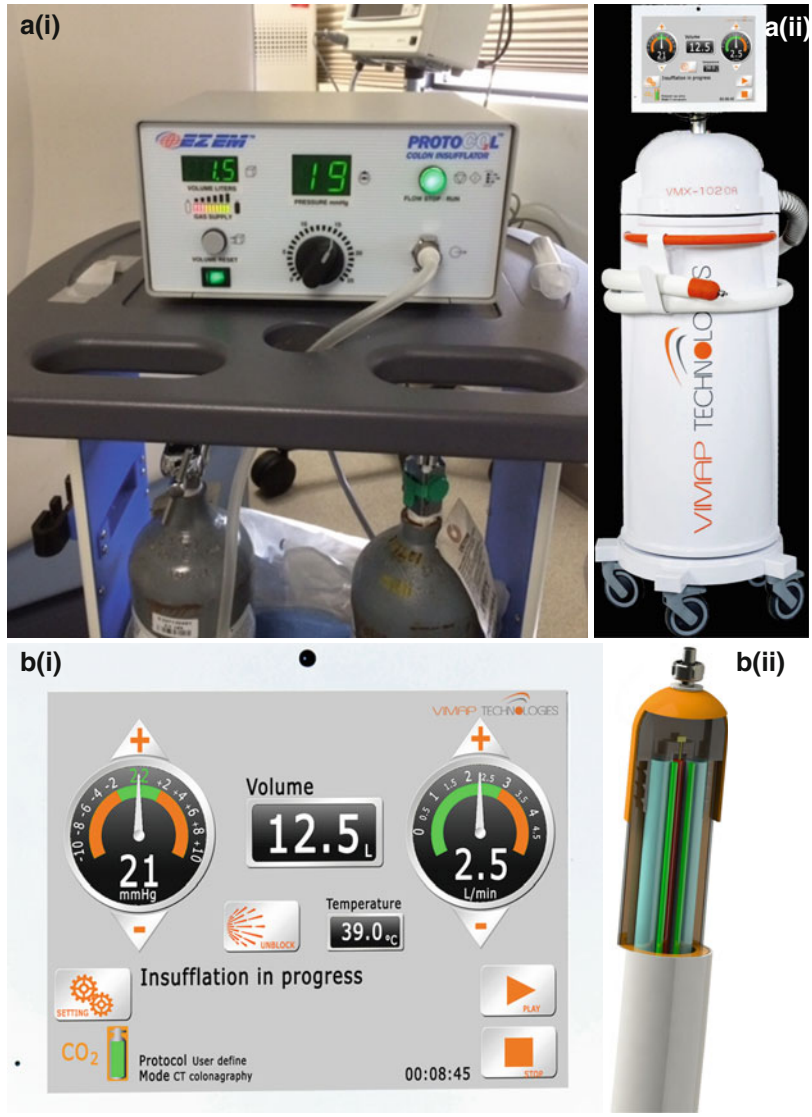

Fig. 9.3 (**a**) (**i**) Close-up view of pressure-controlled insufflator (PROTOCOLS – Bracco ®). Installation pressure set at 15. Rectal intraluminal pressure at 19 mmHg. Left upper dial shows total volume readout of $CO_2 = 1.5$ L. (**a**) (**ii**) Automated CO_2 colonic insufflator (VMX 1020 A – Vimap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

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. [32] 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. [33] 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 [31]. 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 [34]. 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 [35]. A 2006 study by Dachman did not support these findings [36]. 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 [1].

9.7 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.
- Patient with known cardiac or renal insufficiency could be compromised with ‘dry’ preparations; a non-cathartic regime is an option.

9.8 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 carbon dioxide 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. Bortz JH. CT colonography: an approach for a successful examination. S Afr J Rad. 2014;18(1);Art. #607, 11 pages. http://dx.doi/org/10.4102/sajr.v18i1.607 SAJR 2014.
2. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009.
3. Summers R. The elephant in the room: bowel preparation for CT colonography. Acad Radiol. 2009;16(7):777–9. http://dx.doi.org/10.1016/j.acra.2009.04.001.
4. 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. 2011;196(5):1076–82. http://dx.doi.org/10.2214/AJR.10.4334.
5. Harewood GO, Wiersema MJ, Melton 3rd LJ. A prospective controlled assessment of factors influencing acceptance of screening colonoscopy. Am J Gastroenerol. 2002;97(12):3186–94.
6. 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.
7. 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.
8. 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.
9. Markowitz GS, Stoke MB, Radhakrishnan J, D'Agati VD. Acute phosphate nephropathy following oral sodium phosphate bowel purgative: an underrecognized cause of chronic renal failure. JASN. 2005;16(11):3389–96.
10. 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.
11. 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.
12. Yee J, Weinstein S, Morgan T, Alore P, Aslam R. Advances in CT colonography for colorectal cancer screening and diagnosis. J Cancer Educ. 2013;4(3):200–9. http://dx.doi.org/10.7150/jca.5858.
13. 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.
14. OSS: suprep bowel prep kit, Braintree Laboratories, Braintree. Available from: http://www.suprepkit.com
15. 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.
16. 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):11–18. http://dx.doi.org/10.1007/s00261-014-0186x.
17. 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):940–946. http://dx.doi.org/10.1007/s00330-014-3095-z.
18. Gastrografin®. Oral solution. Sodium amidotrizoate 100 mg/mL, meglumine amidotrizoate 660 mg/mL. Gastrografin Australian Approved Product Information from 9 April 2009.
19. Miller SH. Anaphylactoid reaction after administration of diatrizoate meglumine and diatrizoate sodium solution. AJR. 1997;168:959–61.
20. Pickhardt PJ. CT colonography: does it satisfy the criteria for colorectal screening test? Expert Rev Gastroenterol Hepatol. 2014;8(3):211–3.
21. 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.
22. RANZCR. Requirements for the practice of computed tomography colonography (CTC). Sydney: The Royal Australian and New Zealand College of Radiologists. 2013; p. 6.
23. Technology Committee ASGE. Methods of luminal distention for colonoscopy. Gastrointest Endosc. 2013;77(4):519–25. http://dx.doi.org/10.1016/j.gie.2012.09.025.
24. 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. http://dx.doi.org/10.3748/wjg.v18.i25.3250.
25. 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. http://dx.doi.org/10.2214/ajr.04.1506.
26. 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(6):1491–6. http://dx.doi.org/10.2214/ajr.05.0416.
27. 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.
28. Sosna J, Bar-Ziv J, Libson E, Eligulashvili M, Blachar A. CT colonography: positioning order and intracolonic pressure. AJR. 2008;191:W175–80. http://dx.doi.org/10.2214/ajr.07.3303.

29. Williams R. CO2 hand bulb colon distention used with CT colonography. Industrial Scientific Report 2002, Westbury, New York: E-Z-E-M Inc.
30. 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. 2008;190(3):698–706. http://dx.Dio.org/10.2214/AJR.07.2156.
31. 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.
32. 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. http://dx.doi.org/10.1001/archsurg.139.7.739.
33. Glew PA, Campher MJJ, Pearson K, Schofield JC. Davey AK. The effect of warm humidified CO2 on the dissipation of residual gas following laparoscopy in piglets. J Am Ass Gynecologic Laparoscopists. 2004;11(2):204–10.
34. 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.
35. 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.
36. Dachman AH. Advice for optimising colonic distention and minimising risk of perforation during CT colonography. Radiology. 2006;239:317–21.

CTC Technique and Methods of Interpreting Images

10

Joel H. Bortz

Abstract

CT colonography (CTC) is a minimally invasive, fast, safe and accurate screening examination for colorectal cancer. It also allows evaluation of structures outside the colon. There have been several changes in the performance of a study since it was first used in 1994. A successful CTC examination requires the use of an automated pressure-controlled carbon dioxide insufflator, a well-prepared colon, the use of tagging, an adequately distended colon and correct positioning for two-view series and additional view scans. CTC produces two-dimensional (2D) images and three-dimensional (3D) endoluminal views, and software is required to interpret them. How to perform a CTC study is described step by step. Performing a CTC after an incomplete optical colonoscopy (OC) is discussed, with a caveat of assessing whether free air is present before commencing the study. A colonic classification table is used for reporting CTC findings. CTC images are presented to illustrate differentiation of a polypoidal lesion and stool, as well as interpretation of images, and measurement of polyps. The role of translucent display is illustrated with examples.

10.1 Introduction

CTC has been clearly 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]. It has been shown that screening of asymptomatic individuals can reduce CRC mortality [1]. Removal of an advanced adenoma may reduce the incidence of CRC [1].

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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 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 multiple detector 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. The advances in CT hardware have resulted in shorter

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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. Their study included two tagging agents: 2 % w/v barium sulphate to tag stool and diatrizoate meglumine (Gastrografin) to tag remaining fluid (see Table 9.1). In their study tagging agents were administered to all participants (patients) prior to the CTC procedure. Apart from tagging stool, barium has been shown to also lightly cover a polyp, thereby making it more conspicuous on 2D 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].

Use of the relatively high-density barium has several disadvantages and is therefore 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]. Electronic cleansing 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. Furthermore, use of 40 % w/v barium sulphate will prevent a same-day optical colonoscopy (OC) examination being performed.

CTC examinations are straightforward when a clean bowel and an adequately distended colon are imaged with a MDCT scanner. The role of CT

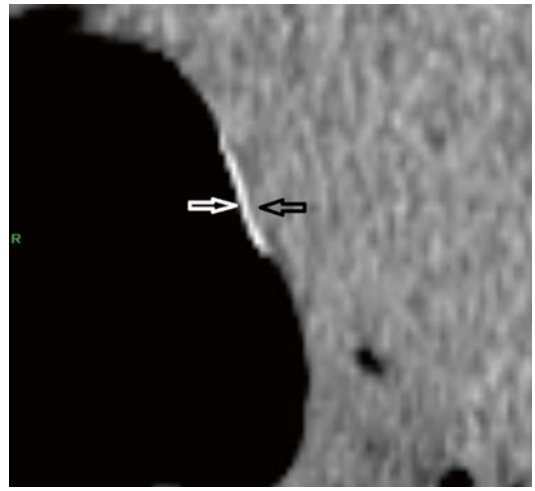

Fig. 10.1 2D axial view showing flat lesion in caecal pole. Note the thin layer of barium (*open white arrow*) covering the soft tissue (*open black arrow*)

software is important in CTC: clinically significant polyps can be readily detected with dedicated software [9]. All CTC components must be in place to perform a successful examination. This entails (i) patient compliance in terms of bowel preparation, (ii) an adequately distended colon, (iii) the use of at least a 16-slice MDCT scanner and (iv) interpretation of images using a dedicated 3D platform. These components are interdependent. A deficiency in any of them can cause a poor CTC result [10]. 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.

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 C1–C4 classification is used when reporting CTC findings. For example, normal colon or benign lesion would be classified as C1. If a polyp or possibly advanced adenoma were noted on the study, the classification would be C3. A non-diagnostic study would be C0. Table 10.2 presents the colonic C1–C4 classifications.

Table 10.2 Colonic classification

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: e.g., colonic diverticula
C2	Small polyps. Surveillance or colonoscopy recommended
	Small polyp 6–9 mm, <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 Zalis et al. [11]

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 [10]. 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 the study.

A CTC study usually 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 obtained from the supine and prone series. 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) illustrates the value of a RLD when there are

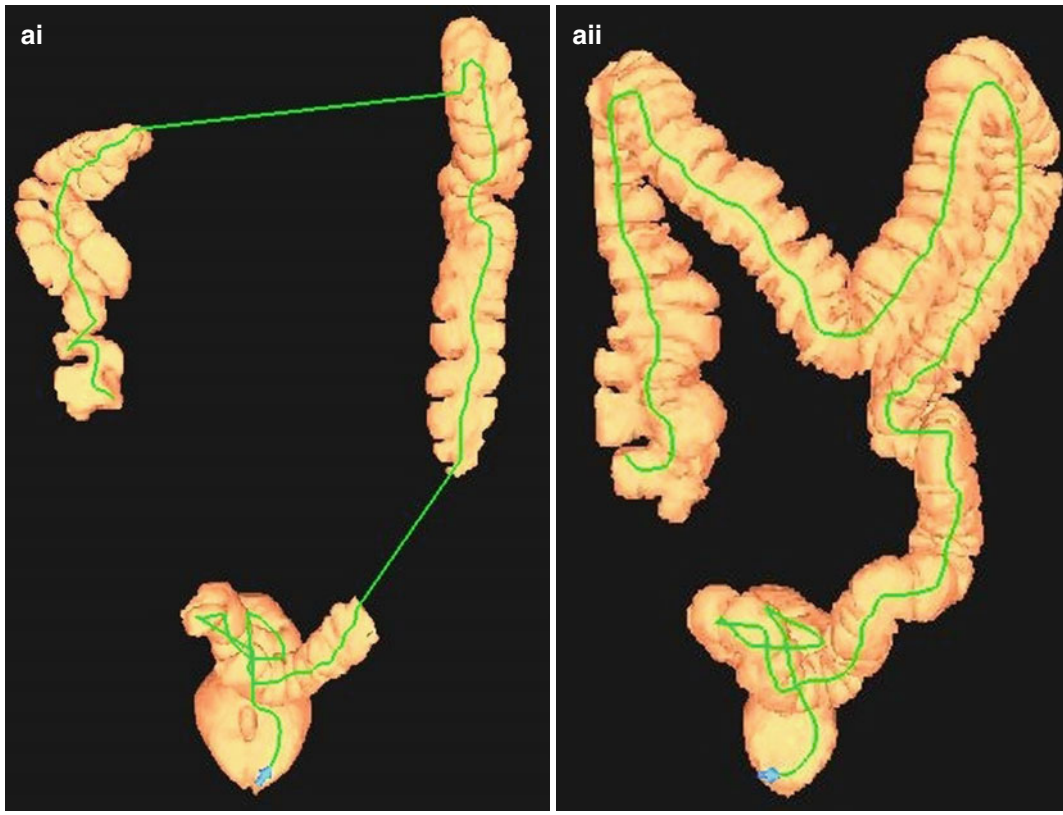

Fig. 10.2 (**a**) (**i**) Colon view showing breaks in colon filling. **A** (**ii**) Complete filling of colon in the RLD scan

b

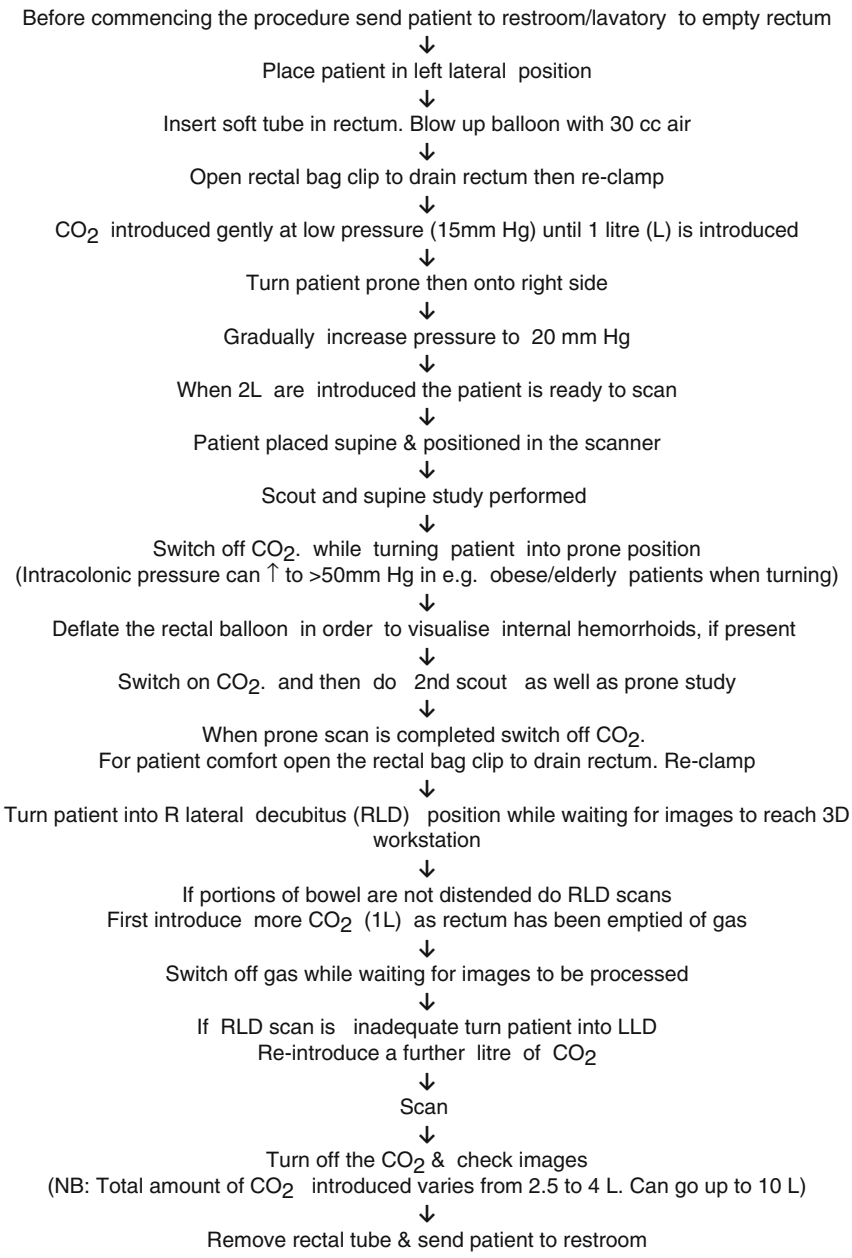

Fig. 10.2 (**b**) Schematic presentation of CTC technique

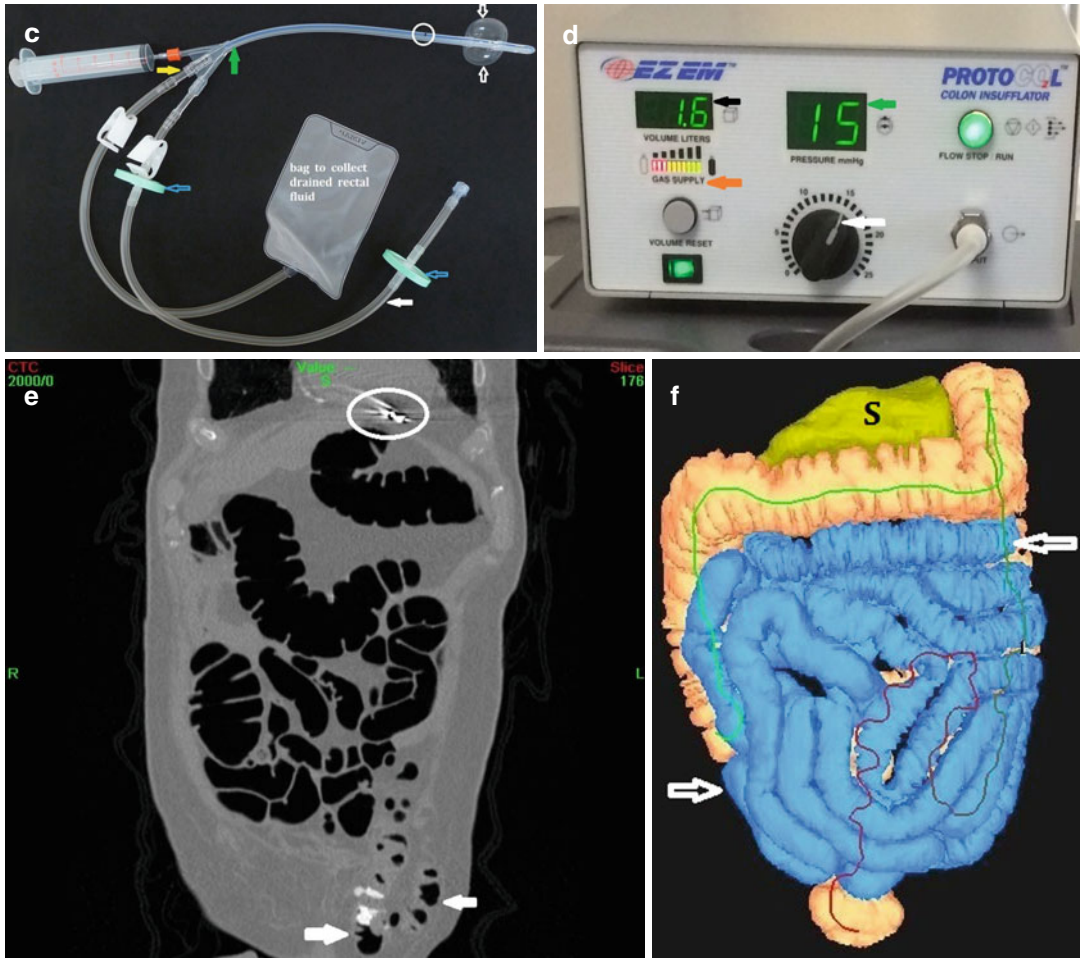

Fig. 10.2 (**c**) Green arrow indicates trifurcation of tube. Attached syringe for balloon distension. *Yellow arrow* indicates rectal drainage bag. *White arrow* indicates connection to CO_2 insufflator. *White circle* shows *black indicator line*. The catheter must not be inserted into the rectum beyond the black line. Inflated balloon (*open white arrows*). *Open blue arrows* indicate two green filters to trap any faecal fluid from entering and contaminating the CO_2 insufflator. (**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

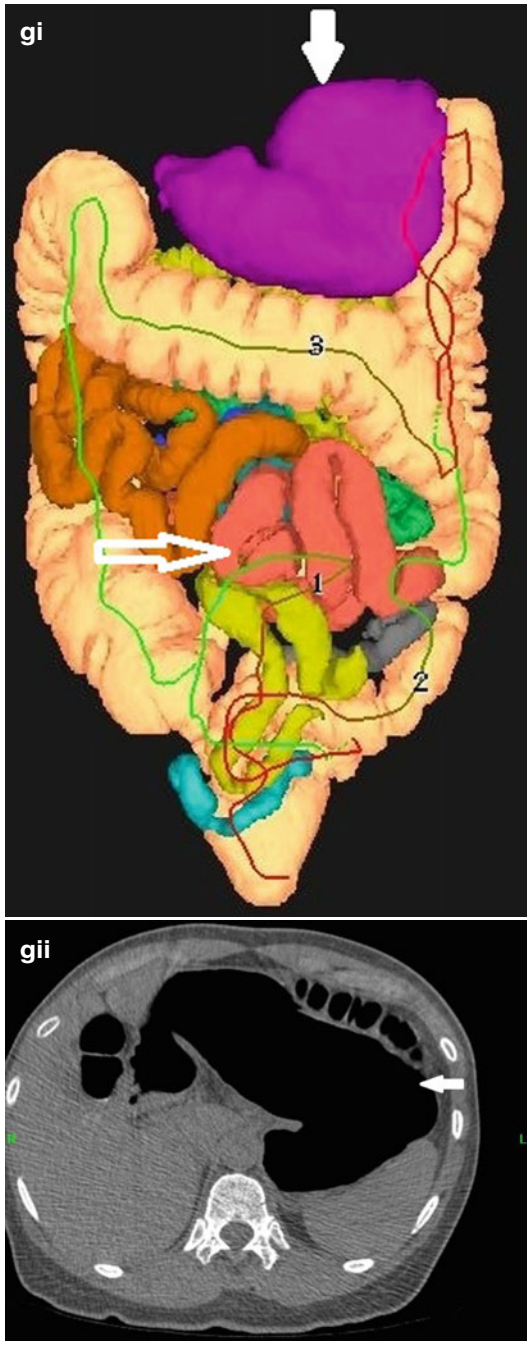

Fig. 10.2 (**g**) (**i**) Air in stomach (*closed white arrow*). Note excessive air in small bowel (*open white arrow*). (**g**) (**ii**) 2D axial view of stomach distension (*arrow*)

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 disposable soft small gauge rubber rectal catheter (25 F or smaller) is then gently inserted into the rectum, and the balloon is insufflated with 30 cc of air employing a three-way connection as shown in Fig. 10.2c. For all female patients, always check that the catheter is in the rectum and not the vagina before commencing insufflation.

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 [10]. 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 [10]. 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.

Next, 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 [10]. Some radiologists use the deflation manoeuvre after completion of the supine scan by emptying the rectum of air and then reinflating for the prone scan; this reduces the incidence of pain [12]. From time to time, it may not be possible for some patients to turn into the prone position, and a lateral decubitus view will be required instead. Ensure that, when scanning in the prone position, a pillow which is placed under the patient's chest does not impinge on the abdomen [10].

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 and the clip of the rectal bag is opened to empty the rectum of CO_2. This manoeuvre gives immense relief to the patient, [10] who is then turned into the right lateral decubitus (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 during scanning, extracolonic structures are also imaged. If the 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 (CO), 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, 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 usually results in inadequate distension of the sigmoid colon. When the patient is in the RLD position, the insufflator is switched on again to allow for introduction of a further L of CO_2, because the rectum was previously emptied when the bag was unclamped [10]. After the CO_2 has been introduced, scanning on breath hold can recommence. Whilst waiting for the images to be processed, the CO_2 is switched off. In the 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. Now and again 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. If a patient does complain of pain early on in the procedure, it is important to immediately check the inguinal regions for possible bowel herniation (Fig. 10.2e) [10]. If no herniation is evident, then the most likely cause of pain is underlying diverticular disease. 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 [10].

10.5 Evaluation of Polypoidal Lesions

There are clues that allow differentiation between a polypoidal lesion and stool: 2D and 3D views are complementary. The former is the most useful method for making the distinction. When a polypoidal lesion is observed on 3D endoluminal flythrough, it is important to ascertain whether it is a polyp or stool. The latter can mimic a polyp, particularly in patients with suboptimal 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 [10]. 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, Macari and Bini [13] 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. However, it is not the polyp that moves, but the segment of 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). If movement is detected, the structure would favour stool and not a polyp. 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 [14]. 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 translucent display (TD) is a Viatronix software tool. It provides a semi-transparent view in different colours beneath the surface [15]. 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

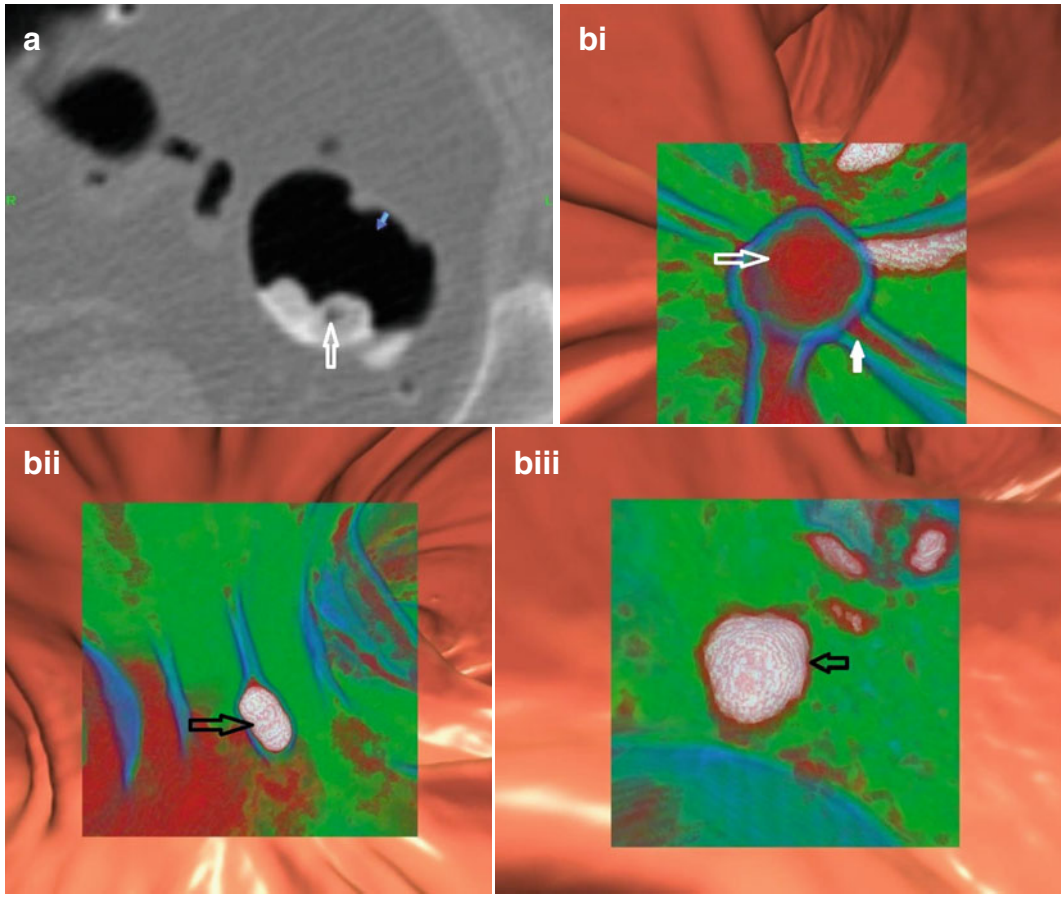

Fig. 10.3 (**a**) 2D view shows air in stool (*white arrow*). (**b**) (**i**) Translucent display (TD) of a pedunculated polyp showing high intensity red centre (*open white arrow*) as well as high intensity stalk (*closed white arrow*). *Green* fatty tissue. (**b**) (**ii**) TD shows barium covered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

attenuation range; and blue indicates negative values, such as air [16]. The use of TD allows for visualisation of the composition of a polypoidal lesion. A polyp on TD 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 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 a centre of a lesion.

The above process may seem to be complicated, but in fact it is an easy process. 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 % [17, 18]. Reasons for a failed OC might include older patients, female gender, colon length, number of acute angle bends and flexures, advanced diver-

ticular disease, prior abdominal surgery, occlusive cancers, benign strictures, colon containing hernias, intestinal malrotation and poor bowel preparation. From a CTC perspective, this group of patients is the most challenging [10]. 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. In addition, 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 Gastrografin), it was necessary to consider a compromise [10]. This entailed giving such a patient 60 cc of Gastrografin on arrival, and a CTC study usually could commence about 2 h later to allow time for the tagging agent to reach the rectum. However, over a period of time, it became obvious that significant lesions were being missed. Most centres that offer CTC have thus changed their protocols by performing the study the day after a failed or incomplete OC. The patient is kept on a liquid diet for a further 24 h, and steps 2–4 in Table 9.1 are followed for bowel preparation.

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 [10]. 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 [19]. 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 [20]. The images are viewed and, if any extra-luminal air is present, a CTC is not performed (see Fig. 10.4). The referring clinician must be immediately informed of this CT finding. If no free is identified to suggest perforation, the scanning protocol in Fig. 10.2b is implemented.

Hough et al. [20] 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 P 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 intramurally [10]. The scanning protocol in Fig. 10.2b is implemented if no free is identified on the pre-procedure low-dose CT scans to suggest perforation.

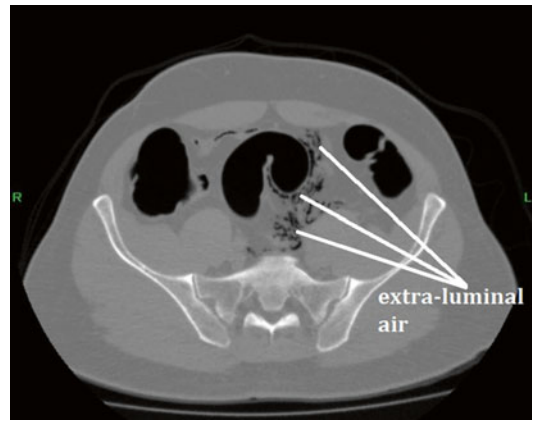

Fig. 10.4 2D axial view shows extra-luminal air indicating colonic perforation following an optical colonoscopy

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 recent study reported that CCE's sensitivity and specificity were 88 % and 82 %, respectively, in terms of identifying conventional adenomas 6 mm or larger [17]. 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 [21]. CTC also detects lesions outside the colon, but this is not possible with CCE.

10.8 Extracolonic Findings

CTC screening is usually performed in healthy asymptomatic individuals using supine and prone scans without intravenous (i.v.) 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. 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. Extracolonic findings are covered in Chap. 18.

10.9 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, 22]. There is consensus that 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 [15]. 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) [10].

Pickhardt et al. [22] maintain that 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 [22]. According to these authors, primary 2D CTC 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 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 [10]. A unidirectional fly-through from the rectum to the caecum

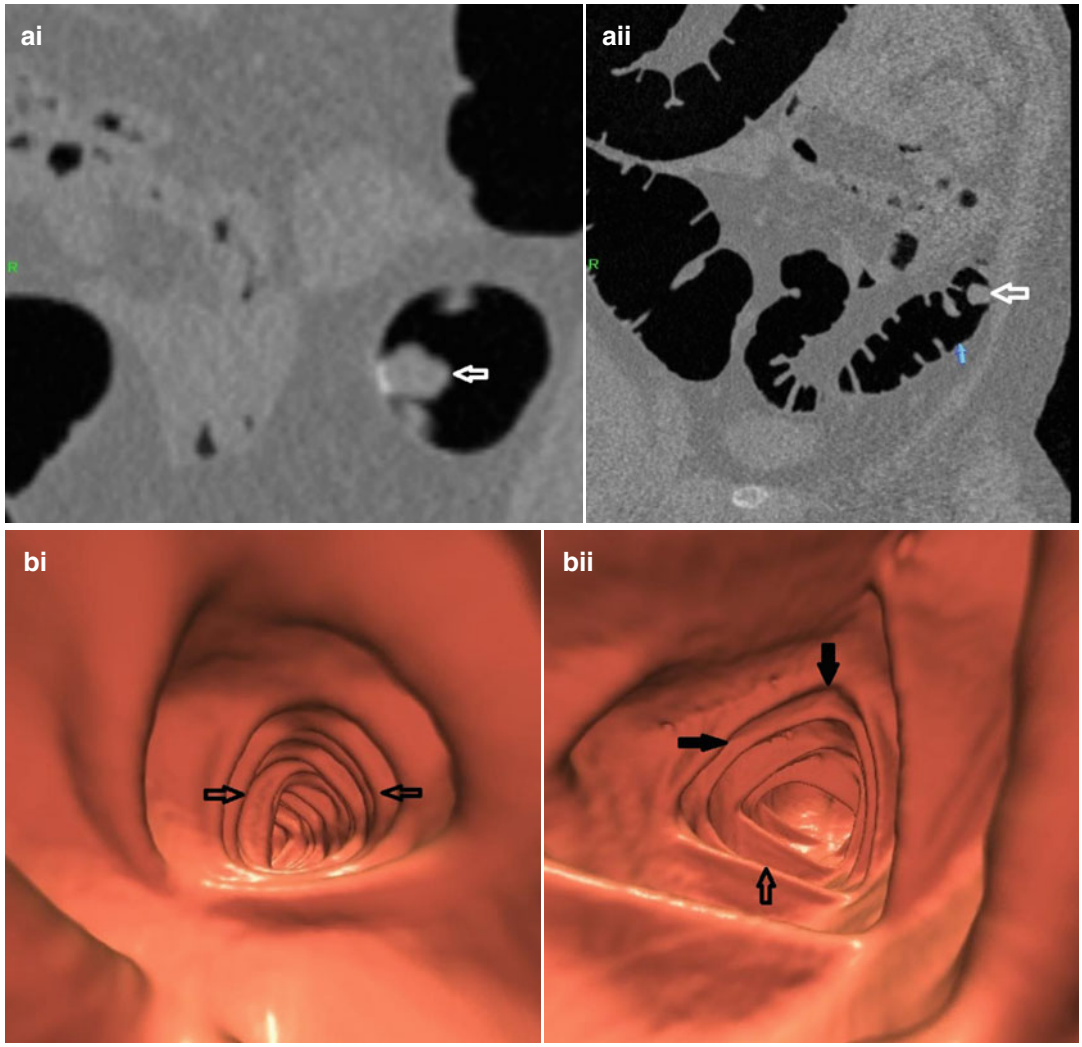

Fig. 10.5 (**a**) (**i**) 2D supine view shows pedunculated polyp on medial wall of colon (*arrow*). (**a**) (**ii**) 2D prone view shows movement of pedunculated polyp to the lateral wall of colon (*arrow*). **(b)** (**i**) 3D showing circular fold in descending colon (*arrows*). **(b)** (**ii**) 3D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

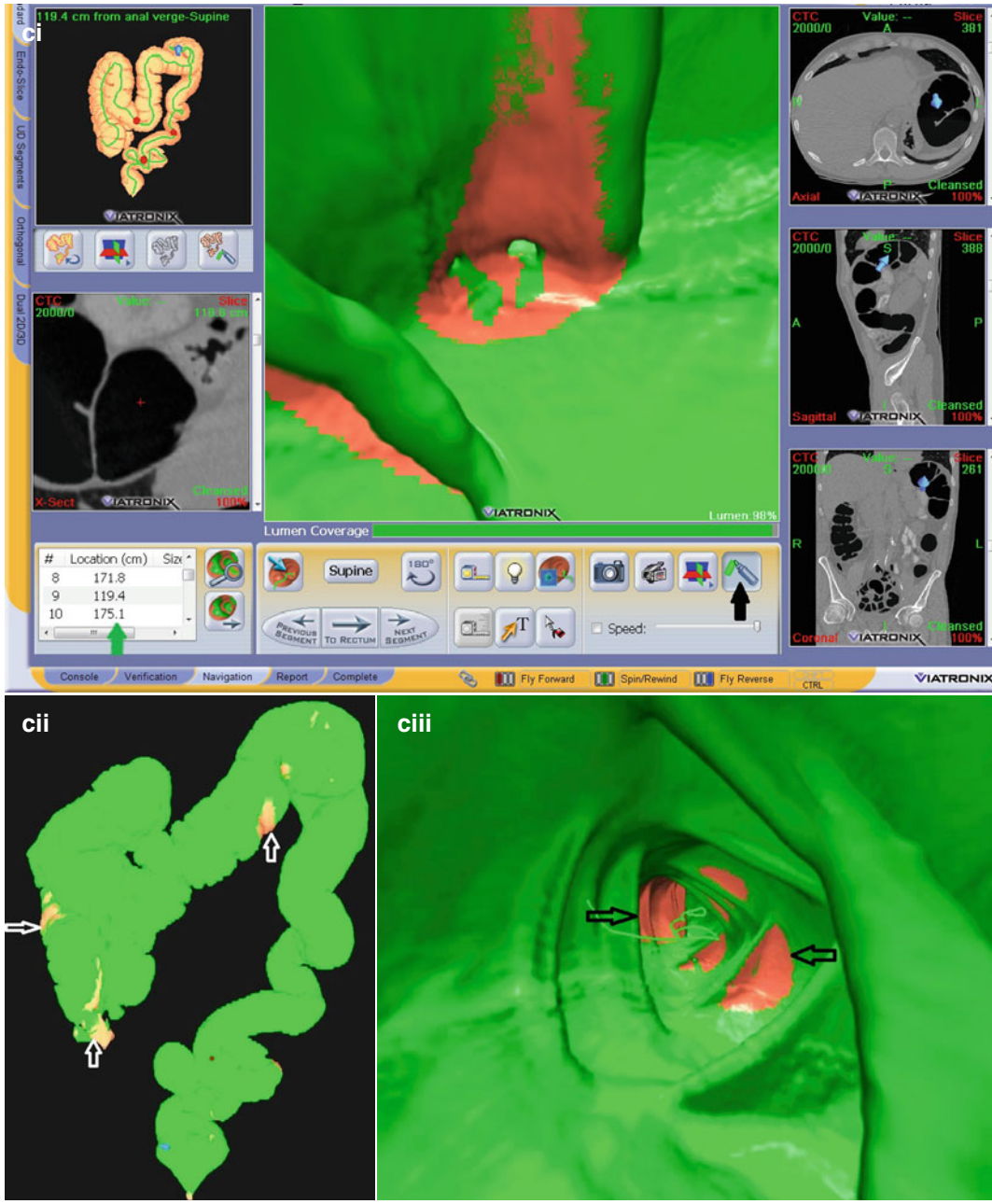

Fig. 10.5 **(c)** (**i**) Viatronix V3D workstation showing all the icons. Spray can icon (*black arrow*). *Green arrow* location of total number of missed areas and their distance from anal verge (image courtesy of Viatronix, Stony Brook, New York). **(c)** (**ii**) Colon view showing three missed areas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

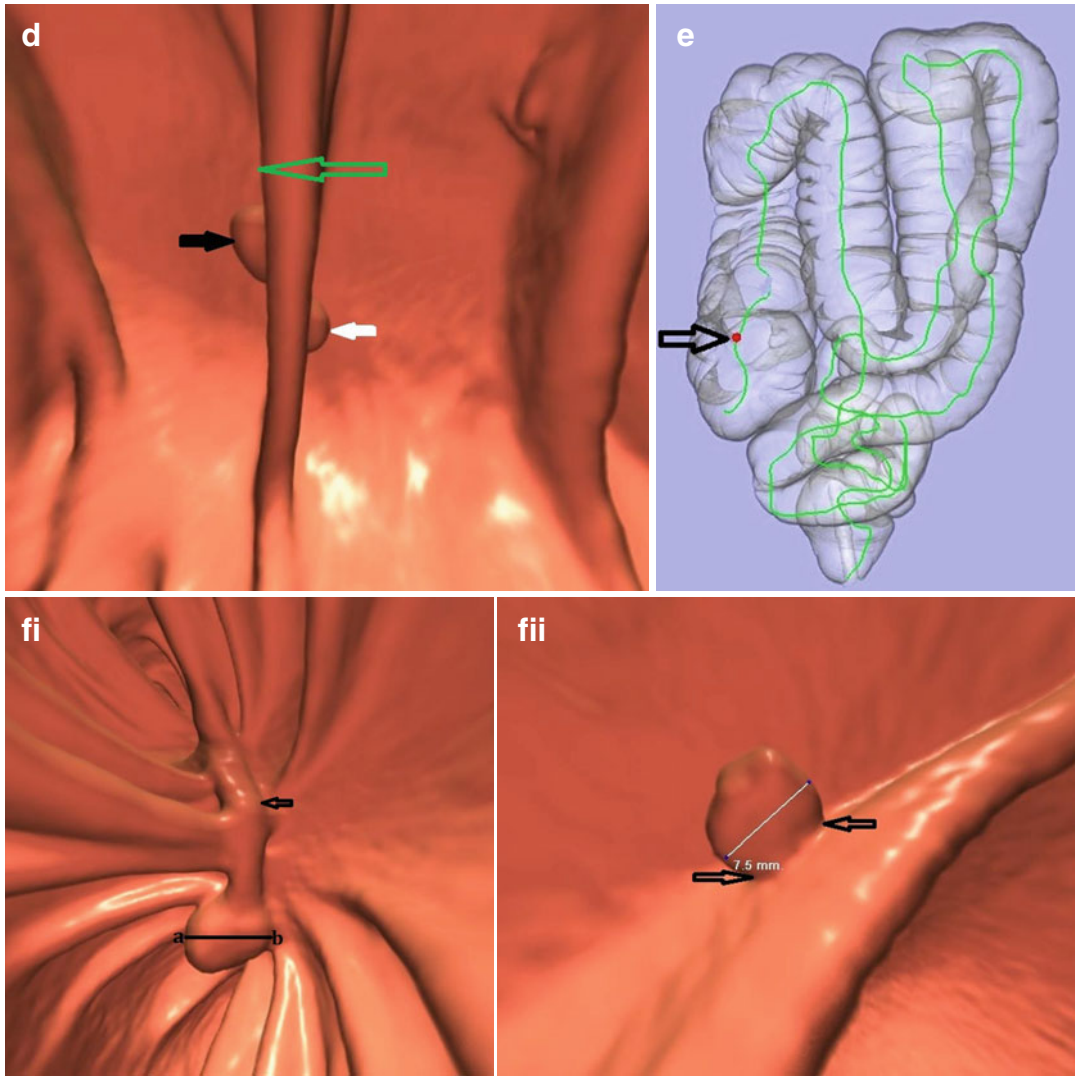

Fig. 10.5 **(d)** *Black arrow* points to a sessile polyp on posterior haustral fold. *White arrow* points to a smaller sessile polyp on anterior haustral fold. *Open green arrow* indicates flight from rectum to caecum. (**e**) Colon-map with a 'bookmark' *red dot* indicating site of lesion (*open black arrow*). Note green centre line. **(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*)

covers only a maximum of 90 % of colonic mucosa. This is the maximum percentage of mucosa visualised at OC on withdrawal of the scope. CTC visualises the total bowel mucosa four times: from the rectum to the caecum and back in the supine position and again in the prone series. This means that 100 % of colonic mucosa is visualised.

For CTC interpretation, the 3D colon-map view and automated centre line are essential for effective 3D evaluation. The centre line 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. The colon-map also indicates relevant anatomy, such as an excessively tortuous portion of bowel. A centre line 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 [10]. 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 detectable 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 [10]. 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 centre line.

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 [20], 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' [10]. A reporting template is included in Chap. 19.

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. A study is considered positive when a lesion ≥6 mm is detected. If there are more than three polyps in the 6–9 mm range, OC is recommended on the same day. If the polyp burden is lower (<3 polyps), an option is a 3-year surveillance. If after 3 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 [23, 24].

A 2015 study that involved 9336 adults reported interesting results in terms of OC' s status as the gold standard colon test [25]. 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, location 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 of 8.5 ± 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 [25]. 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 lesion subsequent follow-up by OC, 40 % proved to be CTC true-positive findings. The remaining balance was 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

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 from Kim et al. [26]

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 [25]. 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 as indicated. The characteristics of advanced adenomas should be known (see Table 10.3) [15, 24, 26].

10.10 Methods and Software to View CTC Images

CTC interpretation is underpinned by knowledge of both normal and abnormal anatomical variations. CTC produces two-dimensional (2D) images comprising axial, multiplanar reformations (MPR) coronal, sagittal and oblique views and three-dimensional (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 [27]. 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 [9]. 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:

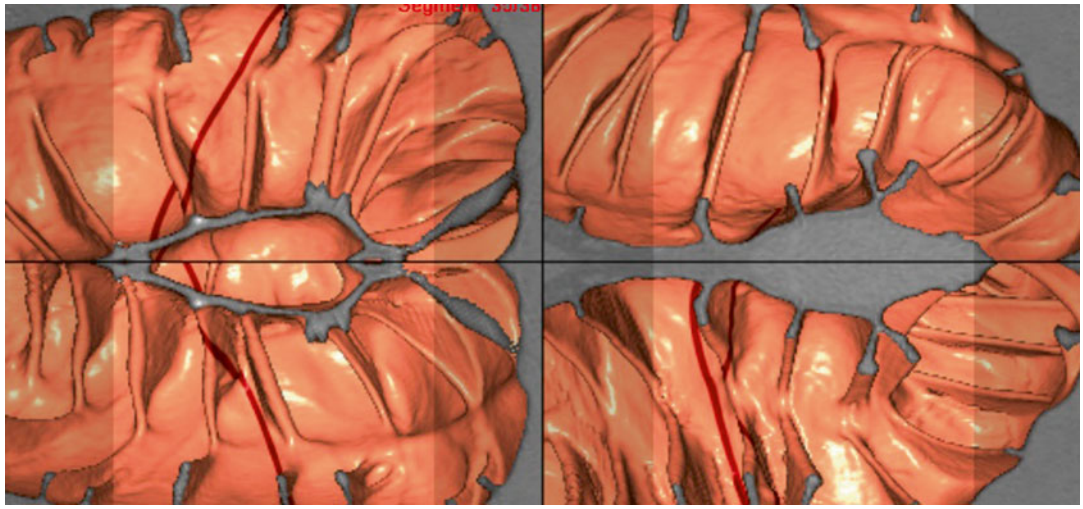

Fig. 10.6 Filet view. Its appearance resembles a pinned pathology specimen

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

Computer-aided detection (CAD) systems have become available [28, 29]. These systems are designed primarily to identify lesions that have been missed by the reader [30]. Reading time using CAD, especially by inexperienced readers, is usually longer [31]. CAD does have a role as either a primary or secondary reader depending on a reader's experience.

10.11 Key Messages

- Check volume of CO_2 in the cylinder before commencing the study.
- Patient must be sent to restroom/lavatory to empty rectum of fluid before the CTC study commences.
- Patient preparation includes cathartic and tagging agents.
- If patient complains of 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.
- Balloon is deflated when patient is in 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. Computer-aided detection (CAD) systems do have a role as either a primary or secondary reader.

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. [http://dx.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. [http://dx.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. [http://dx.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. [http://dx.doi.org/10.1007/s00330-014-3095-z].
8. Pickhardt PJ. Screening CT colonography: how I do it. AJR. 2007;189(2):290–8. [http://dx.doi.org/10.2214/ajr.07.2136].
9. Pickhardt PJ. Three-dimensional endoluminal CT colonography (virtual colonoscopy): comparison of three commercially available systems. AJR. 2003;181(6):1599–606.
10. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Rad. 2014;18(1); Art. #607, 11 pages. http://dx.doi/org/10.4102/sajr. v18i1.607.
11. 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. [http://dx.doi.org/10.1148/radiol.2361041926].
12. Dachman AH. Advice for optimising colonic distention and minimising risk of perforation during CT colonography. Radiology. 2006;239(2):317–21.
13. Laks S, Macari M, Bini E. Positional change in colon polyps at CT colonography. Radiology. 2004;231(3):761–6.
14. 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.
15. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009.
16. Bortz J. Inverted appendix: computed tomographic colonography diagnosis in a patient and lesson learned. S Afr J Rad. 2015;19(1); Art. #748, 4 pages. http://dx.doi.org/10.4102/sajr.v19i1.748.
17. 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.
18. Spada C, Hassan C, Munoz-Navos M, et al. Second generation colon capsule endoscopy compared with colonoscopy. Gastrointest Endosc. 2011; 74(3):581–9.
19. 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(2):464–71. [http://dx.doi.org/10.1148/radiol.2392051101].
20. 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. [http://dx.doi.org/10.2214/ajr.07.2746].
21. 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.
22. 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. [http://dx.doi.org/10.2214/ajr.07.2291].
23. 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. [http://dx.doi.org/10.2214/ajr.08.1709].
24. Johnson CD, Chen M, Toledano AY, Heiken JP, et al. Accuracy of CT colonography for detec-

tion of large adenomas and cancers. N Engl J Med. 2008;359(12):1207–17. [http://dx.doi.org/NEJMoa0800996].
25. 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(2):422–9.
26. 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.
27. 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. [http://dx.doi.org/10.1007/s00330-009-1362-1].
28. 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. [http://dx.doi.org/10.1148/radiol.10092292].
29. 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. [http://dx.doi.org/10.1148/radiol.10100354].
30. De Haan MC, Pickhardt PJ, Stoker J. CT colonography: accuracy, acceptance, safety and position in organized population screening. GUT. 2015;64(2):342–50. doi:10.1136/gutjnl-2014-308696.
31. Helbren EL, Plumb AA, Taylor SA. The future developments in gastrointestinal radiology. Frontline Gastroenterol. 2012;3(Supp 1):i36–41. doi:10.1136/flgastro-2012-100121.

Anatomy of the Colon

11

Joel H. Bortz

Abstract

Knowledge of normal anatomy of the colon, its variants, and extrinsic impressions on it is essential for interpretation of 2D and 3D CTC images. A brief description of the anatomy, including malrotation of the bowel, is accompanied by CTC images of the colon as well as extrinsic impressions on it. Interpretation of CTC images, using two-dimensional (2D) and three-dimensional (3D) software options, is briefly covered in terms of detection of polyps in the colon.

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]. A CTC reader must know the normal anatomy of the colon, as well as normal variants, and malrotation of the bowel, to interpret images. 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. Both 2D and 3D images are used to interpret the scans performed. Computer-aided detection (CAD) software systems could also be used by readers [4, 6, 7].

11.2 Anatomy of the Bowel Wall

The wall of the colon has four layers: (i) mucosa (epithelial/innermost) layer comprising connective tissue and a thin muscle layer (muscularis); (ii) submucosa comprising connective tissue, nerves, and lymphatics; (iii) muscularis propria (muscle layer) consisting of two bands, namely circular and longitudinal; and (iv) serosa is the outermost layer present from the sigmoid to caecum.

The proximal colon develops from the midgut, and its blood supply is the superior mesenteric

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artery (SMA). The distal colon develops from the hindgut; its blood supply is the inferior mesenteric 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).

11.3 Colon Anatomy

The colon length in adults varies from 150 centimetres (cm) (5 ft) to 180 cm (6 ft) or up to 300 cm (10 ft) [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 the splenic flexure to the anorectal 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. A mirror image of the two procedures is thus not possible as the folds are pushed and pulled during an OC.

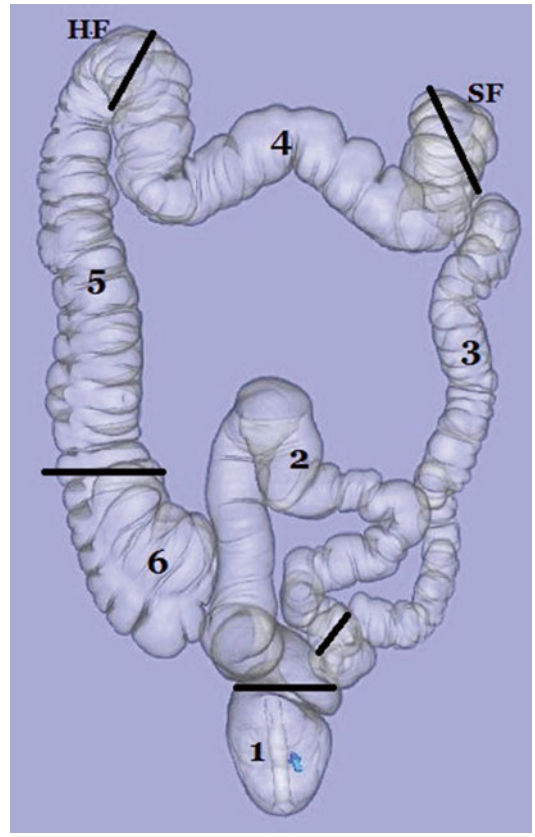

Fig. 11.1 Normal colon. Colon-map showing normal six segments of the colon: *1* rectum, *2* sigmoid colon, *3* descending colon, *4* transverse colon, *5* ascending colon, *6* caecum, *SF* splenic flexure, *HF* hepatic flexure

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 taeniae 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]. In a CTC study, the valves are depicted as three semilunar folds in the rectum (Fig. 11.2 (i), (ii)). In 50 % of people, the supe-

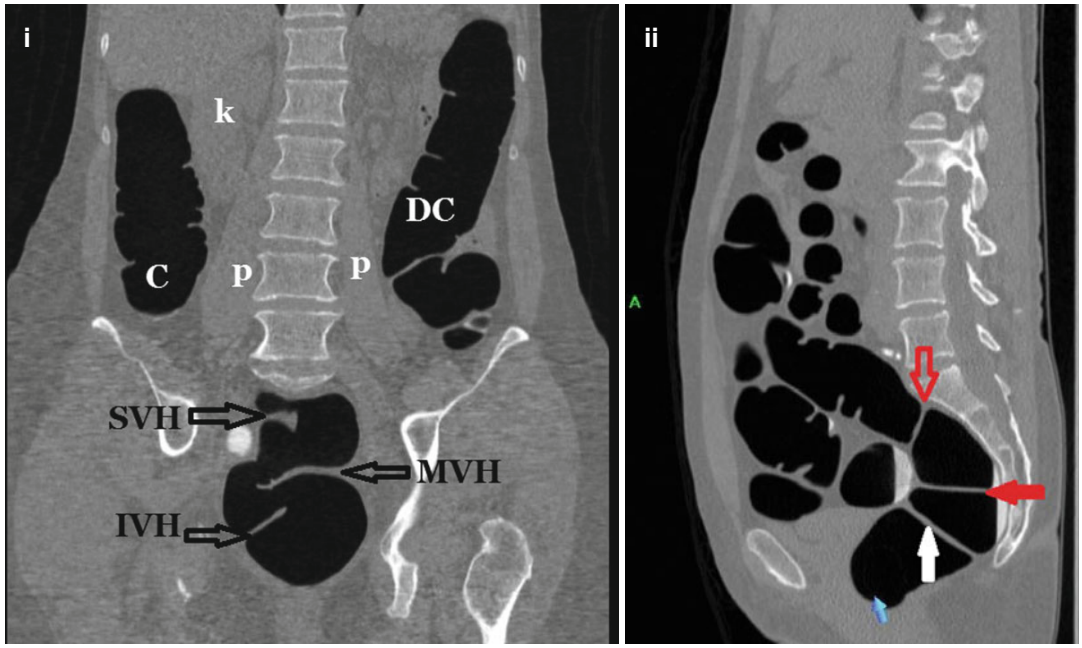

Fig. 11.2 Rectum. (**i**) 2D coronal view showing the inferior valve of Houston (IVH), middle valve of Houston (MVH), and superior valve of Houston (SVH). (**ii**) 2D sagittal view showing the three valves of Houston in the rectum. IVH (*white arrow*); MVH (*closed red arrow*); SVH (*open red arrow*)

rior and inferior folds are located on the left side of the rectum; the middle valve is more prominent and is on the right. In about 33 % of people, the configuration is reversed. 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 flythrough, 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 MPR images where the rectosigmoid colon moves upwards 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) demonstrates a normal sigmoid colon. Figure 11.3b (i), (ii) demonstrates a displaced sigmoid colon. The sigmoid colon is often smaller in calibre than the 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.

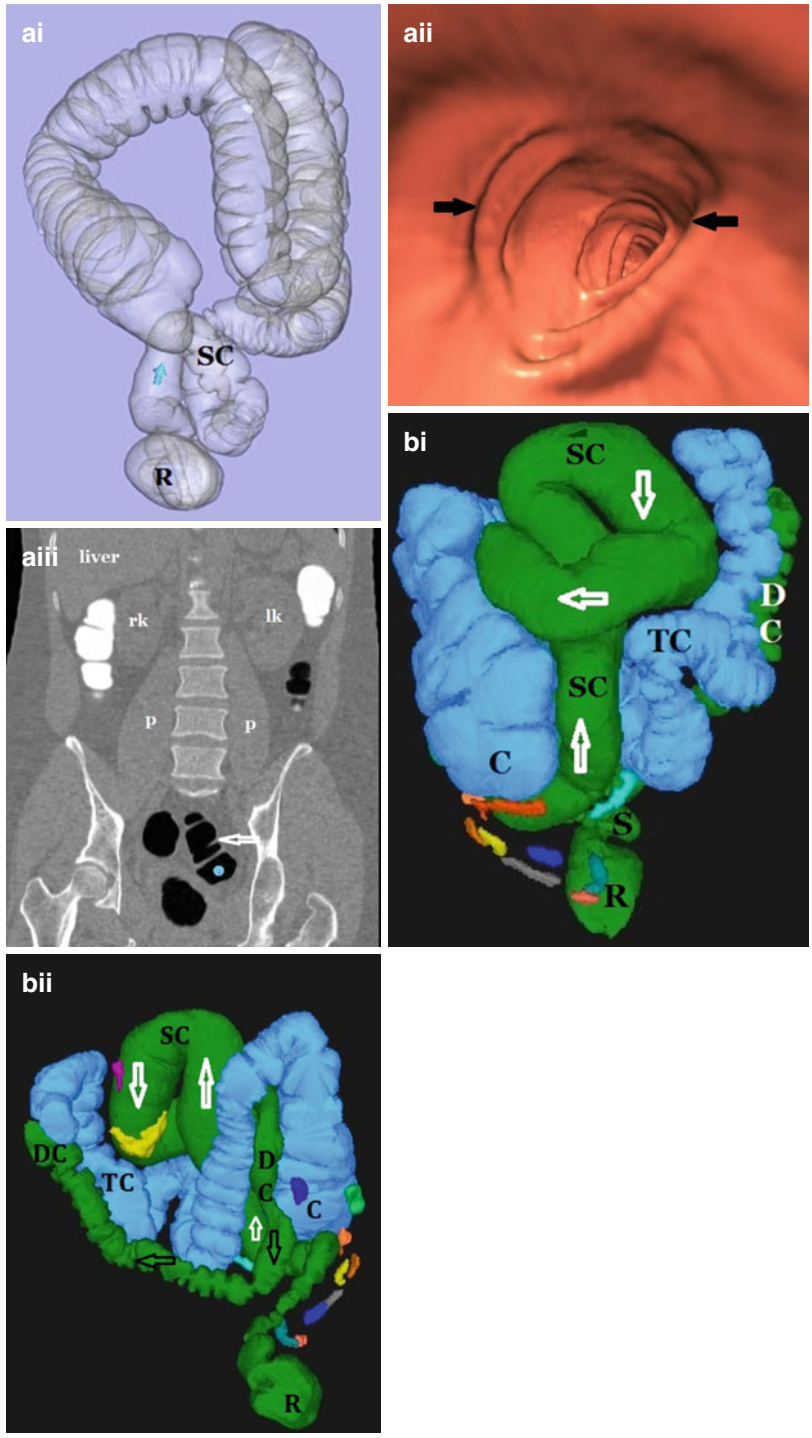

Fig. 11.3 Rectosigmoid colon (**a**) (**i**) Colon-map showing the sigmoid colon (*SC*) and rectum (*R*). (**ii**) 3D view shows circular folds (*arrow*) in the sigmoid colon. (**iii**) 2D coronal view showing the sigmoid colon (*open white arrow*). Psoas muscle (*p*); right kidney (*rk*); left kidney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

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)).

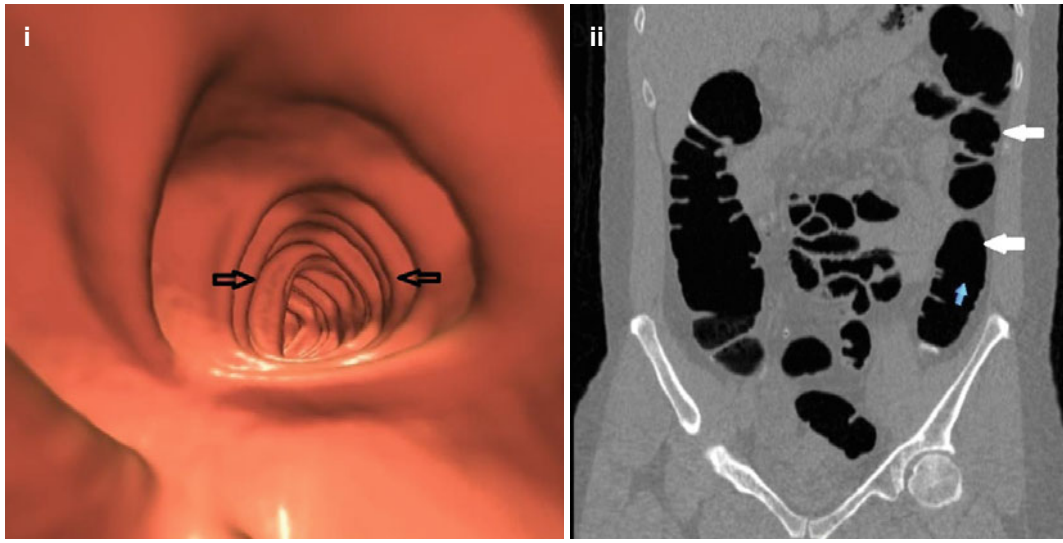

Fig. 11.4 Descending colon (**i**) 3D view of a circular fold in the descending colon (*open black arrows*). (**ii**) 2D coronal view showing the descending colon (*white arrows*)

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)).

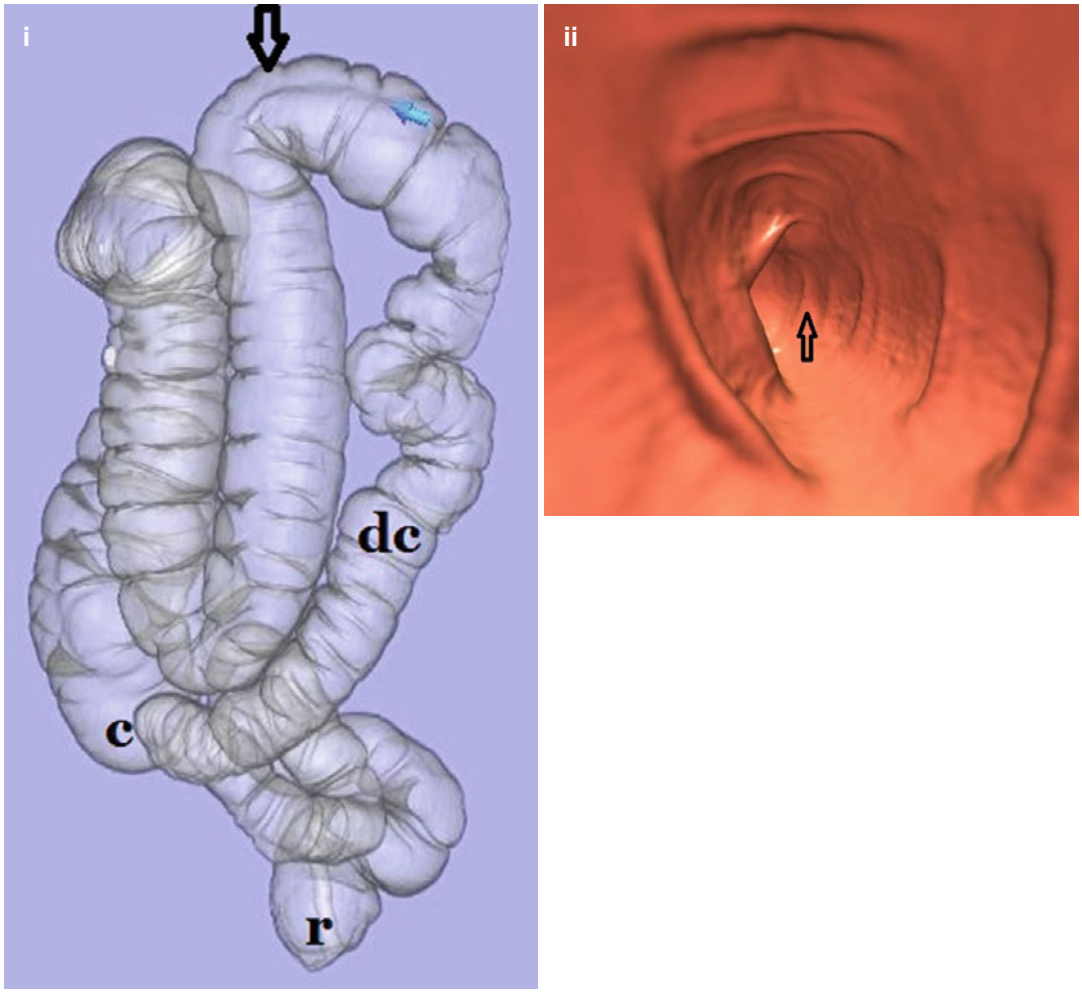

Fig. 11.5 Splenic flexure (**i**) Colon-map showing the splenic flexure (*open black arrow*). Rectum (*r*); descending colon (*dc*); caecum (*c*). (**ii**) 3D view of the splenic flexure (*open black arrow*)

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].

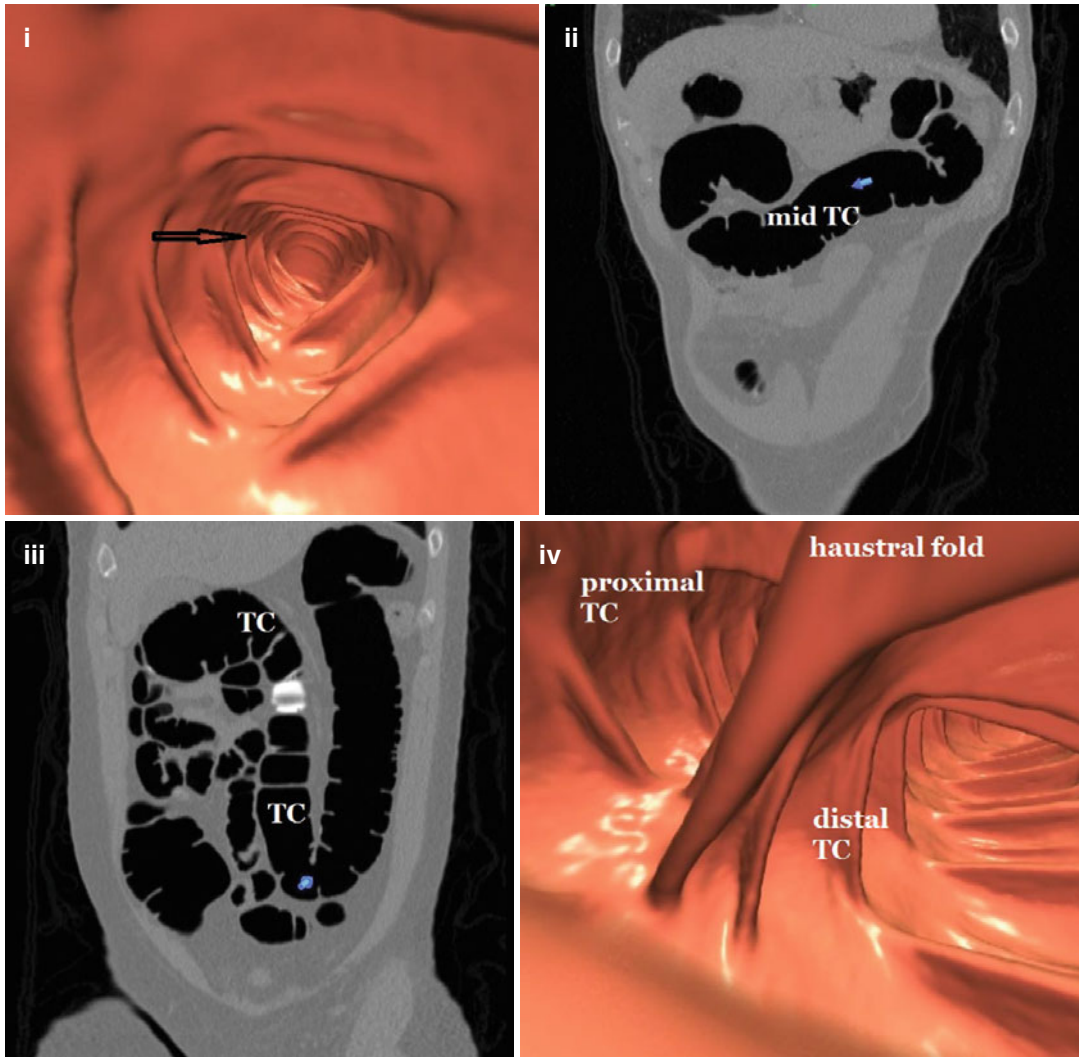

Fig. 11.6 Transverse colon (**i**) 3D view of a triangular fold in the transverse colon (*open black arrow*). (**ii**) 2D coronal view of the mid-transverse colon (mid-TC). (**iii**) 2D coronal view showing the mid-transverse colon (*TC*) dipping into the pelvis. (**iv**) 3D showing view of the mid-transverse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

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)).

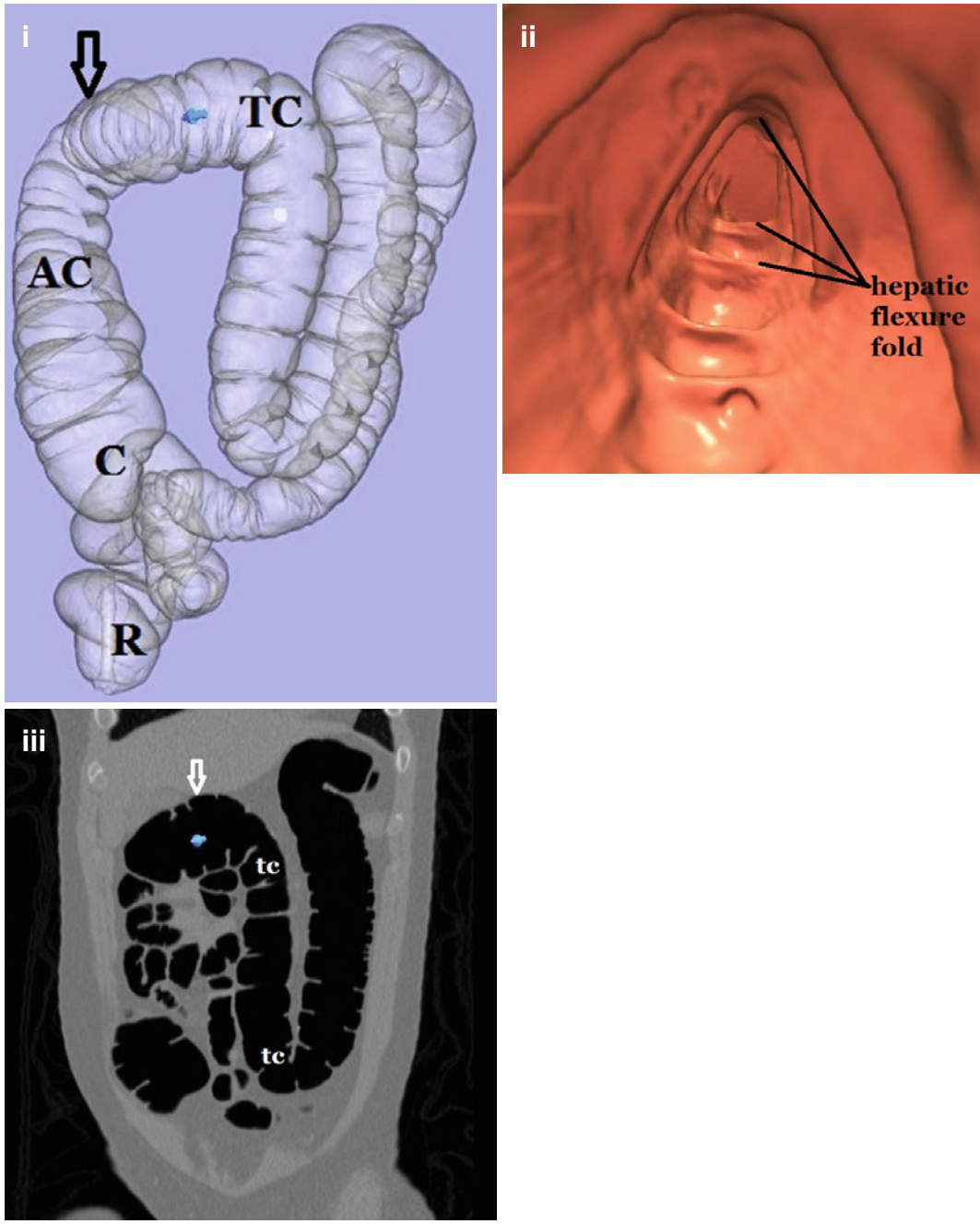

Fig. 11.7 Hepatic flexure (**i**) Colon-map showing the hepatic flexure (*open black arrow*). Rectum (*R*); transverse colon (*TC*); ascending colon (*AC*); caecum (*C*). (**ii**) 3D showing triangular fold of the hepatic flexure. (**iii**) 2D coronal view showing the hepatic flexure (*open white arrow*)

11.3.7 Ascending Colon

This 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 which is depicted in Chap. 10. This is due to a collection of fluid in this location of the colon [3]. The folds are triangular in appearance (Fig. 11.8 (i)) and slightly thicker than those in the transverse colon. Figure 11.8 (ii) shows a normal distended ascending colon.

11.3.8 Ileocaecal Valve (ICV)

The ICV valve is easy to identify. 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), (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 (Fig. 11.9a (iii)). An ICV on a CTC study may be open (patent) or closed. Figure 11.9b demonstrates a closed ICV. If it is open, then reflux of carbon dioxide may occur (Fig. 11.9c (i)–(iv)). The ICV is located posteromedially where the terminal ileum enters the caecum. An ICV may be completely replaced with fat (Fig. 11.9d (i), (ii)). It may have a high intensity (red) on translucent display (TD) as shown in Fig. 11.9d (iii). Polyps or adenocarcinoma may occur on the surface of the ICV because it is covered by mucosa.

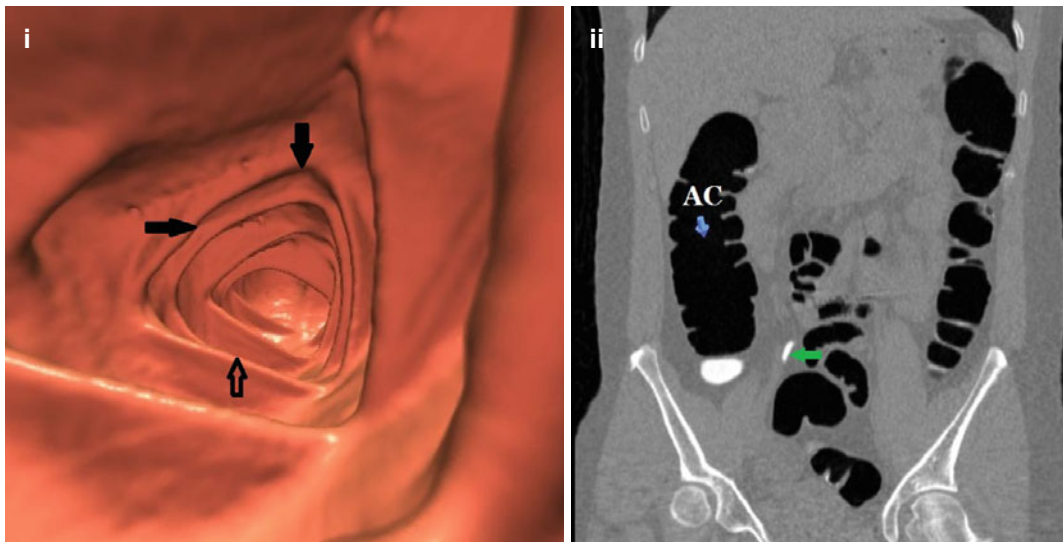

Fig. 11.8 Ascending colon (**i**) 3D view of a triangular fold in the ascending colon (*arrows*) (**ii**) 2D coronal view showing the ascending colon (*AC*). *Green arrow* = appendix

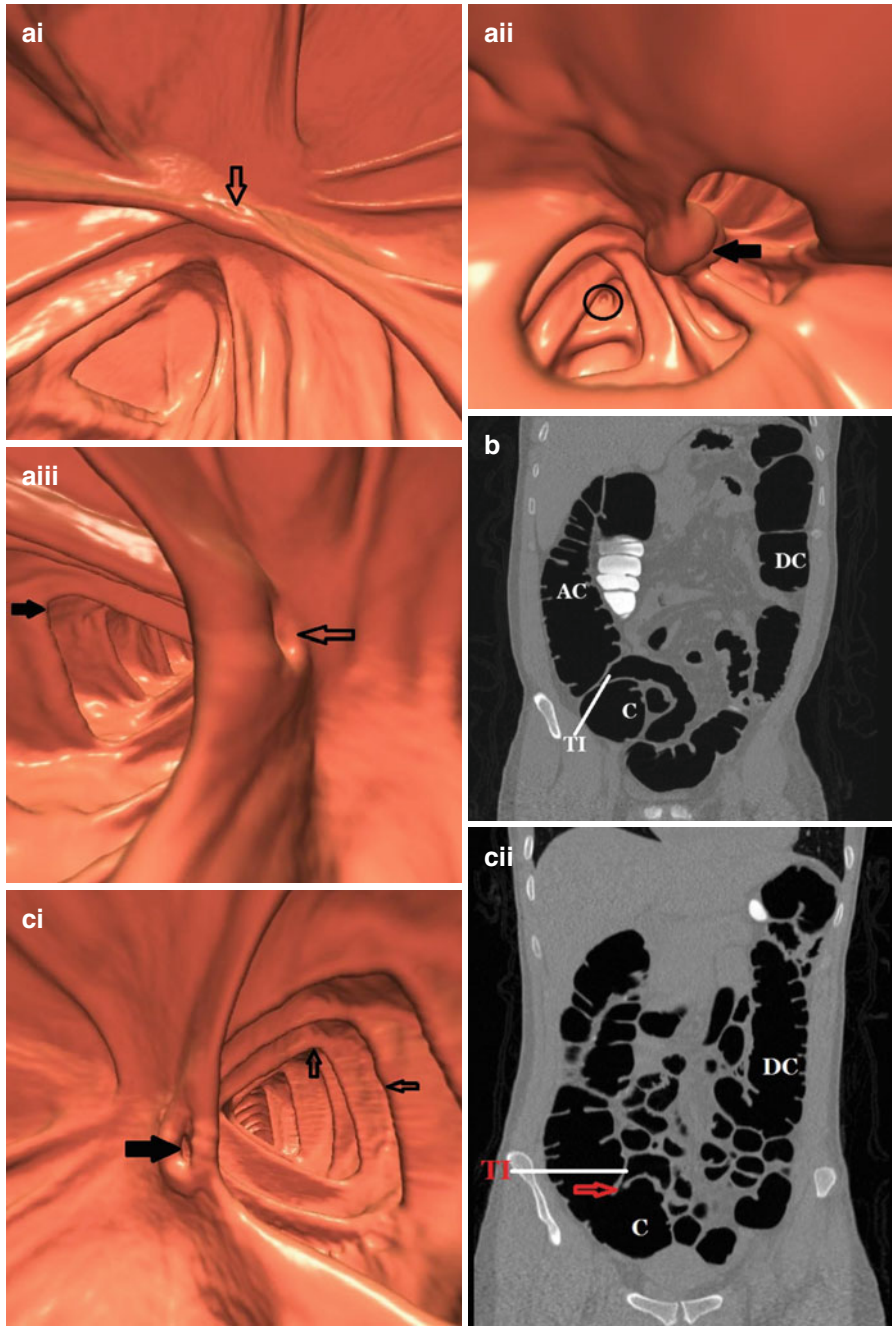

Fig. 11.9 Ileocaecal valve (**a**) (**i**) 3D view shows the labial ICV (*open black arrow*). (**ii**) 3D view of a bulbous ileocaecal valve (*black arrow*). Appendiceal orifice (*circle*). (**iii**) 3D view of ICV showing depression or 'pit' orifice (*open black arrow*) where the terminal ileum empties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

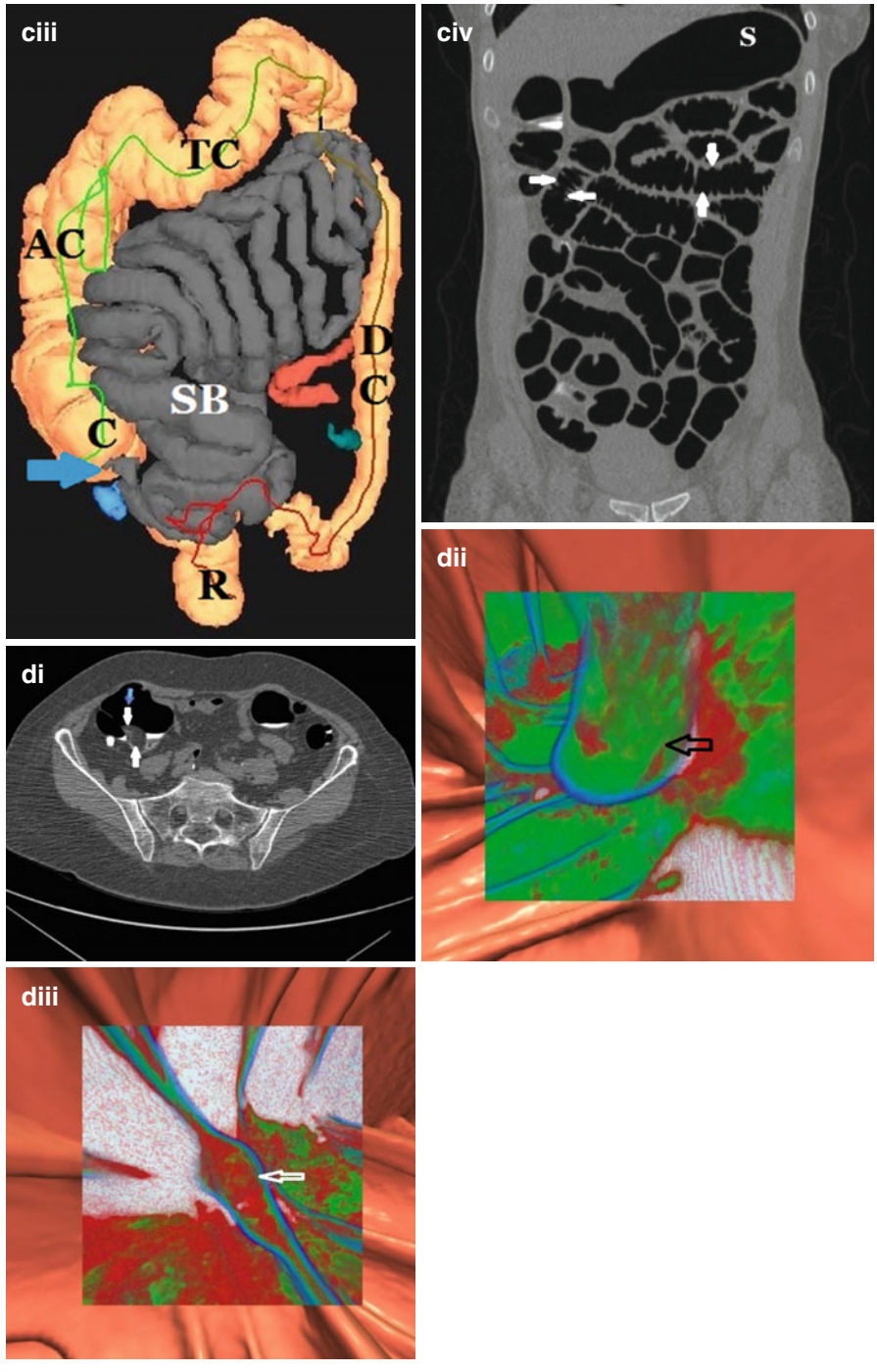

Fig. 11.9 (**iii**) Colon-map showing reflux of gas into the small bowel (SB grey) due to patent ICV (*blue arrow*). (**iv**) 2D coronal view showing the small bowel valvulae conniventes (*white arrows*) and gas in the stomach (S). (**d**) (**i**) 2D soft tissue axial view of a fatty ICV (*white arrows*). (**ii**) TD (translucent display) shows predominately 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 (Fig. 11.10 (i), (ii)). This occurs because 10 % of people have no peritoneal fixation of the ascending colon thereby allowing for caecal mobility (Fig. 11.10 (iii), (iv)). The caecum is more capacious than the ascending colon.

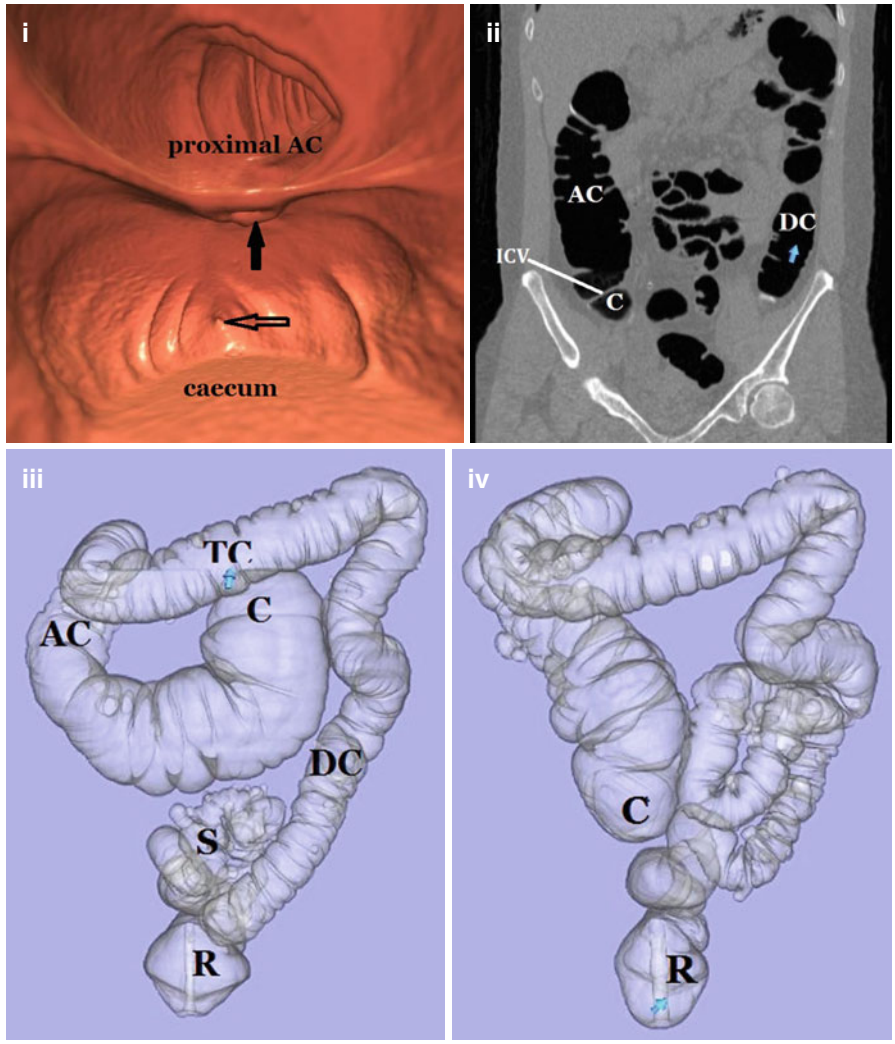

Fig. 11.10 Caecum (**i**) 3D view of the ICV (*closed black arrow*), caecum, proximal ascending colon (*AC*), and appendiceal orifice (*open black arrow*). (**ii**) 2D coronal view: ascending colon (*AC*); ileocaecal valve (*ICV*); caecum (*C*); descending colon (*DC*). (**iii**) Supine colon-map showing abnormal position of the 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 the 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 and its base is usually situated 2 cm below the ileocaecal valve. 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 foot that flank the appendiceal orifice and is shown on the 3D endoluminal view (Fig. 11.11a (i)) [3]. Figure 11.11a (ii), (iii) demonstrates the orifice of the appendix and appendiceal lumen. Figure 11.11b (i) to d (iv) is of a range of 2D and 3D images of the appendix in various locations in the abdomen. Figure 11.11e (i), (ii) is of an appendix in the inguinal canal.

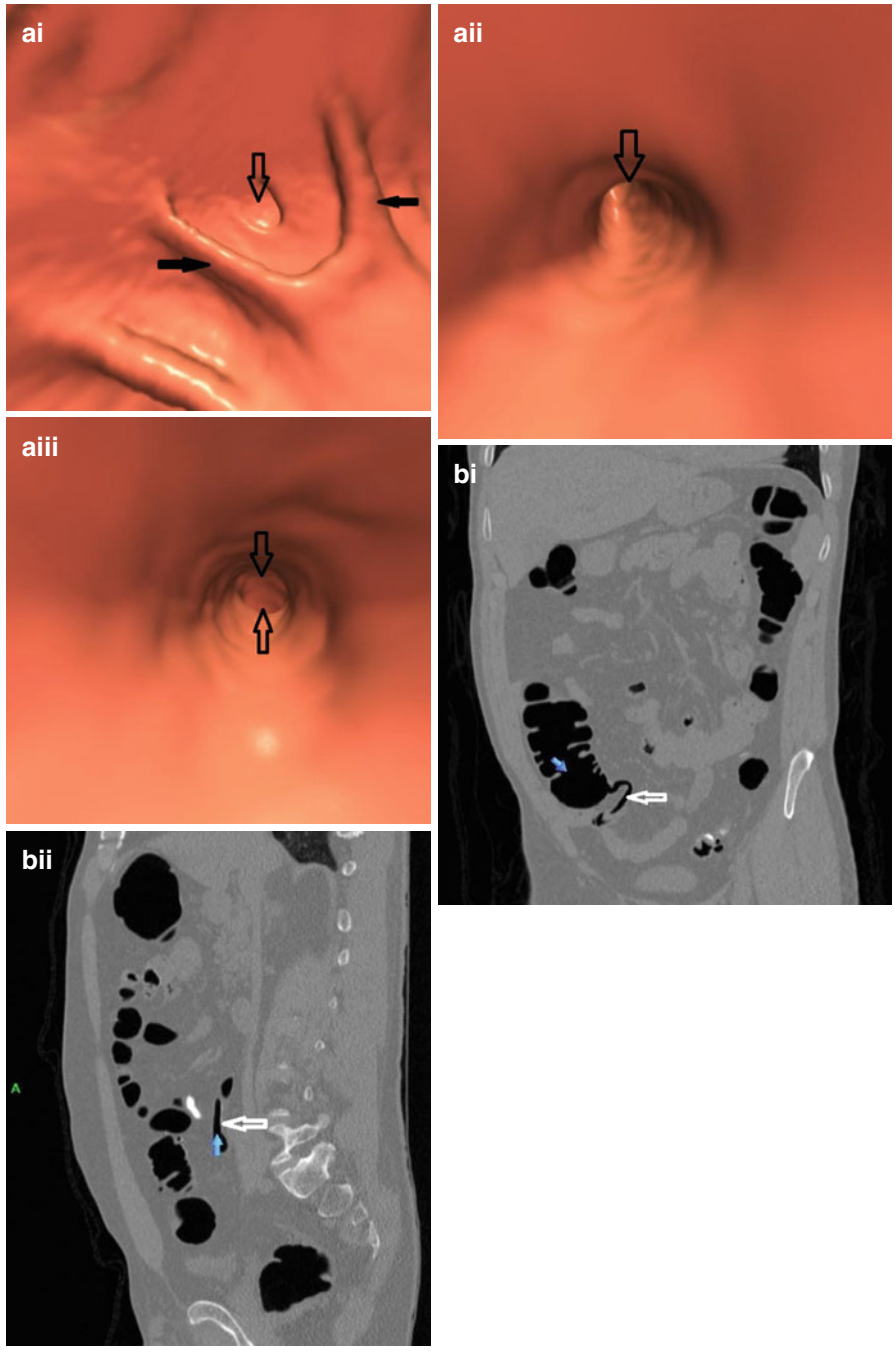

Fig. 11.11 Appendix. (**a**) (**i**) 3D view of the appendiceal orifice (*open black arrow*) and crow's foot (*closed black arrows*). (**ii**) 3D view of the orifice of appendix (*open black arrow*). (**iii**) 3D view of the appendiceal lumen (*open black arrows*). (**b**) (**i**) Air in the appendix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

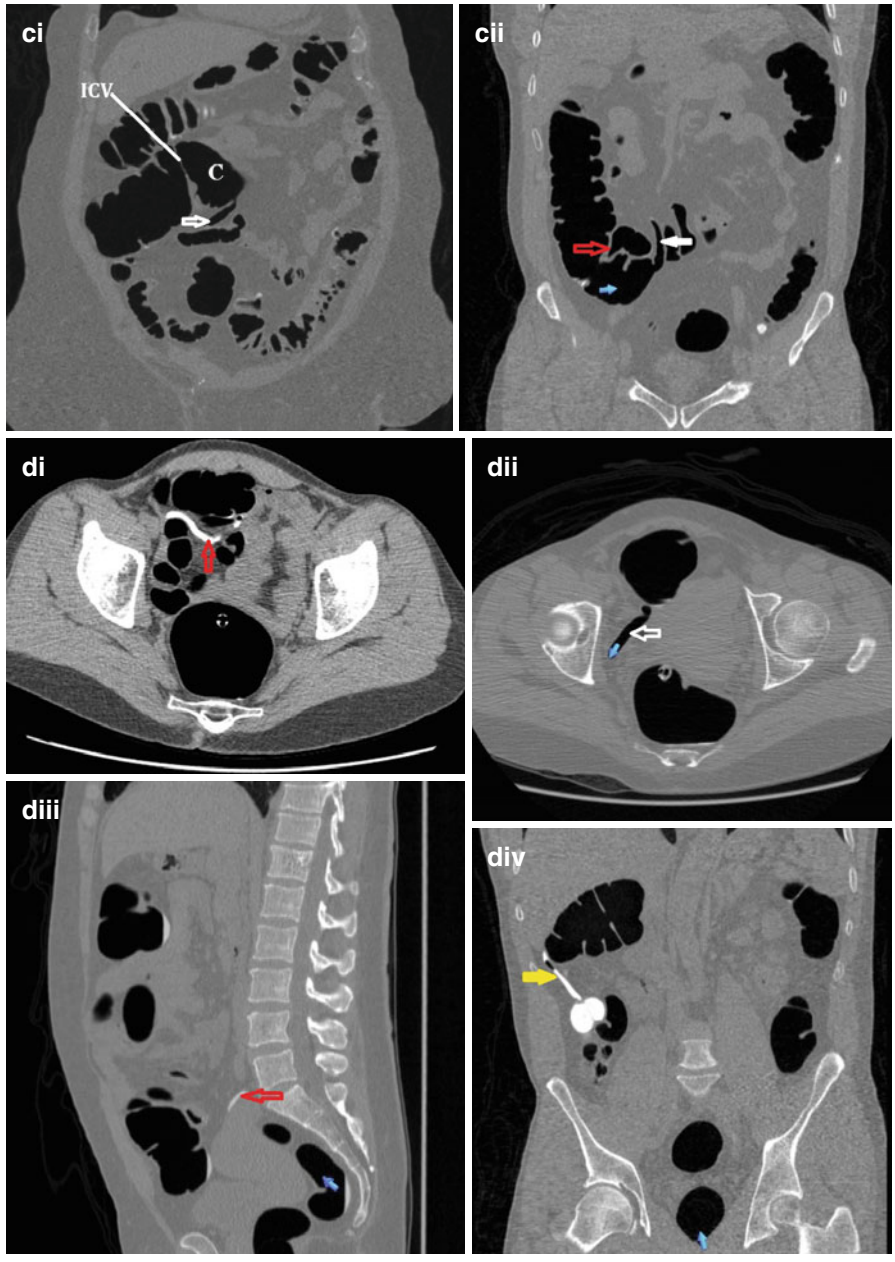

Fig. 11.11 (**c**) (**i**) 2D coronal view showing the malrotated caecum (*C*), air-filled appendix (*open white arrow*), and ileocaecal valve (*ICV*). (**ii**) 2D coronal view showing air in the terminal ileum (*open red arrow*) and air in the appendix (*closed white arrow*). (**d**) (**i**) 2D axial showing the barium-filled appendix (*open red arrow*). (**ii**) 2D axial showing the retrocaecal appendix filled with air (*open white arrow*). (**iii**) 2D sagittal view showing the appendix (*open red arrow*) adjacent to the spine. (**iv**) 2D coronal view showing the sub-hepatic appendix (*yellow arrow*)

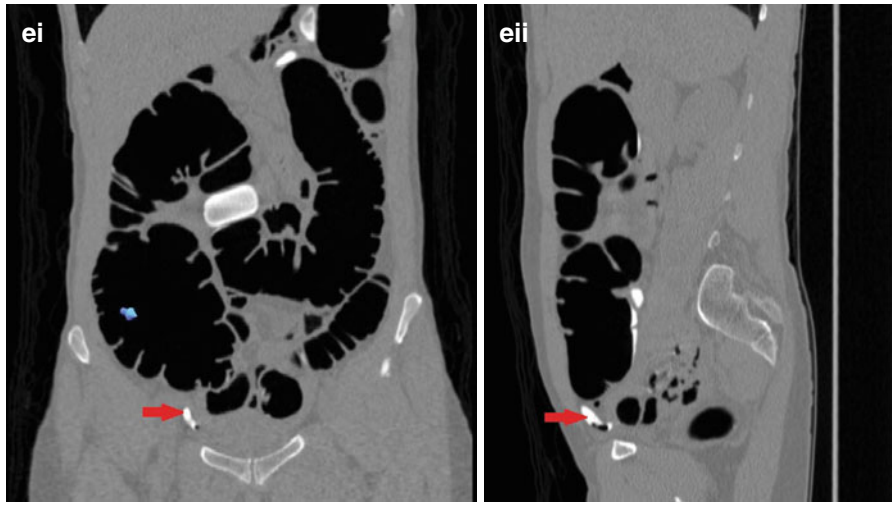

Fig. 11.11 (**e**) (**i**) 2D coronal view showing the appendix (*closed red arrow*) in the inguinal canal. (**ii**) 2D sagittal view showing the appendix (*closed red arrow*) in the inguinal canal

11.4 Malrotation of the Bowel

Malrotation is a failure during 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 postnatal 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 would 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]. Examples of such pathology are presented in Fig. 11.12a (i) to b.

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.

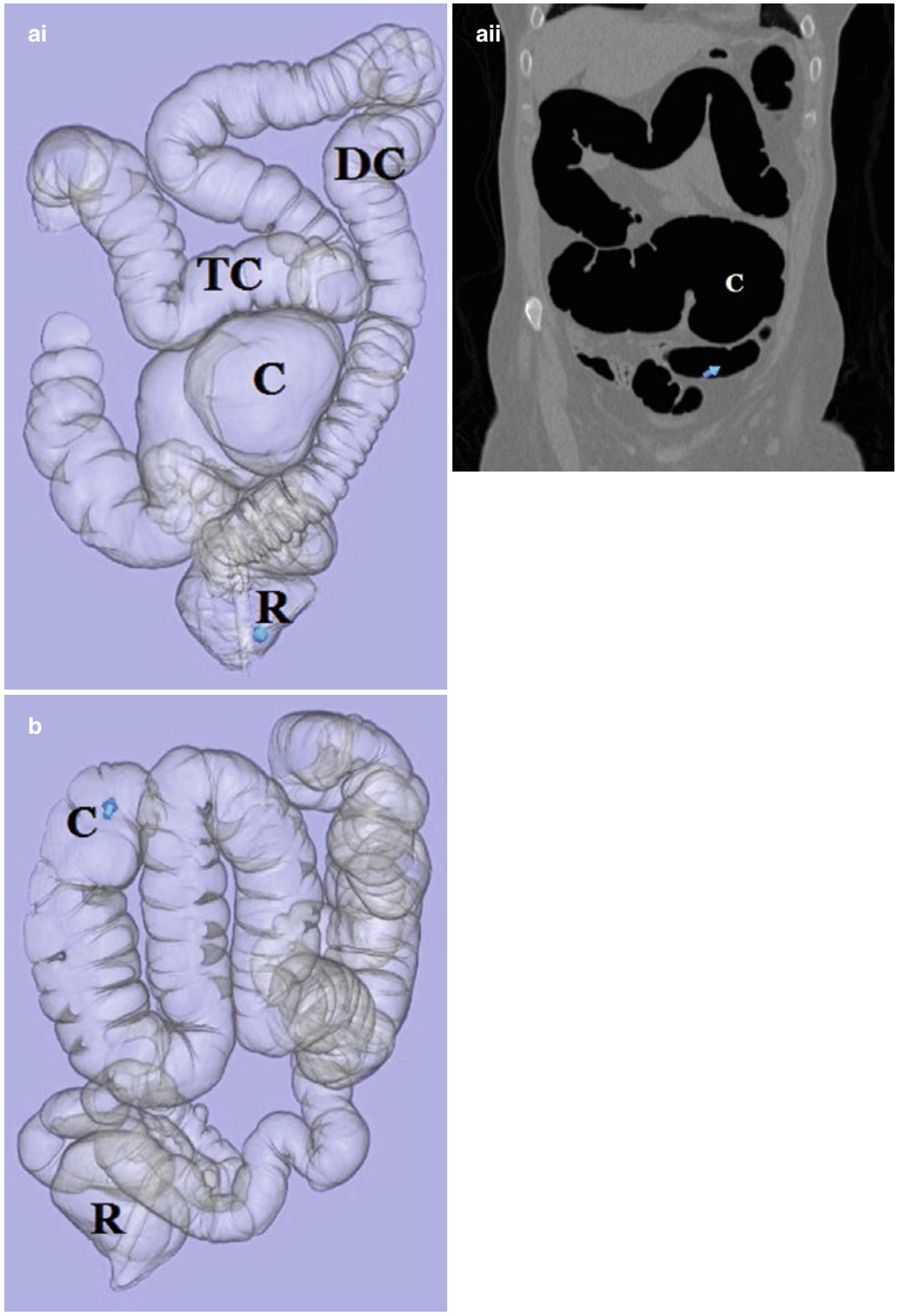

Fig. 11.12 Malrotation of the bowel. (**a**) (**i**) Supine colon-map of a malrotated caecum (*C*). Rectum (*R*); descending colon (*DC*); transverse colon (*TC*). Note the gap in the ascending colon (technical). (**ii**) 2D coronal view of a malrotated caecum (*C*). (**b**) Supine colon-map showing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

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. The caecum usually lies in the right iliac fossa as demonstrated on Fig. 11.1 above. 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), (ii) demonstrates mobility of the caecum.

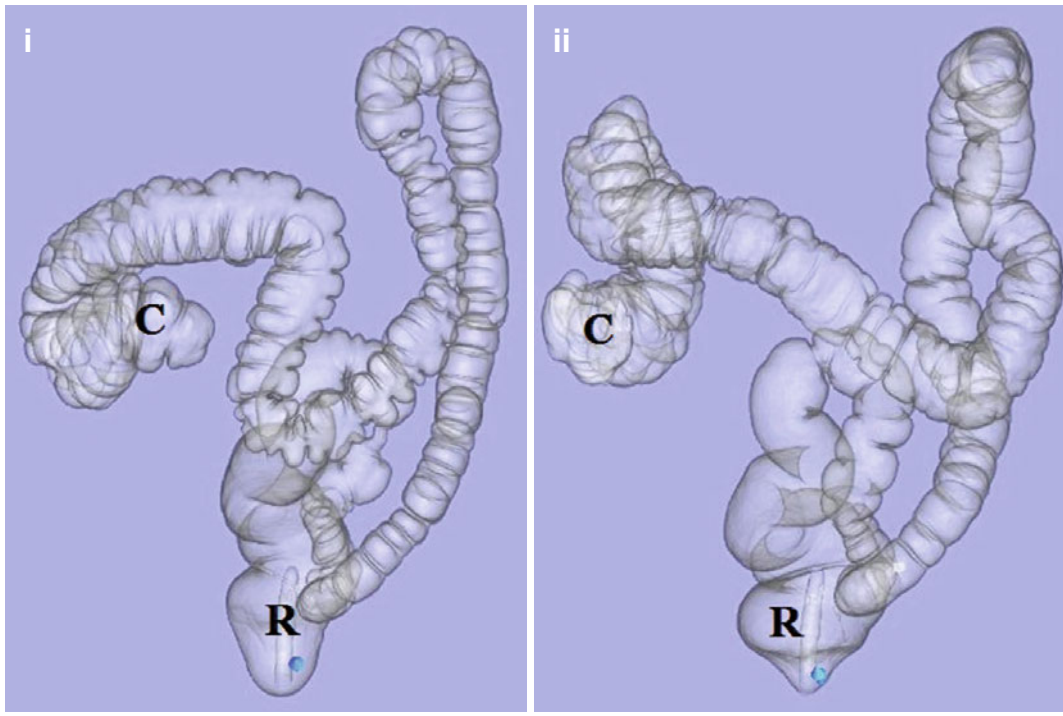

Fig. 11.13 Mobility of colon segments (**i**) Supine colon-map. Caecum (*C*) and rectum (*R*). (**ii**) Prone colon-map shows different position of the caecum (*C*). Rectum (*R*)

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 multiplanar reformation (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) to g (ii) is an example of extrinsic impressions on 3D and 2D images.

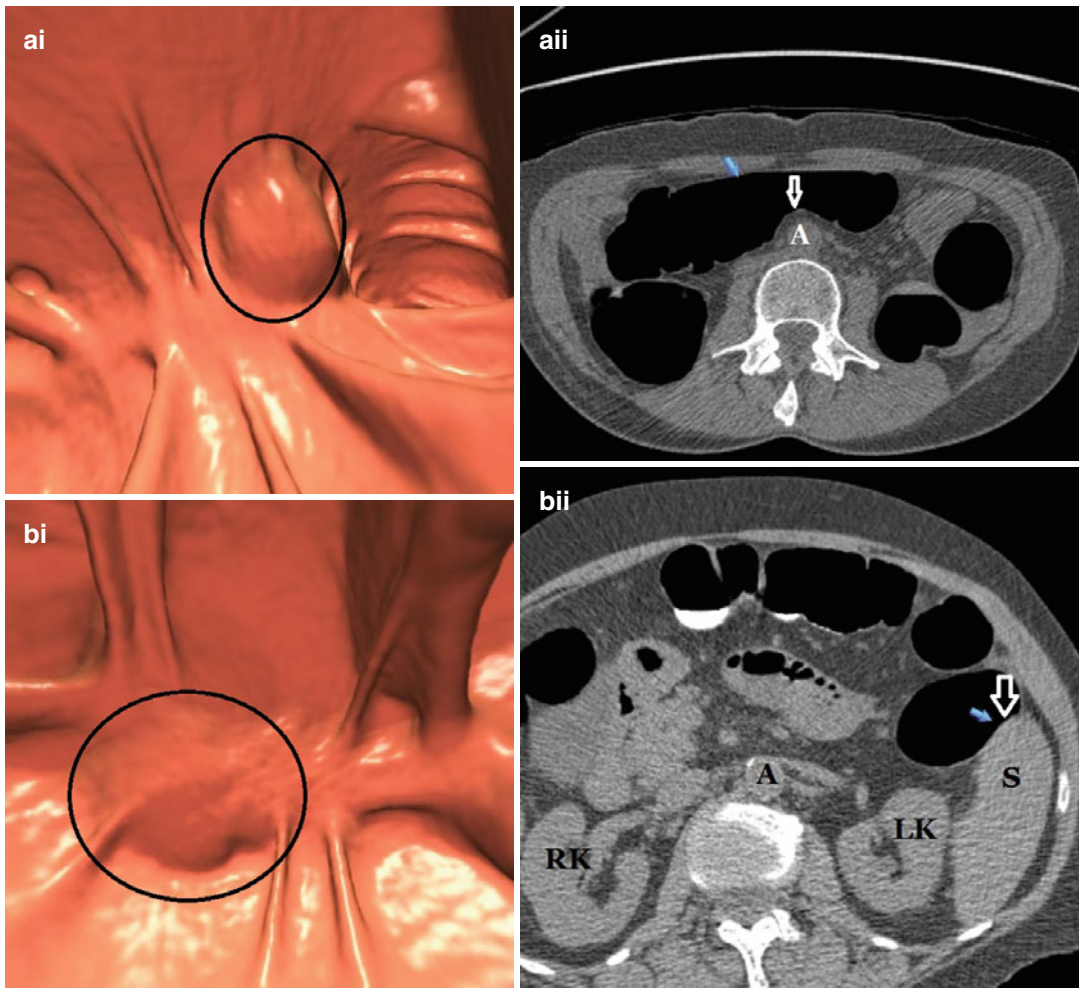

Fig. 11.14 Extrinsic impressions (**a**) (**i**) 3D view of an extrinsic impression (*circle*) on the bowel caused by the aorta. (**ii**) 2D axial view shows the aorta (*A*) causing external impression on the colon (*open white arrow*). (**b**) (**i**) 3D view of the spleen (*circle*) causing an extrinsic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

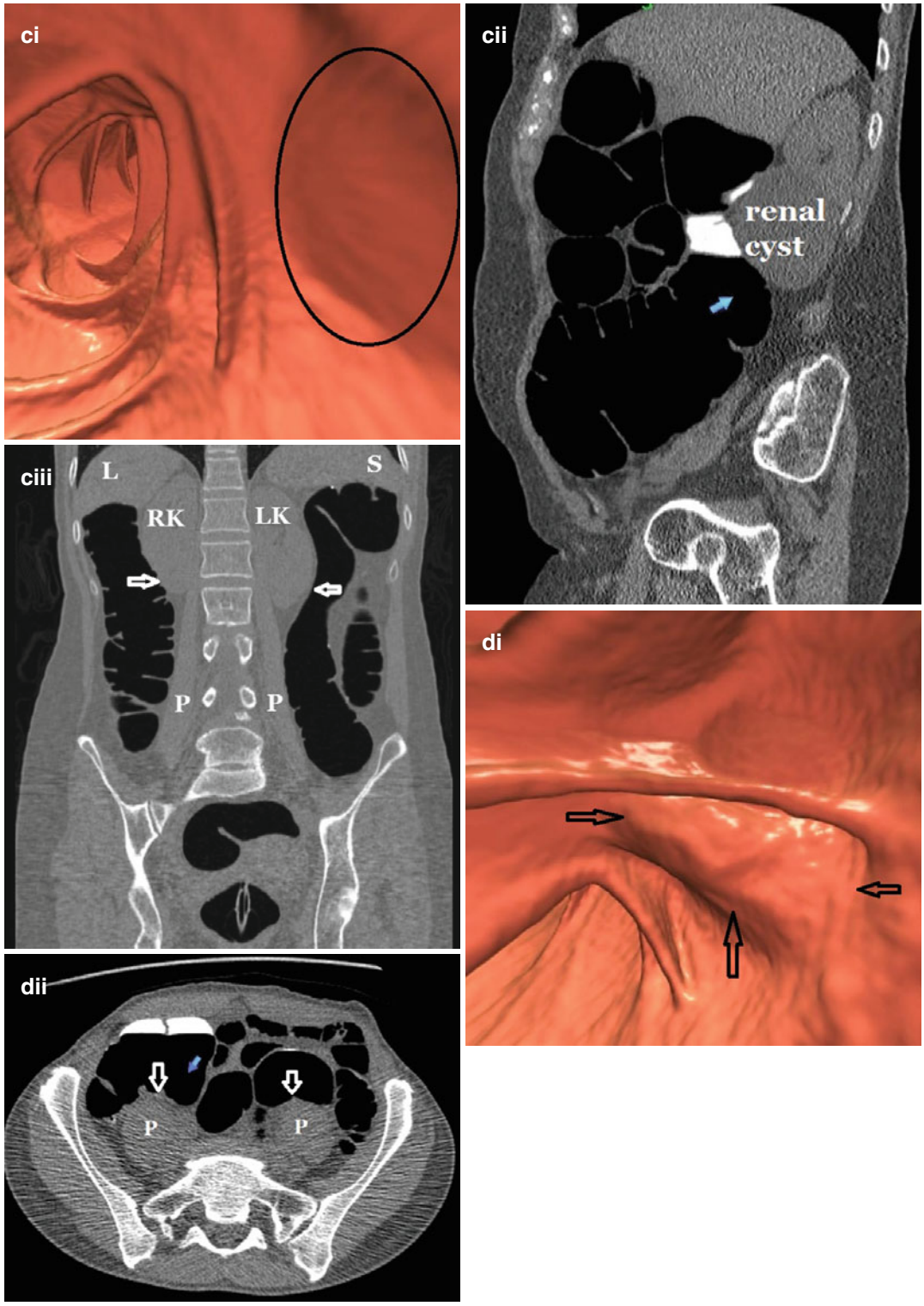

Fig. 11.14 (**c**) (**i**) 3D view showing extrinsic impression on the colon due to a renal cyst (*circle*). (**ii**) 2D sagittal view shows renal cyst in lower pole of the right kidney impinging on the caecum. (**iii**) 2D coronal view shows extrinsic impression of lower pole of the kidneys (*open white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

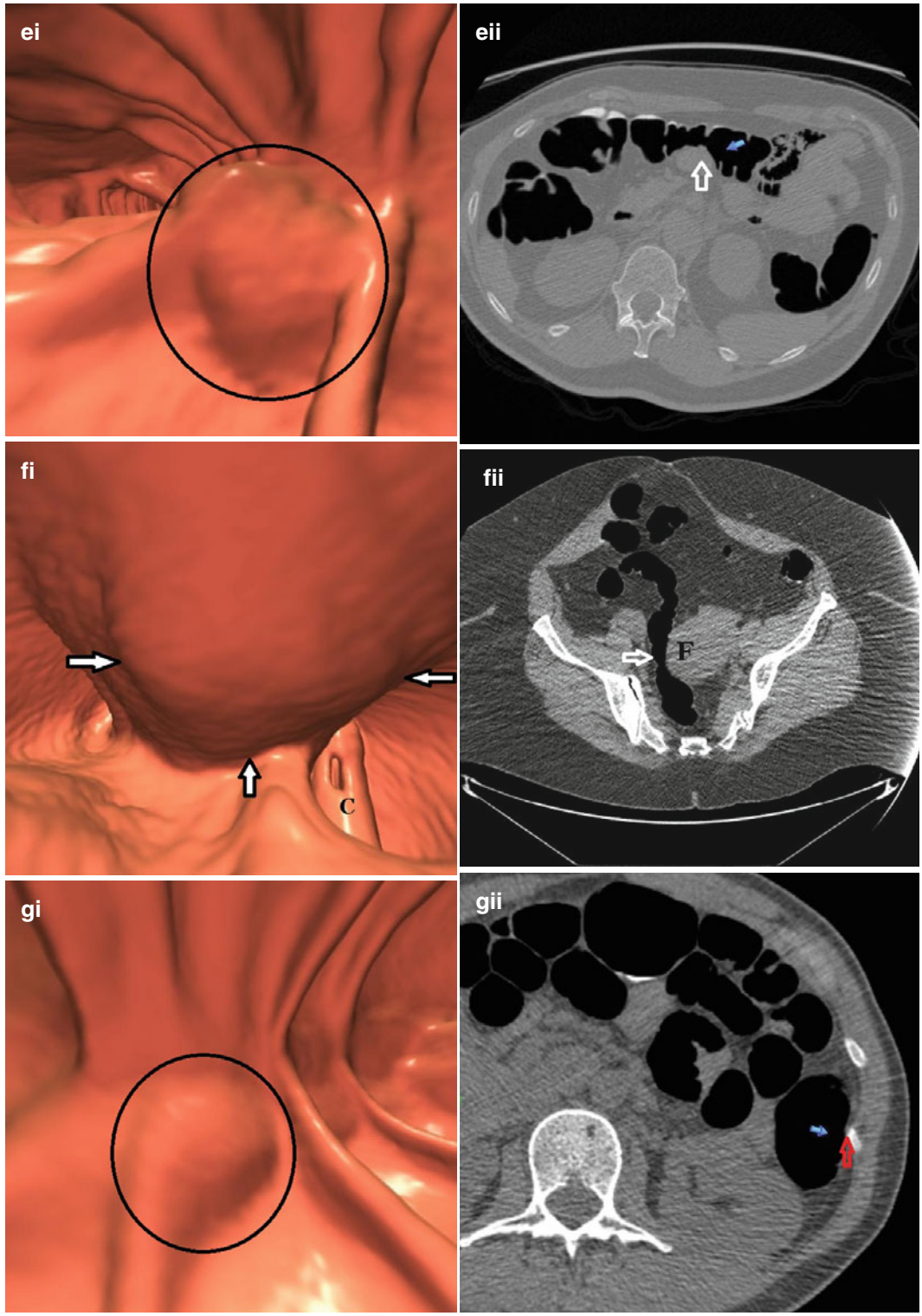

Fig. 11.14 (**e**) (**i**) 3D view showing extrinsic impression by the small bowel (*circle*). (**ii**) 2D axial view shows extrinsic impression of the small bowel (*open white arrow*) on the colon. (**f**) (**i**) 3D view shows extrinsic impression of uterine fibroid (*arrows*). Rectal catheter (*C*). (**ii**) 2D axial view of a pedunculated uterine fibroid (*F*) causing narrowing of the rectum (*open white arrow*). (**g**) (**i**) 3D view shows a rib causing extrinsic impression (*circle*). (**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 two-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 on CTC studies. Mobile segments may change position during a standard two-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. http://dx.doi.org/10.1002/cncr.2820360944
2. Pickhardt PJ. Screening CT colonography: how I do it. AJR. 2007;189(2):290–8. http://dx.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):342–45. http://dx.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). http://dx.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):168–76.
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):469–6. http://dx.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, p. 54–63.
9. Hamilton SR. Structure of the colon. Scand J Gastroentrol. 1984;93(Suppl):13–23.
10. Abramson DJ. The valves of Houston in adults. Am J Surg. 1978;136:334–6.
11. Ahmed I, Asgeirson K, Beckingham I, Lobo D. The position of the vermiform appendix at laparoscopy. Surg Radiol Anat. 2007;29:165–8. http://dx.doi.org/10.1007/s00276-007-0182-8
12. Varsamis N, Pouggouras K, Salveridis N, et al. Appendiceal intussusception. In Dr Godfrey Lulu (Ed) Current concepts in colonic disorders, 2012:47–64. [cited 22 June 2015]. Available from: 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. http://dx.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.

Pitfalls and Artefacts

12

Joel H. Bortz

Abstract

The use of CTC is intended for diagnosis of both polyps and malignancy in screening of asymptomatic individuals over the age of 50 years. There are however lesions and disease processes that may mimic both colonic polyps and cancer on CTC. The most basic of these pitfalls is the thickened or complex fold, which may be encountered on both 2D and 3D imaging. The most common pitfall is the presence of homogenous adherent stool. This may be mistaken for a polyp. Tagging is essential to distinguish stool and polyp on CTC images. Other potential pitfalls include, for example, anatomical locations and structures, position of the rectal catheter, external impressions on the colon lumen and a range of artefacts. These are described, with examples, in this chapter.

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 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 pitfalls and artefacts at CTC interpretation is underscored with examples.

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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) shows examples of complex folds. Submucosal lesions and stool-filled diverticula become more of an issue on 3D. However, the complementary nature of 2D and 3D evaluation usually resolves these issues. Potential pitfalls, including artefacts, are divided into twelve broad groups, namely

- Cathartic preparation and tagging solutions
- Sigmoid diverticular disease
- Polyp morphology
- Anatomical locations and structures

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- 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 broad headings of potential pitfalls and artefacts are discussed with examples.

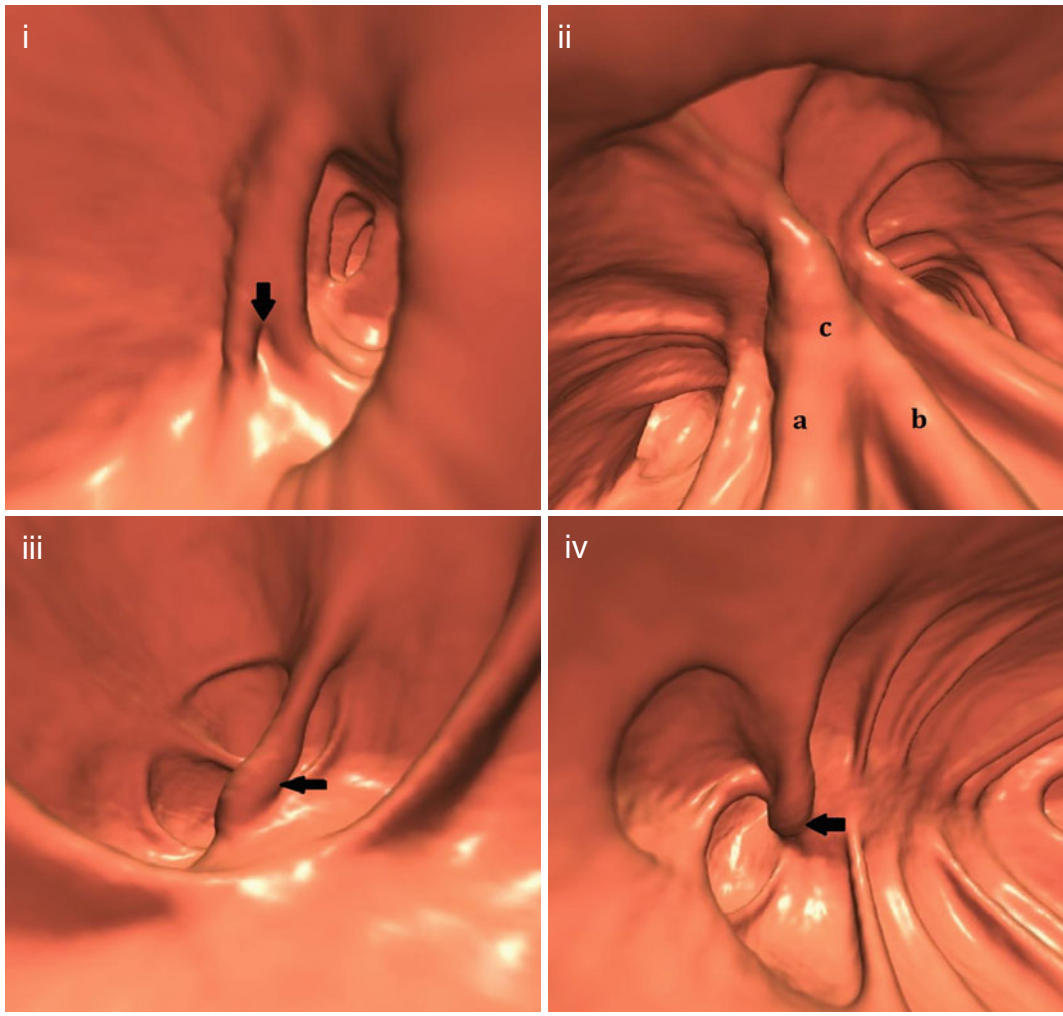

Fig. 12.1 (**i**) Bifid fold (*arrow*). (**ii**) Two folds (*a* and *b*) joining to form a single fold (*c*). (**iii**) Mild twisting of haustral fold (*arrows*). (**iv**) Shortened and thickened fold (*arrow*)

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 pitfalls that may be caused by poor bowel preparation in terms of

(i) Retained stool
(ii) Different appearances of stool and its characteristics
(iii) Movement of stool during postural change, e.g. 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 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.

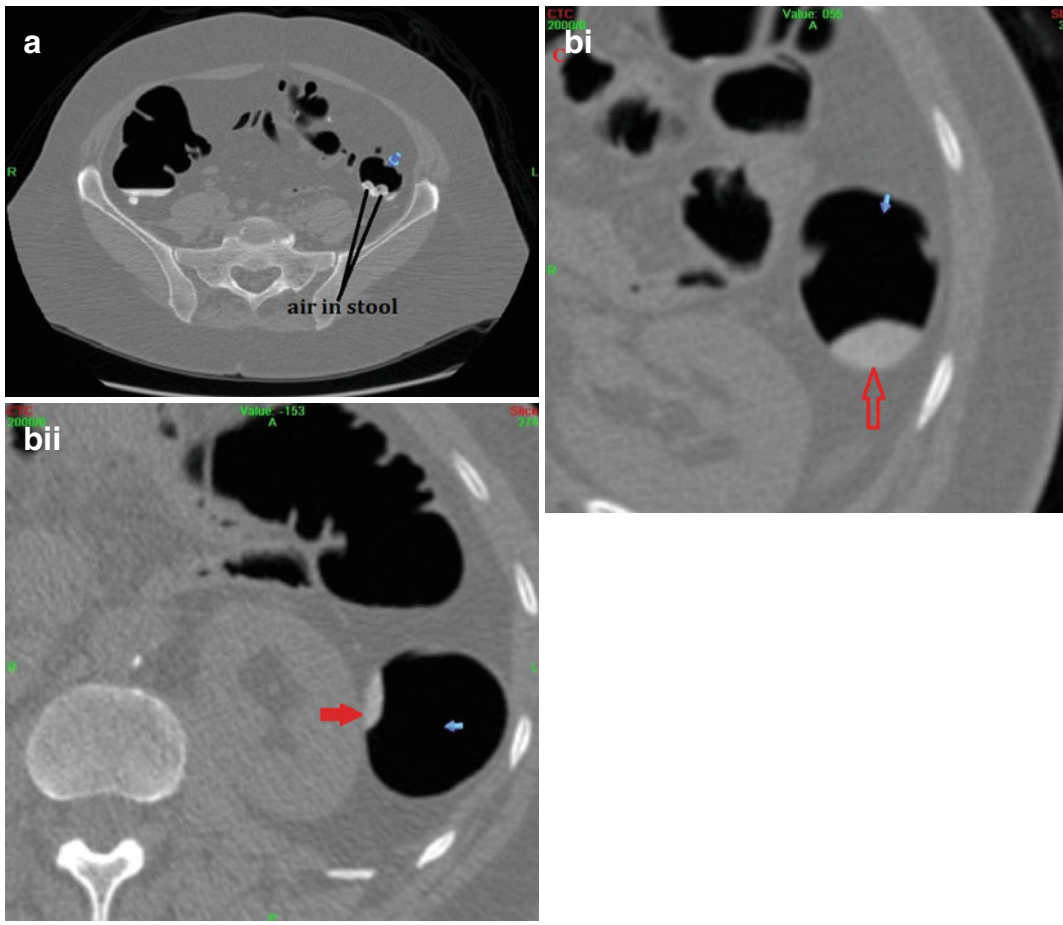

Fig. 12.2 (**a**) 2D axial view showing air in stool. (**b**) (**i**) 2D axial supine showing stool (*open red arrow*). (**ii**) 2D RLD view showing movement of stool (*red arrow*)

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 cleaning 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 remains. The shape may be squared, faceted or polypoidal 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) is a range of examples of stool being a potential pitfall.

Tagging is an integral part of the 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].

Gastrografin has a dual action. It stains 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]. Gastrografin provides 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.

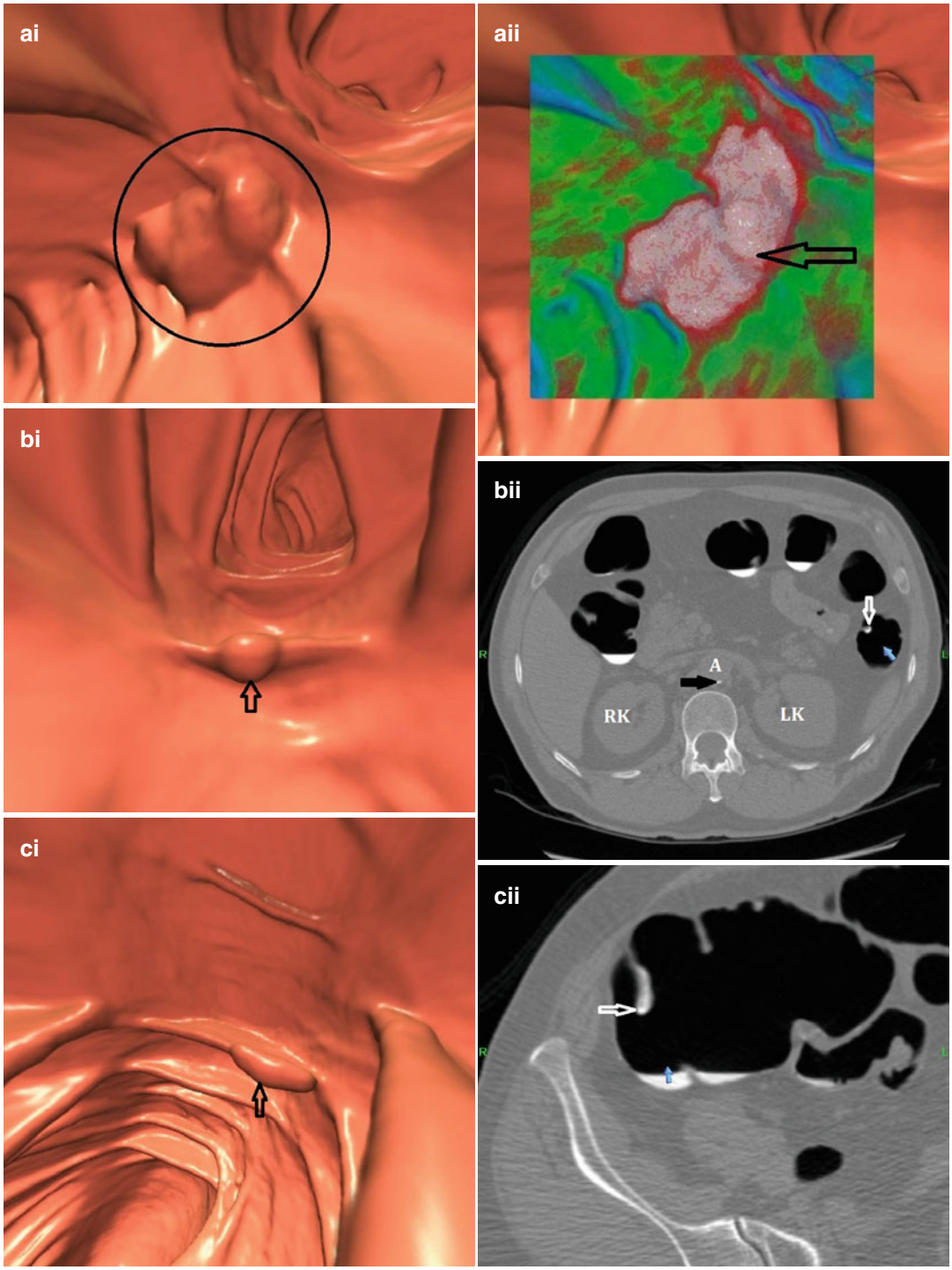

Fig. 12.3 (**a**) (**i**) 3D endoluminal view showing lobulated polypoidal lesion (*circle*). (**ii**) TD confirming stool (*open black arrow*) and not a polyp. (**b**) (**i**) 3D view showing polypoidal lesion on haustral fold (*open black arrow*). (**ii**) 2D axial showing stool (*open white arrow*).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

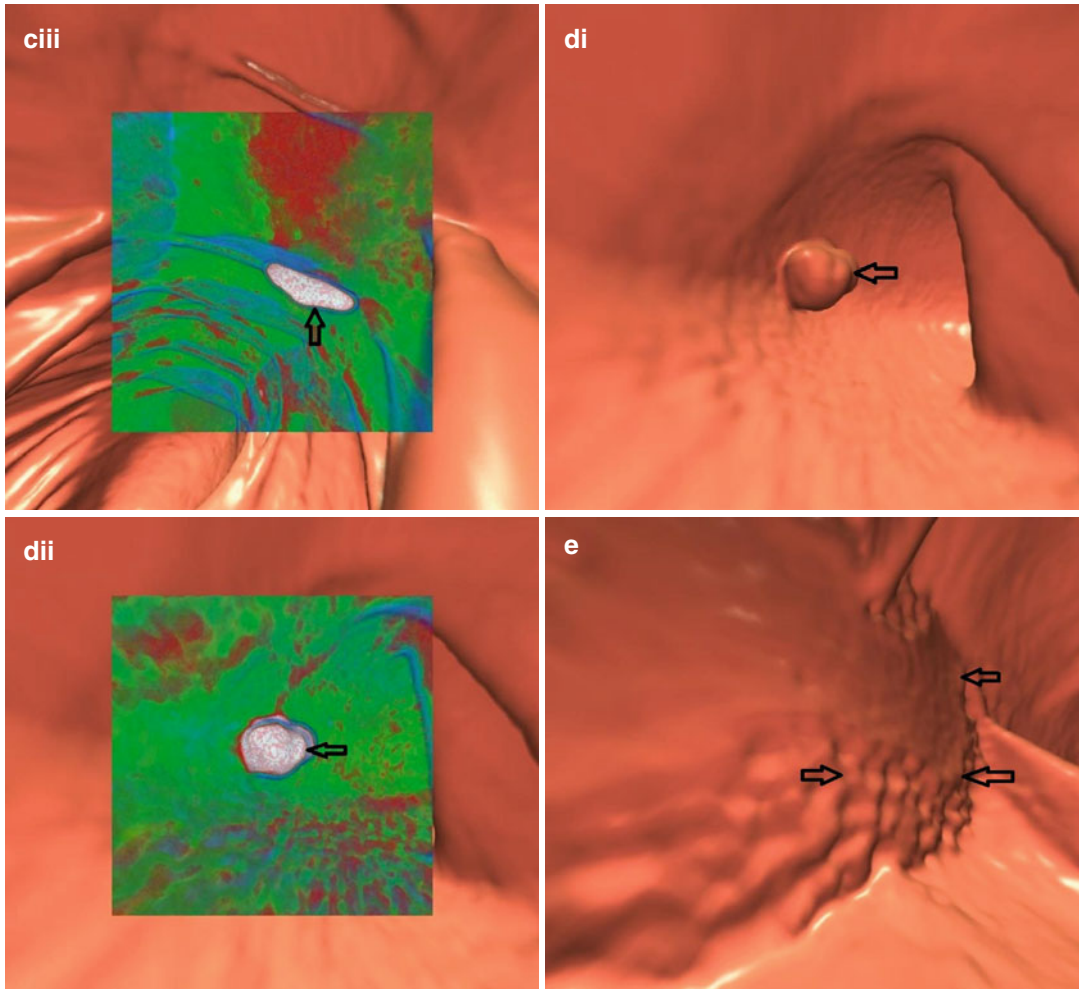

Fig. 12.3 (**iii**) TD confirming barium (*black arrow*) and not a polyp. (**d**) (**i**) 3D endoluminal view showing a sessile lobulated polypoidal lesion (*arrow*). (**ii**) TD showing stool (*arrow*) and not polyp. (**e**) Adherent non-opacified stool having indentations similar to the appearance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

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**.**

Same-day CTC examinations, after an incomplete or failed optical colonoscopy (OC), tend to be suboptimal as tagging has not been performed (see Chap. 10) [4]. Untagged stool is a thus 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.

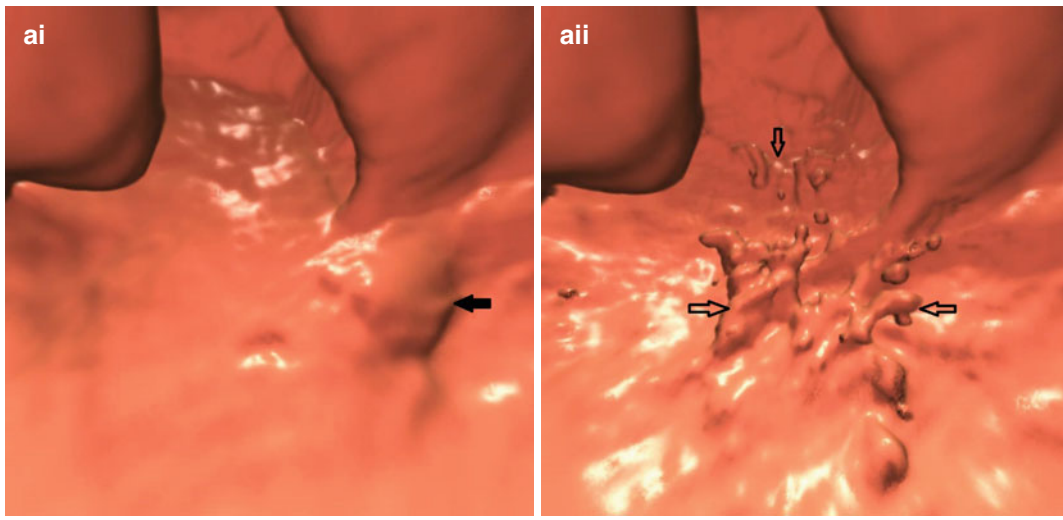

Fig. 12.4 (**a**) (**i**) 3D view showing stool (*arrow*) that may be obscuring lesions (Courtesy of Viatronix, Stony Brook, NY). (**ii**) 3D view showing artefacts (*arrows*) caused by electronic cleansing (Courtesy of Viatronix, Stony Brook, NY)

12.2.3 Sigmoid Diverticular Disease

This disease is covered in more detail in Chap. 16. For the purpose of discussion, the following potential pitfalls 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.

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

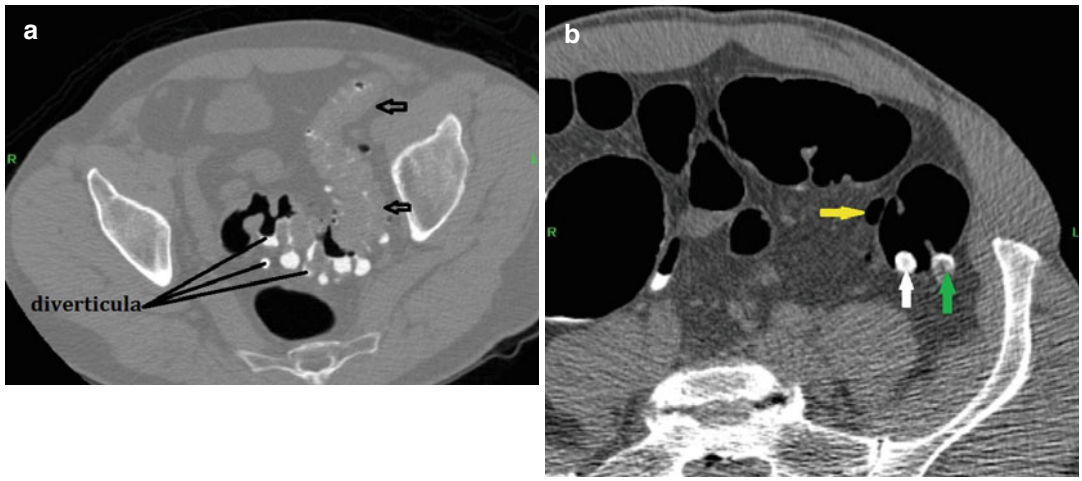

Fig. 12.5 (**a**) Axial 2D showing very poor distension of the colon (*open black arrows*) and multiple diverticula. (**b**) 2D axial view shows stool (*white arrow*) and impacted diverticulum (*green arrow*). *Yellow arrow* shows diverticulum filled with air

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 pitfall; thus, we need to ensure measurements are accurate as discussed in Chap. 14. Shifting pedunculated polyps can be potential pitfalls. It is important to use a 2-view scan for 3D and 2D evaluation as evident in Fig. 12.6(i) and (ii).

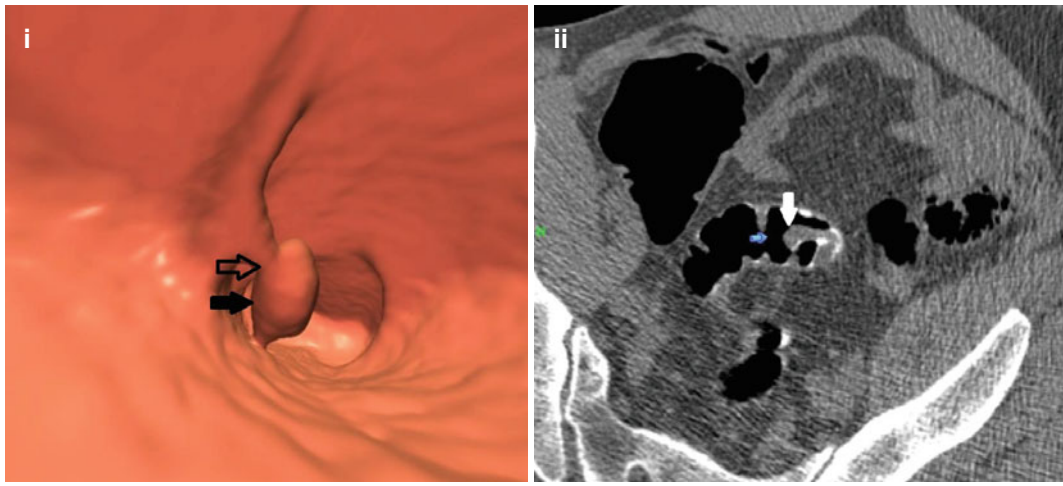

Fig. 12.6 (**i**) 3D endoluminal view showing pedunculated polyp (*black arrow*) on a short stalk (*open black arrow*). (**ii**) Axial 2D view shows pedunculated polyp (*white arrow*)

12.2.5 Anatomical Locations and Structures

Both the location and structure of the appendix and the ileocaecal valve (ICV) are potential pitfalls when evaluating CTC images. The vermiform appendix is part of the caecum. Its length varies from 2.5 centimetres (cm) to 33 cm [8]. Its average length is between 5 cm to 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, b shows examples of varying abdominal positions of an appendix. Several examples of different anatomical locations of both the appendix and ICV are presented in Chap. 11.

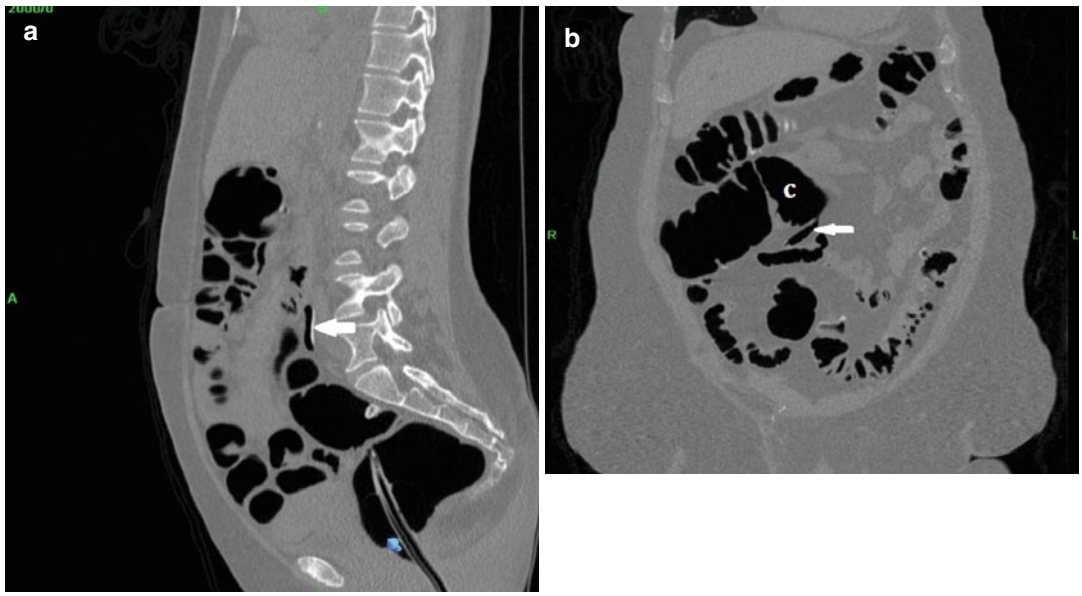

Fig. 12.7 (**a**) Sagittal 2D view showing prevertebral appendix (*white arrow*). (**b**). Coronal 2D showing a malrotated caecum (**c**) with appendix (*white arrow*)

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) demonstrates an extrinsic impression on the colon lumen caused by spondylolisthesis. A range of extrinsic impressions on the colon are presented in Chap. 11.

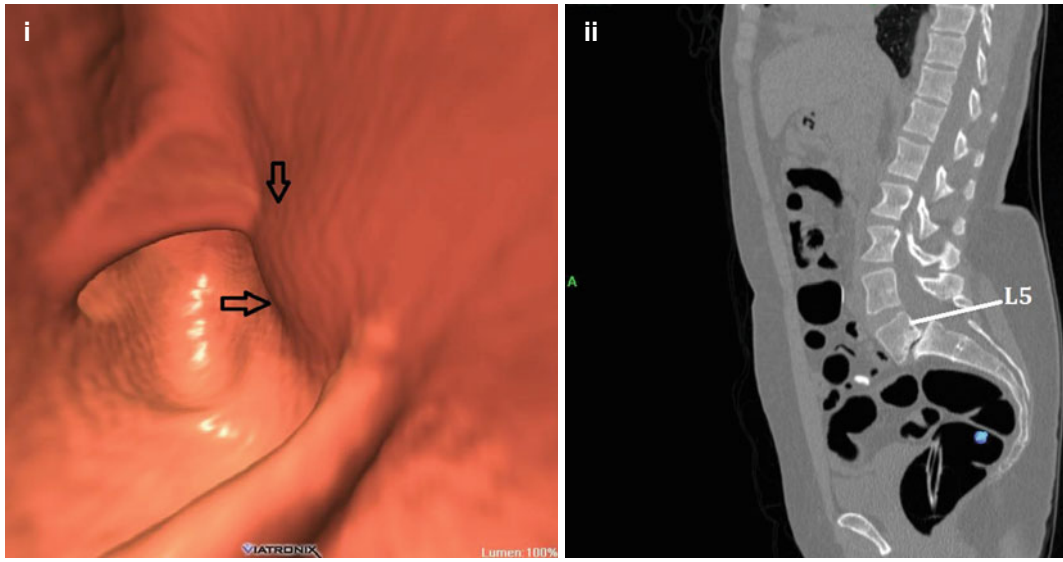

Fig. 12.8 (**i**) 3D view of the sigmoid colon showing extrinsic soft tissue bulge (*arrows*) due to spinal spondylolisthesis. (**ii**) Sagittal 2D grade 2 spondylolisthesis of L5 on S1. This is associated with disc degenerative disease between L5 and S1

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 that 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 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 360^0 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.

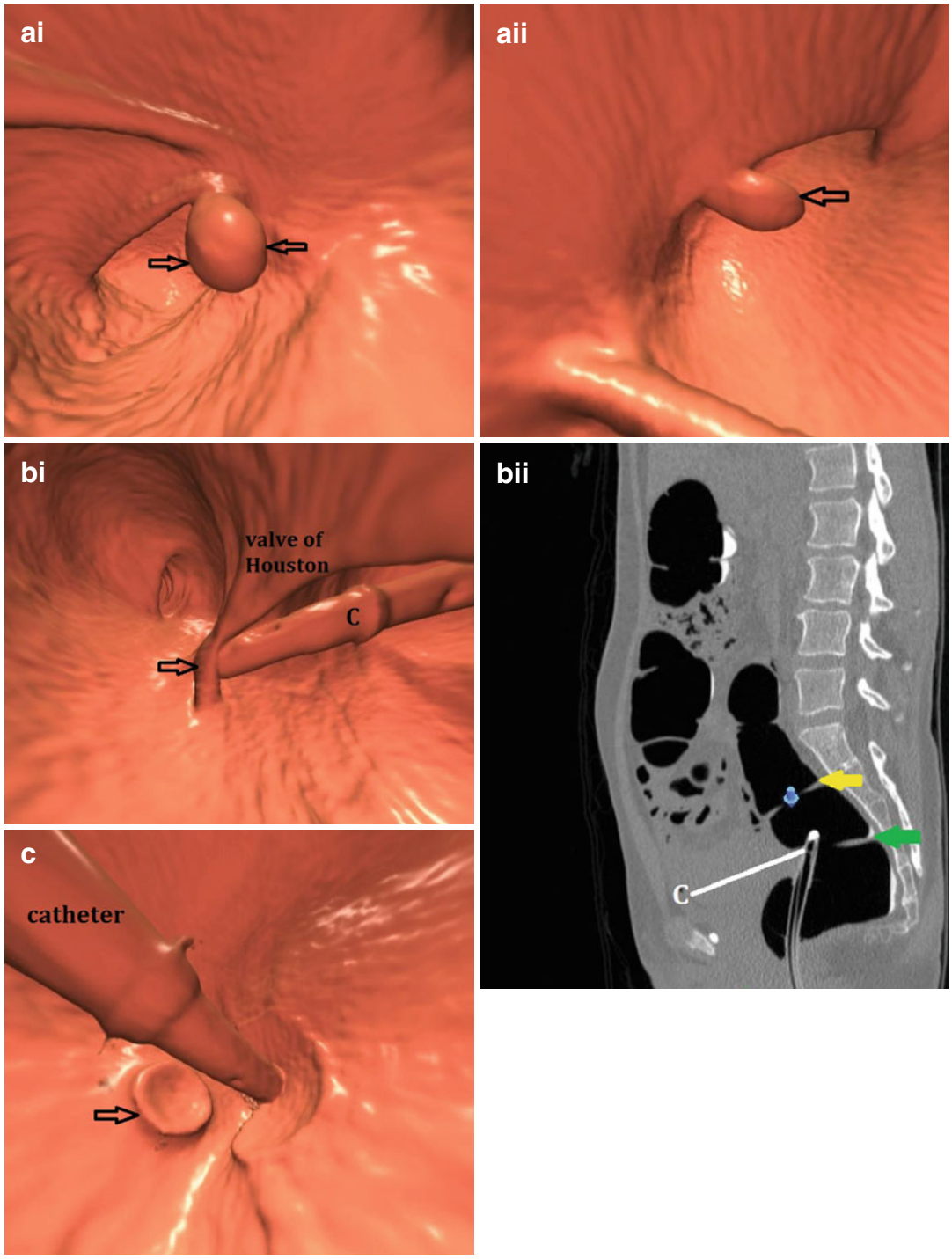

Fig. 12.9 (**a**) (**i**) 3D view showing catheter tip simulating a polyp (*arrows*). (**ii**) 3D view showing catheter tip simulating a polyp (*arrow*). (**b**) (**i**) 3D view showing catheter tip distorting fold (*open black arrow*). Rectal catheter = C. (**ii**) Sagittal 2D view showing tip of catheter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

12.2.8 Movement Artefacts

As discussed in Chaps. 9 and 10, it is essential that patients cooperate during CTC examinations. 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 on 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.

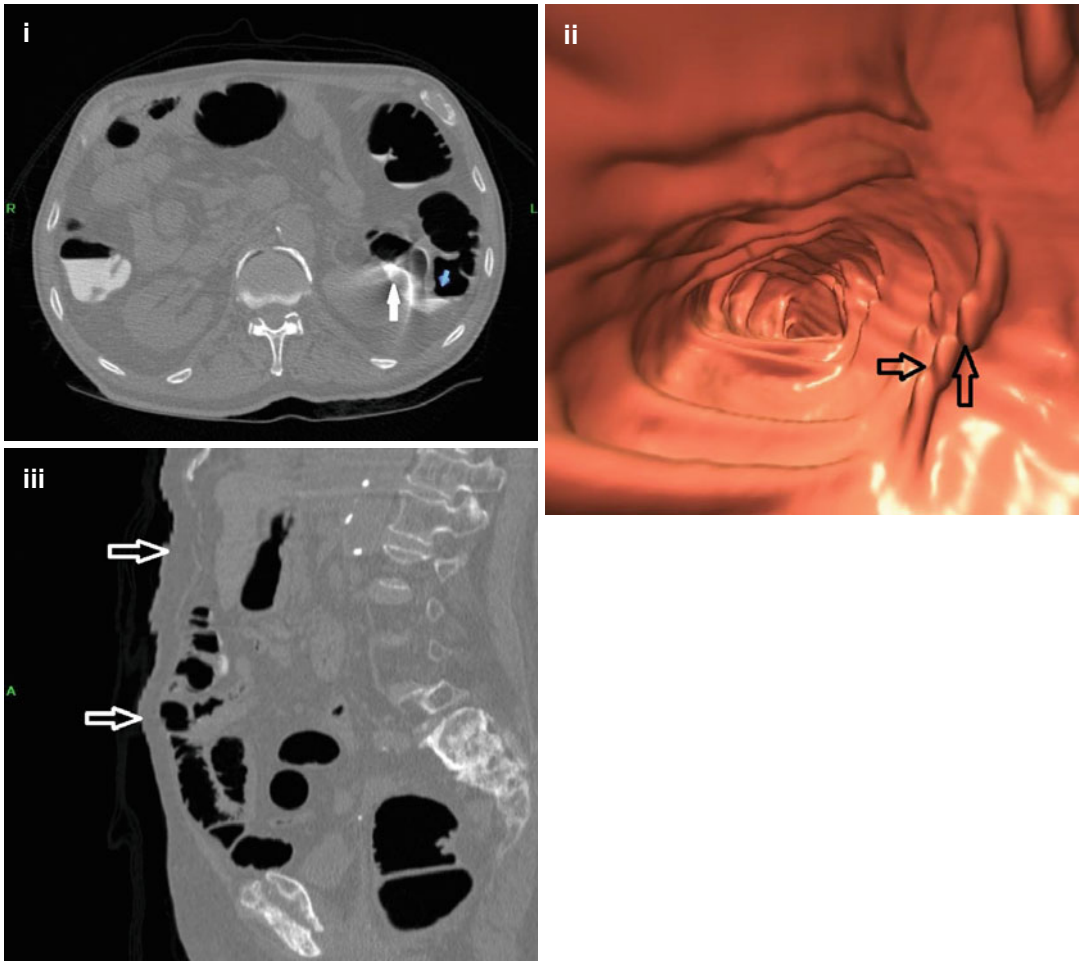

Fig. 12.10 (**i**) 2D axial view showing focal motion artefact in the descending colon (*white arrow*). Rest of the colon is normal. (**ii**) Example of a breathing stepped artefact (*open black arrows*). (**iii**) Sagittal 2D showing breathing artefact on skin surface (*open white arrows*)

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. Figure 12.11a (i)–e shows examples of beam-hardening artefacts.

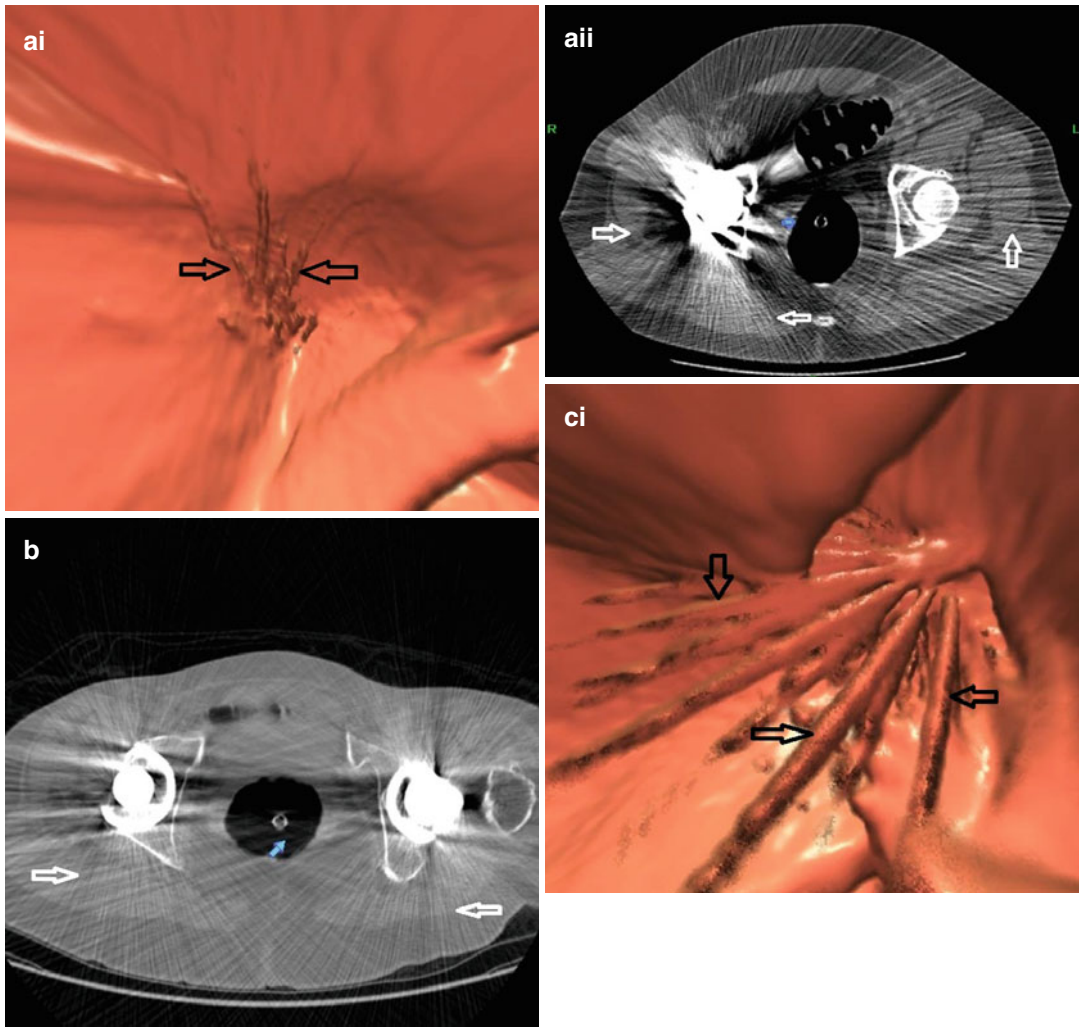

Fig. 12.11 (**a**) (**i**) Beam-hardening artefact (*open black arrows*) due to right hip prosthesis. (**ii**) Axial 2D showing streak artefact (*open white arrows*) due to right hip prosthesis. (**b**) Axial 2D showing streak artefact (*open white arrows*) due to bilateral hip prostheses. (**c**) (**i**) Streaks due to beam-hardening artefact (*open black arrows*)

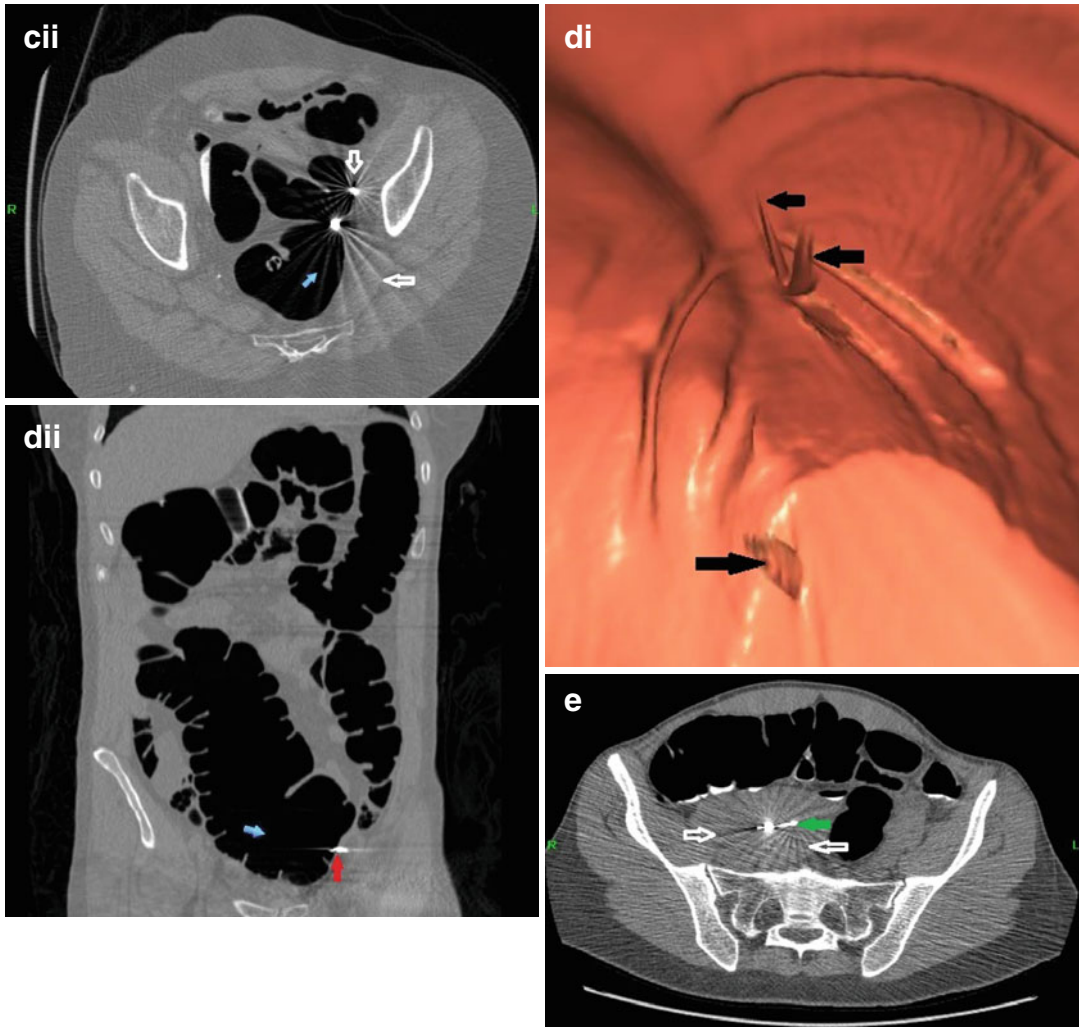

Fig. 12.11 (**ii**) 2D view streaks from surgical clip (*open white arrows*). (**d**) (**i**) Streaks due to beam-hardening artefact from surgical clips (*arrows*). (**ii**) 2D coronal view shows surgical clip (*red arrow*) in appendiceal region. (**e**) 2D axial view showing streak artefact (*open white arrows*) from an intrauterine device (*green arrow*)

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 as discussed in Chap. 9. An ingested vitamin tablet may resemble a polyp (Fig. 12.12a). 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 3D display. Figure 12.12b (i–iii) shows 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.

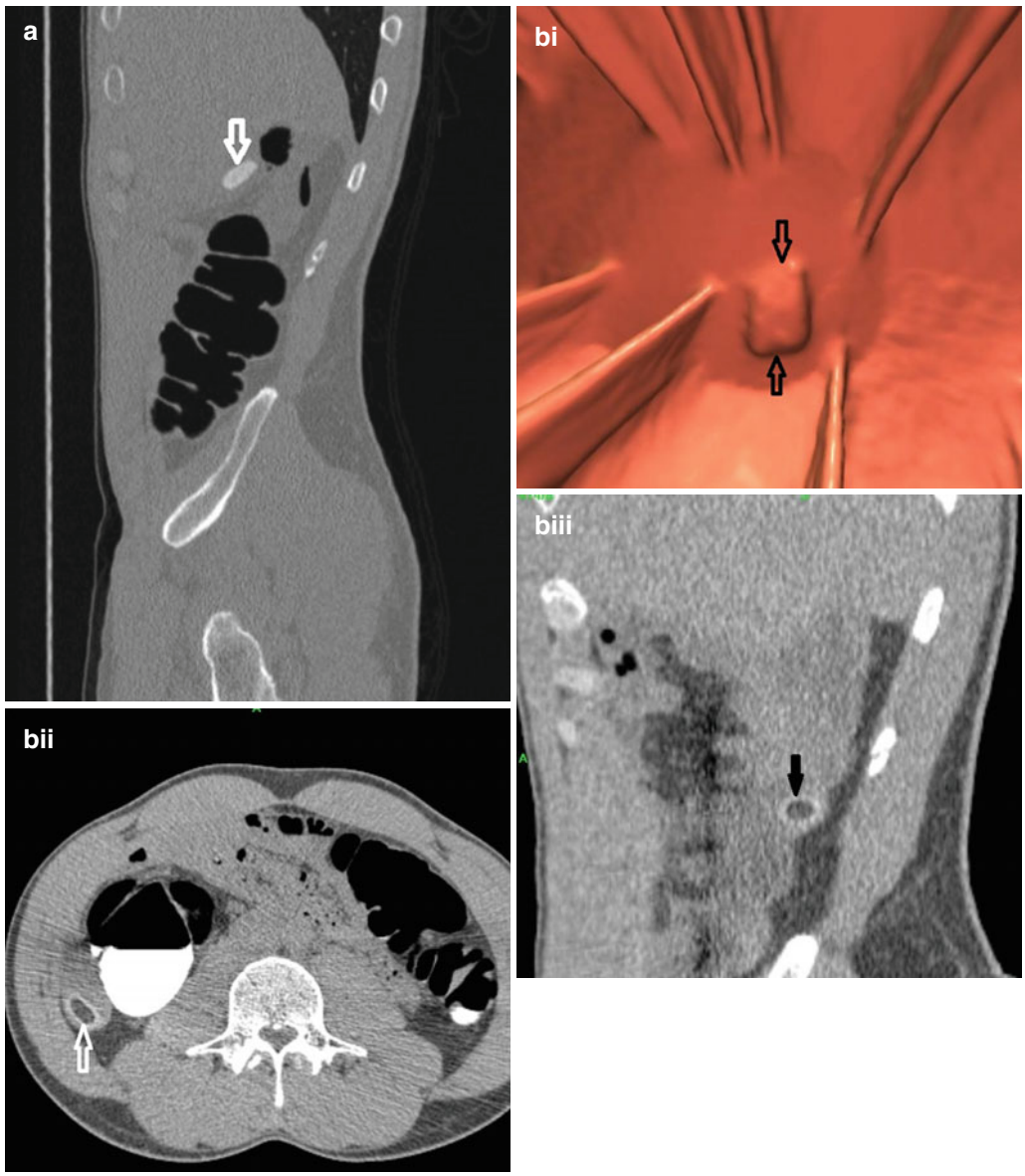

Fig. 12.12 (**a**) 2D sagittal view shows multivitamin capsule (*open white arrow*). (**b**) (**i**) 3D view shows density due to fish oil capsule (*open black arrows*). (**ii**) 2D axial view shows oil capsule (*open white arrow*). (**iii**) 2D sagittal view shows oil 'fat' centrally (*black arrow*)

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. 12.13(i) and (ii). Occasionally the tagging agent (barium) may be incorporated into the strand and will show as a high density of TD.

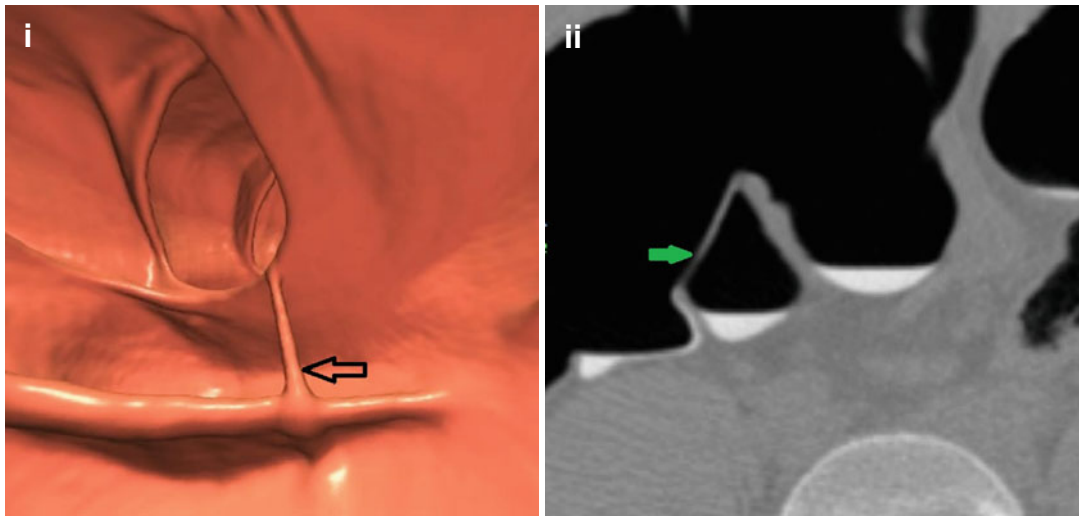

Fig. 12.13 (**i**) Open black arrow points to mucus strand between two haustral folds. (**ii**) 2D axial view shows mucus strand between folds (*green arrow*)

12.2.12 Tampon and Vaginal Pessary

Figure 12.14a (i) and (ii) is an example of a tampon visualised on 2D. Figure 12.14b shows a vaginal pessary. A vaginal pessary is a removable device that is used to support pelvic organ prolapse, such as bladder, uterus and/or rectum.

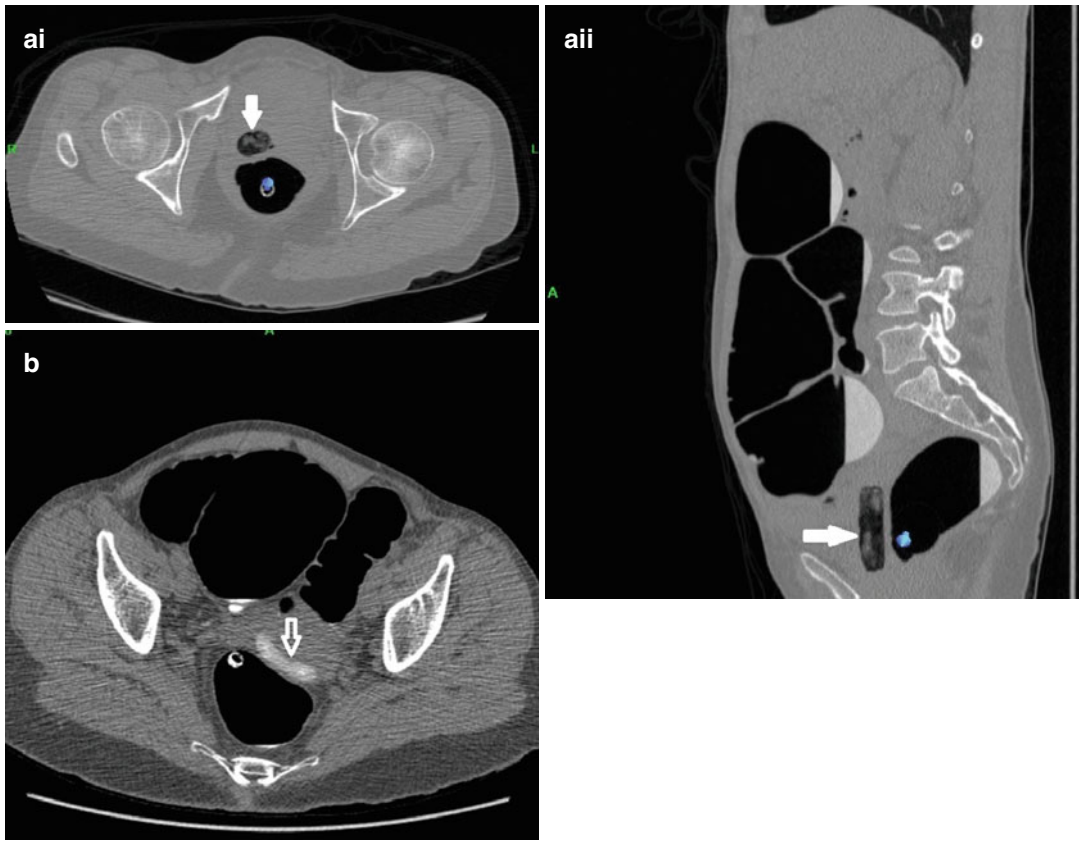

Fig. 12.14 (**a**) (**i**) Axial 2D showing vaginal tampon (*white arrow*). (**ii**) Sagittal 2D showing vaginal tampon (*One white arrow*). (**b**) Axial 2D showing curvilinear density (*white arrow*) in keeping with vaginal pessary supporting the uterus

12.3 Key Messages

- Poor bowel preparation could be a potential pitfall as adherent stool may obscure polyps.
- Poor bowel distension could result in nonvisualisation 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.
- 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.

12.4 Summary

There are many potential pitfalls 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 cooperation. 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); http://dx.doi/org/10.4102/sajr.v18i1.607[www.sajr.org.za]
5. Pickhardt PJ. Screening CT colonography: How I do it. AJR. 2007;189(2):290–8. http://dx.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. http://dx.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. http://dx.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.

Internal Haemorrhoids and Other Anorectal Lesions

13

Joel H. Bortz

Abstract

To best visualise internal haemorrhoids, the balloon must be deflated when the patient is in the prone position. The rationale being that an inflated rectal catheter balloon could compress internal haemorrhoids that might be present. 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. They lie in close proximity to the rectal catheter. Both anal papilla and rectal tumours need to also be considered when evaluating structures in the anorectal region in close proximity to the rectal catheter. If the catheter is incorrectly positioned, it may cause confusion in image interpretation. Images are presented to illustrate these points when interpreting CTC studies.

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 anoscopy 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.

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As discussed in Chap. 10, when the patient is in the prone position, the catheter's balloon is deflated in order to visualise internal haemorrhoids, if present [2]. The correct placement of the catheter is important in CTC. Since this chapter focuses on internal haemorrhoids, it is important to describe their causes and anatomical location [3]. In addition, we need to consider anal papillae and tumours [4]. Catheter-related pitfalls are presented below.

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

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cause an extrinsic impression on an adjacent rectal fold, for example, or the tip itself may appear polypoidal at 3D. 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, but the author prefers the VIMAP product; these catheters can withstand 100 cc air inflation without fear of the balloon bursting. A further advantage of the catheter is that it 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 as shown in Chap. 10 (see Fig. 10.2c).

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 patient is in the prone the position usually eliminates such interpretation problems. Figure 13.1a (iii) shows the 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.

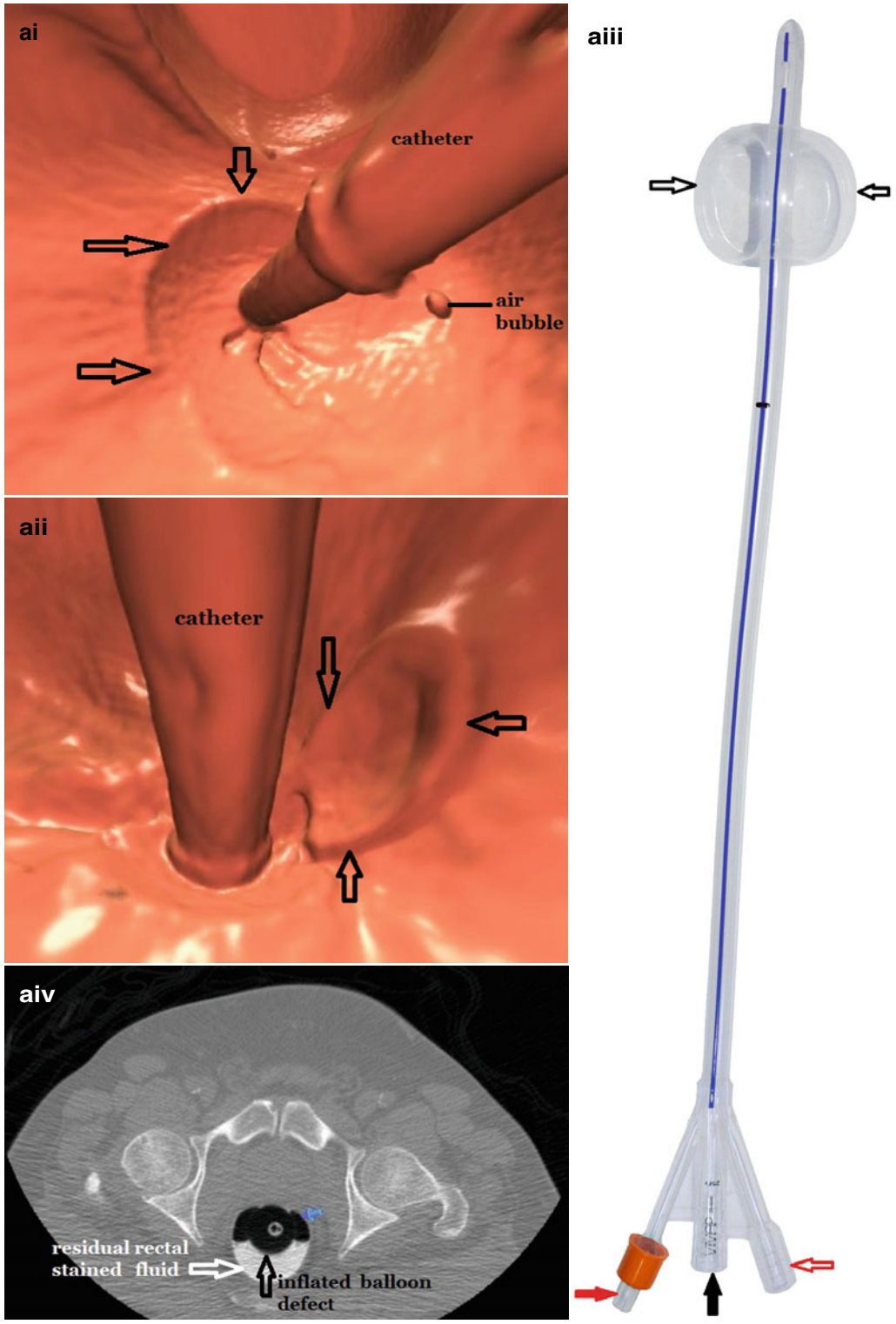

Fig. 13.1 (**a**) **(i)** 3D supine view shows meniscal defect (*open black arrows*) due to inflated balloon. **(ii)** 3D supine image shows inflated balloon to the side of the catheter causing a meniscal defect (*open black arrows*). **(iii)** Vimap 3-way connection catheter. Connection to inflate balloon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

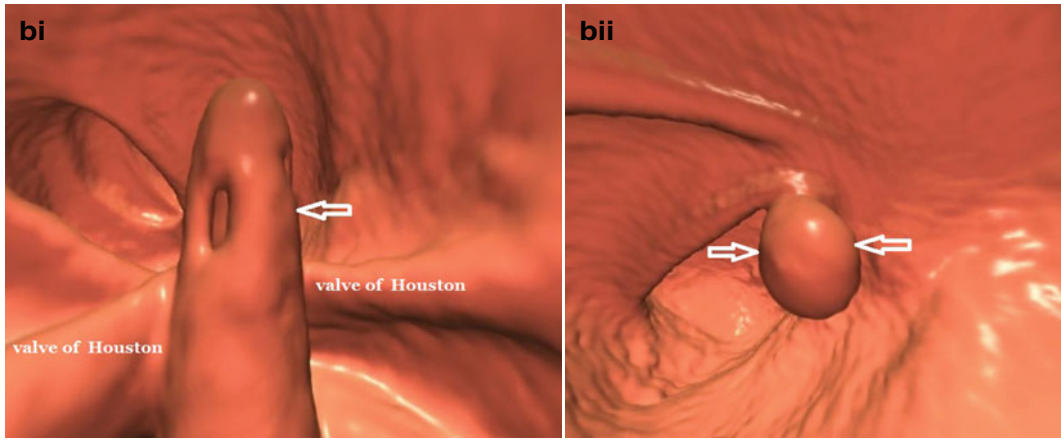

Fig. 13.1 (**b**) **(i)** 3D image shows the catheter incorrectly placed. Its tip (*open white arrow*) extends beyond the valve of Houston. **(ii)** 3D image shows tip of catheter projecting beyond the valve of Houston simulating a polyp (*open white arrows*)

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. The anatomical location of both internal and external haemorrhoids is described below.

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) and (ii) demonstrates the anatomy of rectum as well as location of internal and external haemorrhoids. Haemorrhoids are vascular structures 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'.

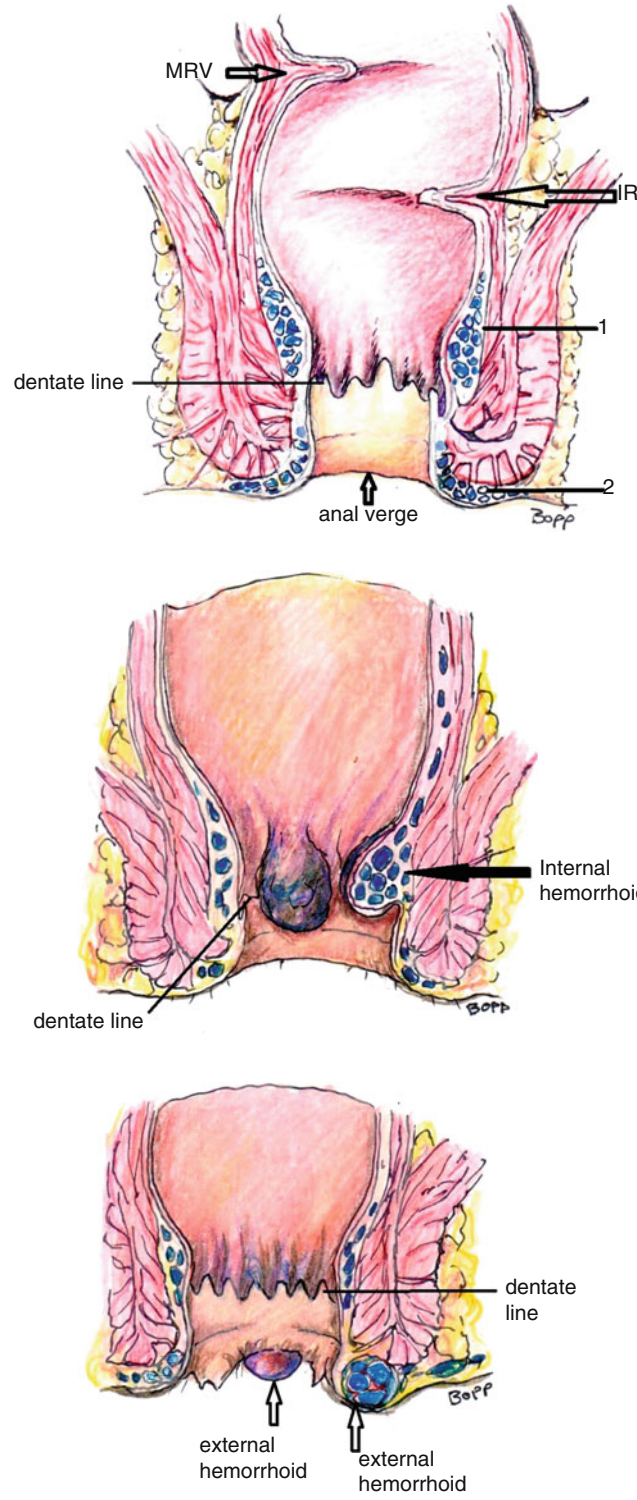

Fig. 13.2 **(i)** Anatomy of rectum. Middle rectal fold of valve of Houston (MRV). Internal rectal fold of valve of Houston (IRV). 1 = submucosal space and internal haemorrhoidal plexus. 2 = external haemorrhoidal plexus in perianal space (Adapted from [5]). **(ii)** Internal haemorrhoid above the dentate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

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 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.

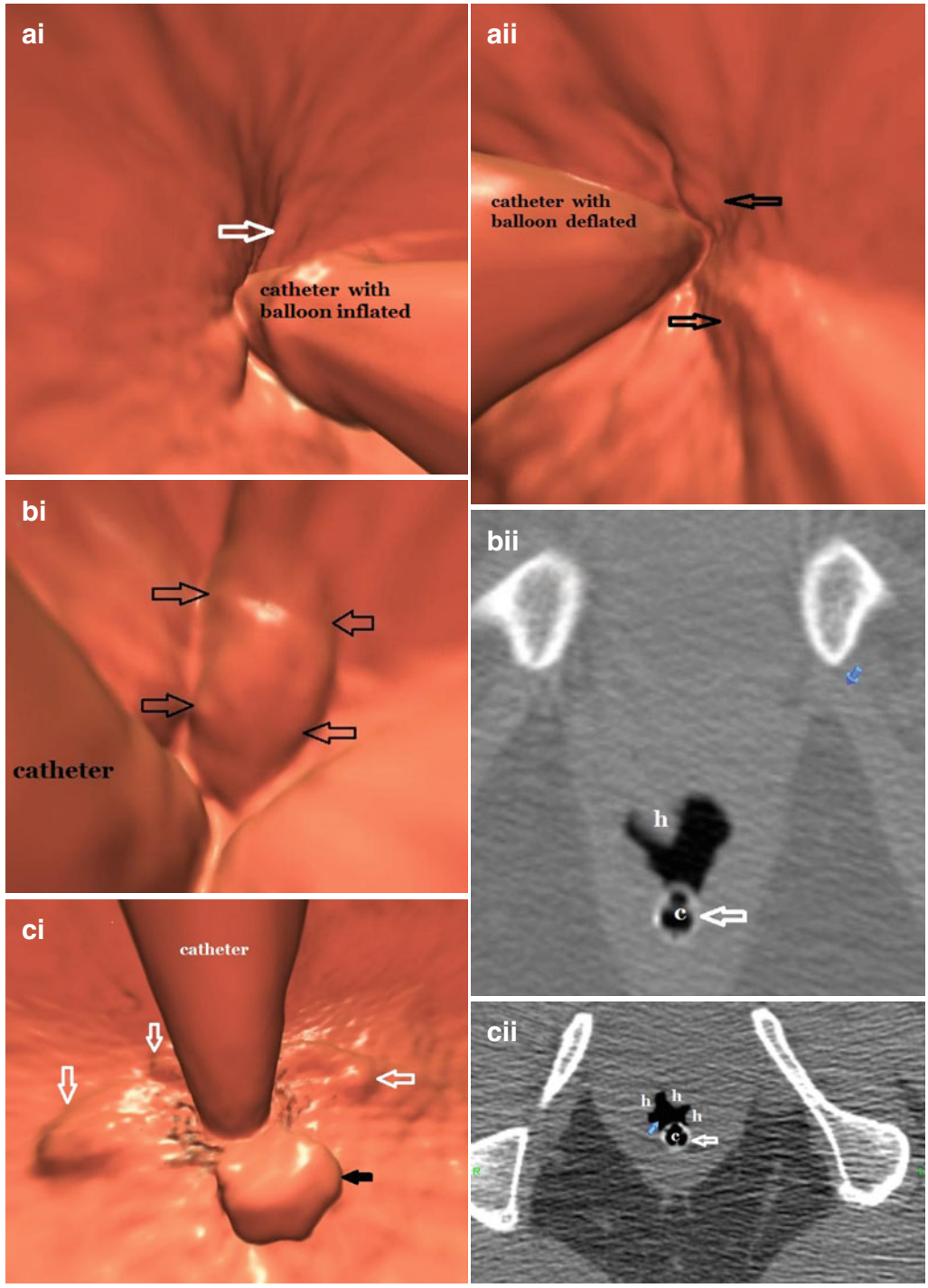

Fig. 13.3 (**a**) **(i)** 3D view of inflated balloon. Internal haemorrhoid (*open white arrow*). **(ii)** 3D prone view with deflated balloon shows internal haemorrhoids more prominently (*open black arrows*). (**b**) **(i)** 3D image shows polypoidal internal haemorrhoid (*open black arrows*). **(ii)**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

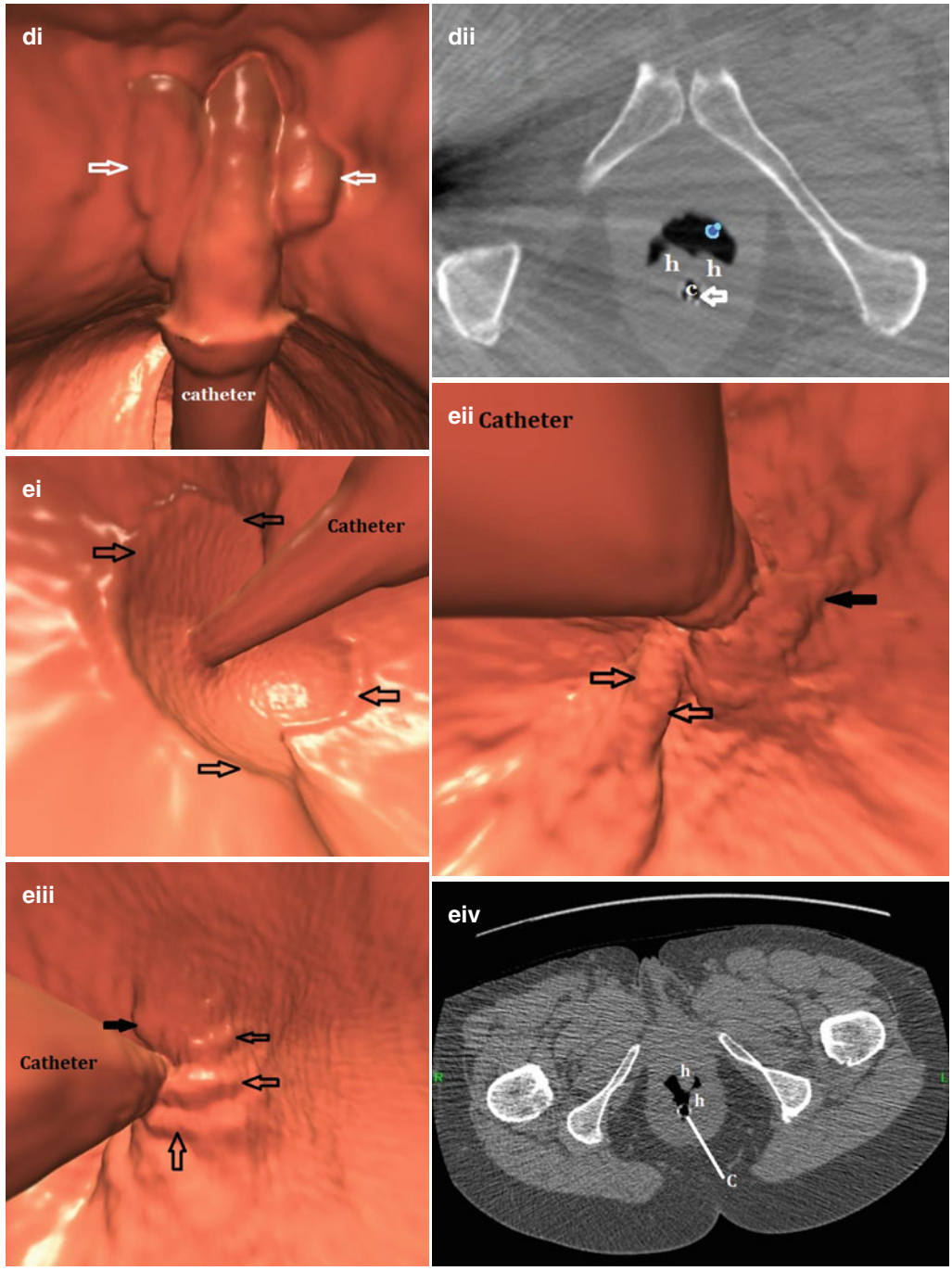

Fig. 13.3 (**d**) **(i)** 3D supine image of large polypoidal internal haemorrhoids (*open white arrows*). **(ii)** 2D axial image showing internal haemorrhoids (*h*). *C* rectal catheter (*open white arrow*).(**e**) **(i)** 3D endoluminal supine view showing artefact (*arrows*) caused by inflated balloon 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

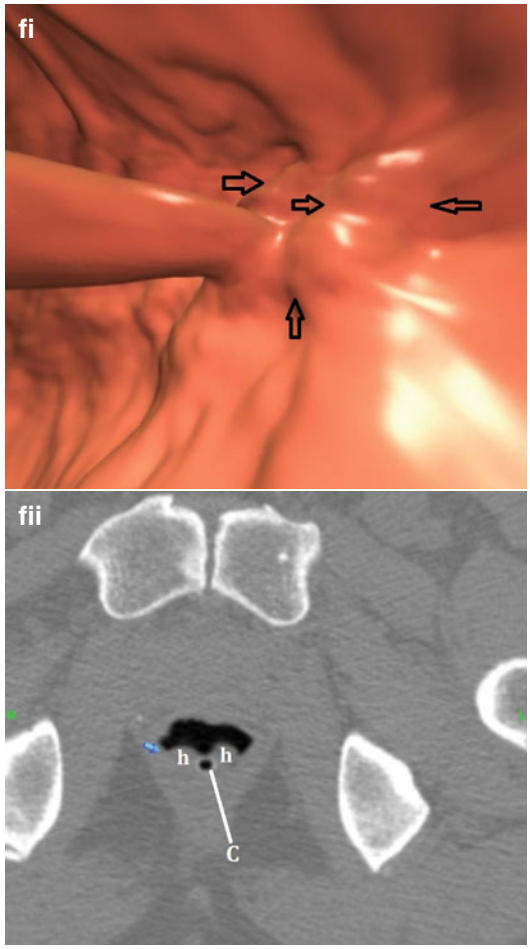

Fig. 13.3 (**f**) **(i)** 3D endoluminal view showing large internal haemorrhoids (*arrows*). **(ii)** 2D axial view showing internal haemorrhoids (*h*). *C* rectal catheter

Other Anorectal Pathology

13.4.2 Anal Papilla

Internal haemorrhoids may be confused with a 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).

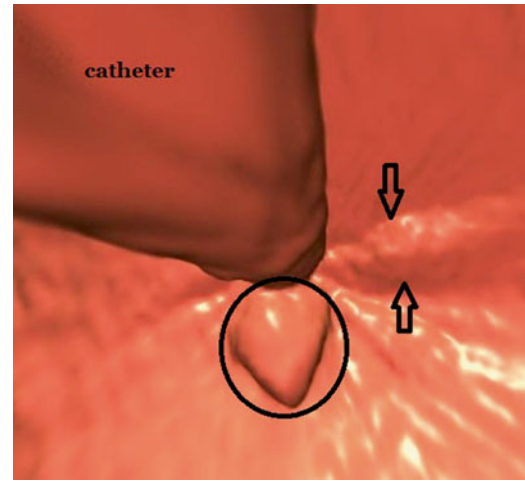

Fig. 13.4 3D image showing linear internal haemorrhoids (*open black arrows*) and anal papilla (circle)

13.4.3 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].

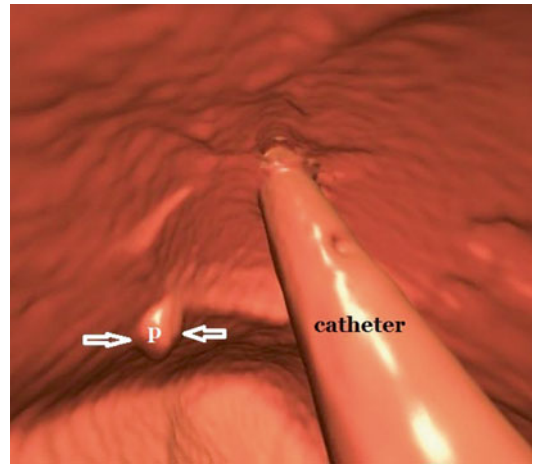

Fig. 13.5 3D image shows polyp (*p and open white arrows*) away from the catheter

13.4.4 Rectal Tumors

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 13.6a (i)–(iii) shows rectal 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].

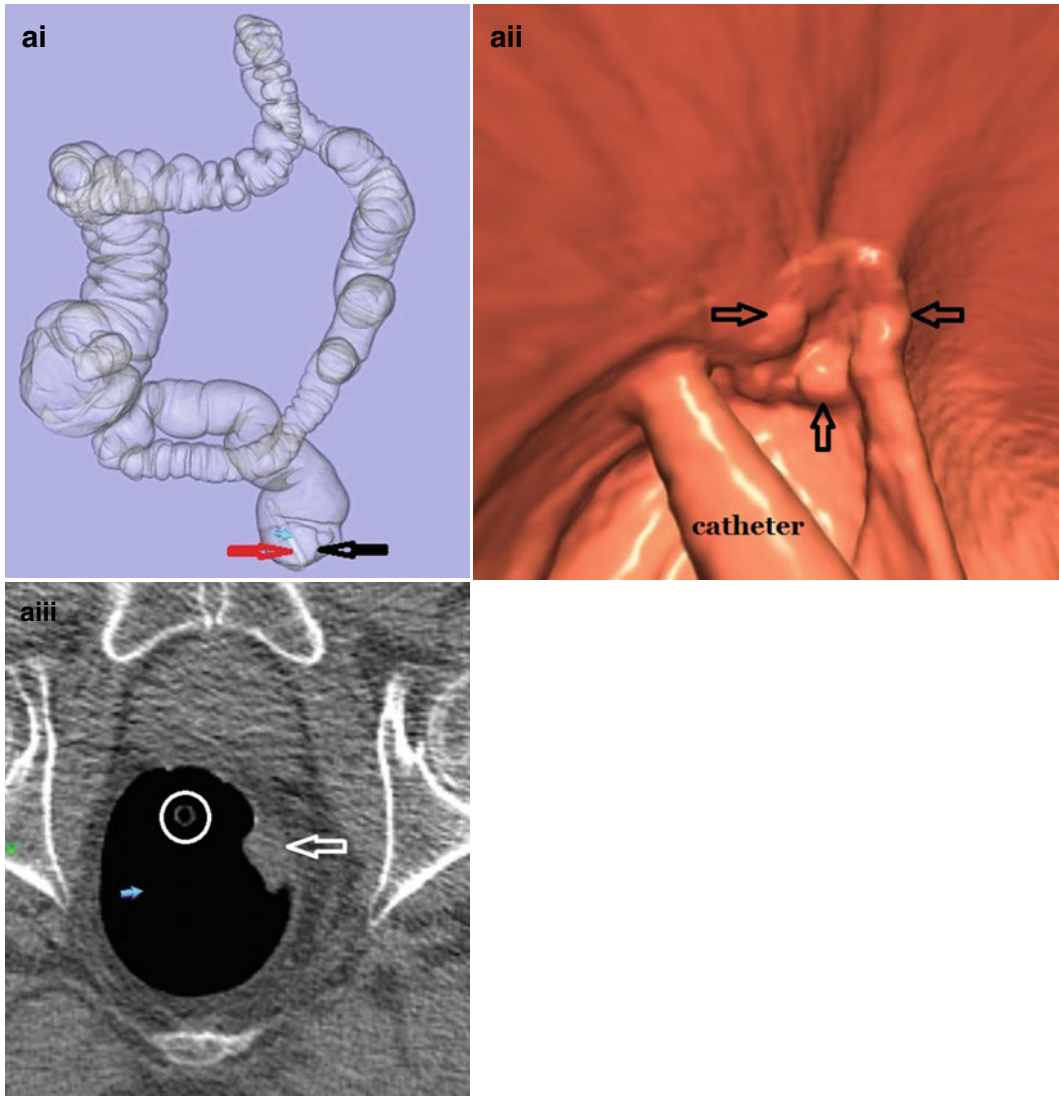

Fig. 13.6 (**a**) **(i)** Prone colon-map showing left rectal wall lesion (*open black arrow*). Rectal catheter (*open red arrow*). **(ii)** 3D view of an irregular polypoidal lesion in rectum in keeping with cancer (*open black arrows*). **(iii)** 2D axial image shows catheter (*white circle*) and lesion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

13.5 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.

13.6 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.

Acknowledgements Clinton Bopp is thanked for drawing the diagrams illustrating internal and external haemorrhoids

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); http://dx.doi/org/10.4102/sajr. v18i1.607 [www.sajr.org.za]
3. Yee J. Virtual colonoscopy. Philadelphia: Lippincott/Williams & Wilkins; 2008. p. 123–4.
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, Digestive system. Part 2. Lower digestive tract, vol. 3. New York: Colour Press; 1962. p. 58.

Polyps

14

Joel H. Bortz

Abstract

Being able to readily identify the different types of polyps on a CTC study is important in terms of patient management. Sessile, pedunculated, flat and carpet lesions are described with examples of 2D and 3D CTC images. Although a reader can describe the size and shape of polyps on a CTC study, their histological type has to be confirmed by biopsy. Colon polyps are described with accompanying CTC images. It is important to have a working knowledge of polyp morphology and how to accurately measure polyps. Examples of volume measurements and positioning of polyps in a head-on position are used to highlight the importance of accurate polyp measurement. There is a critical threshold 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. Non-neoplastic mucosal lesions, and submucosal lesions are covered with some examples.

14.1 Introduction

The primary aim of a screening CTC study is to detect and identify lesions in the colon. How to manage polyps is important. 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]. 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).

A study is considered positive when a lesion ≥6 mm is detected. 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.

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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 therefore 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) was the fifth most common site of cancer in both men and women in 2012 [8]. Since CRC in the United States of America (USA) remains the third most common cancer and the second leading cause of cancer deaths, the value of screening lies in the ability of CTC to detect and prevent CRC rather than CRC detection alone [9]. 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. What are its main advantages compared with OC? There are several. For example:

- It is safer: it is a minimally invasive study with an extremely low risk of perforation.
- No risk of introduction of infection as the 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.

There are four main disadvantages of CTC:

- It is a nontherapeutic 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 fairly broad agreement 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 findings of a recent publication by Pooler et al. [15] on polyps missed with OC despite previous detection and localisation with CTC showed a 21.5 % miss rate. 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.

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 therefore a structure that arises from the colonic mucosa. This structure 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. Polyps 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 evident in Fig. 14.1a. 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 polypoid 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 section 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.

Measurements of colon polyps must be as accurate and exact as possible because management of CTC patients with polyps is dependent on polyp size. For example, a deviation of 1 mm in a small polyp's measurement (6–9 mm) could result in a change of diagnosis. To put this differently, 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 overmeasurement 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 nonadenomatous for the rest. An advanced adenoma is at a higher risk for cancer progression thus polyps ≥10 mm are routinely removed. An overmeasurement would cause a patient to undergo an unnecessary polypectomy. To obtain the closest exact size of polyps means that 2D and 3D measurements of multiplanar images are essential to avoid under/overmeasurements.

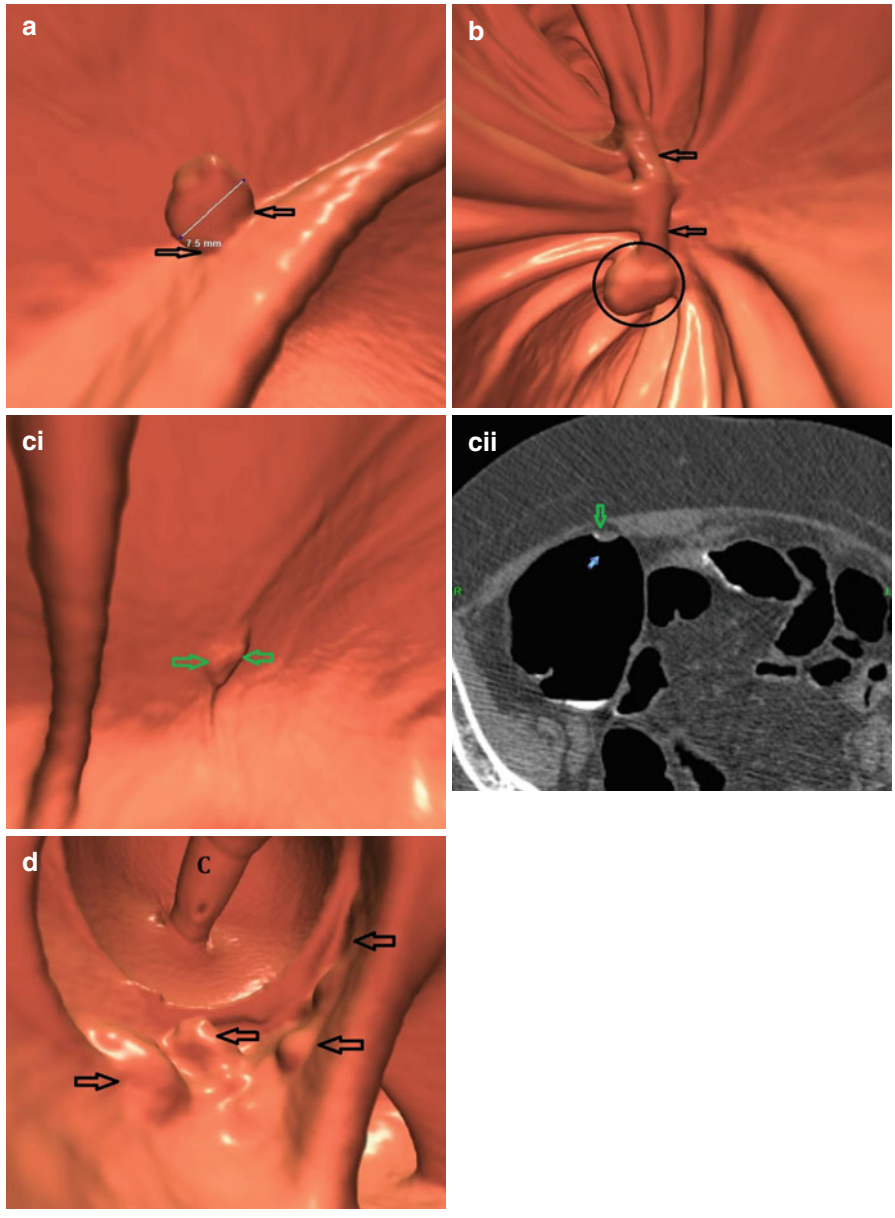

Fig. 14.1 (**a**) 3D endoluminal view showing small (7.5 mm) sessile polyp on posterior aspect of haustral fold. Broad base of attachment (*arrows*). (**b**) 3D endoluminal view showing pedunculated polyp. Head = circle. Stalk = arrows. (**c**) (**i**). 3D view shows a flat, mildly lobulated interhaustral lesion (*open green arrows*). (**c**) (**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)

14.4 Polyp Measurement

The rationale 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. Therefore an average of both measurements is 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 optical colonoscopy (OC), they are usually removed in most patients.

Polyps 6–9 mm are termed small polyps. Figure 14.2b (i)–e (iii) shows a range of examples of small polyps. 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 reassessed 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 general agreement that large lesions >10 mm should be removed by OC. Figure 14.2f (i)–h (iii) demonstrates the features of large lesions at CTC. 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, of a patient who is under a 3-year surveillance programme, must have measurements as accurate as possible on a baseline 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 callipers 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 evident in Fig. 14.2i (i, ii). This software does however allow for a semiautomated 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 2,000 HU and 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 in 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 coronal view on 2D (Fig. 14.2j (iv)), it passes through the long axis of the polyp and will be the most correct measurement.

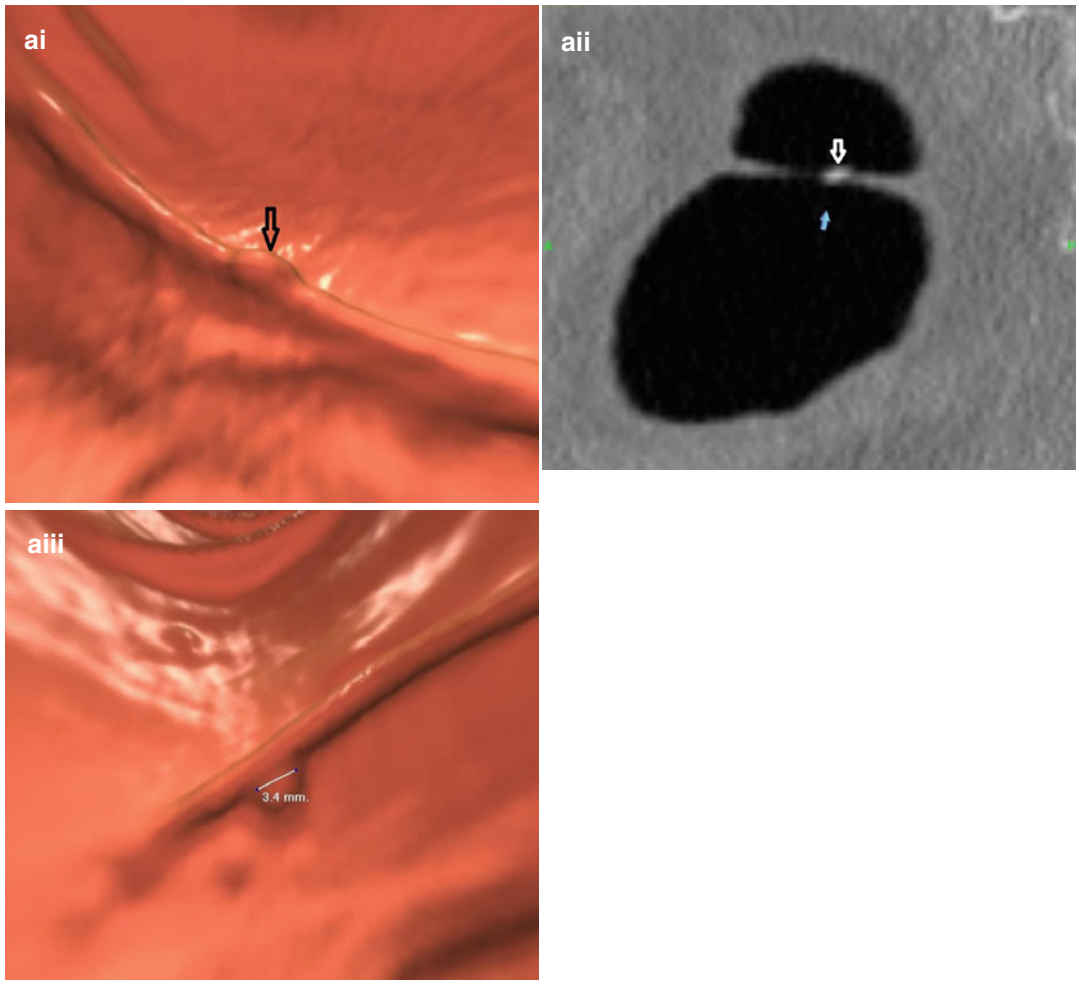

Fig. 14.2 (**a**) (**i**) 3D endoluminal view showing 4 mm haustral fold polyp (*arrow*). (**a**) (**ii**) 2D view showing density on haustral fold (*arrow* = polyp). (**a**) (**iii**) 3D view showing a 3.4 mm sessile polyp on posterior haustral fold

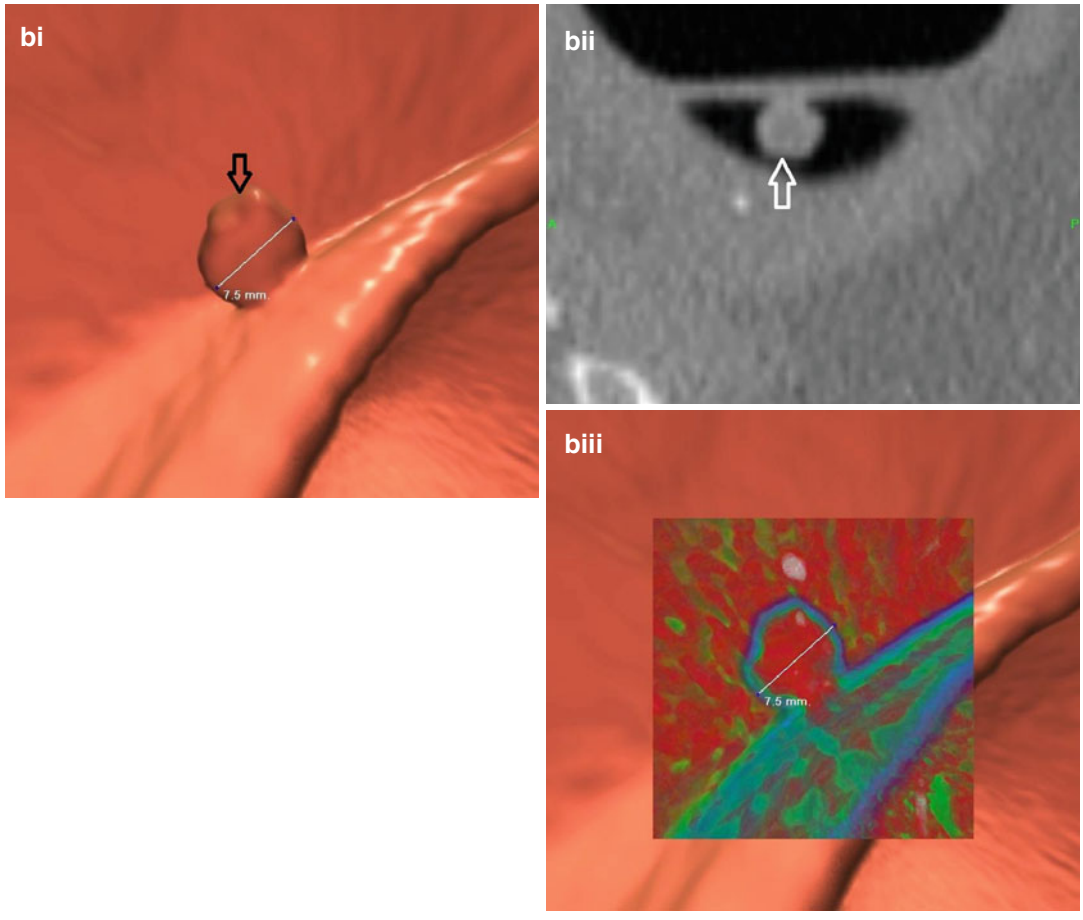

Fig. 14.2 (**b**) (**i**) 3D view showing small (7.5 mm) sessile polyp on posterior aspect of haustral fold. (**b**) (**ii**) 2D coronal view showing sessile polyp arising from posterior fold (*arrow*). (**b**) (**iii**) TD showing typical features of a polyp: high intensity centrally (*red*) surrounded by light green and blue

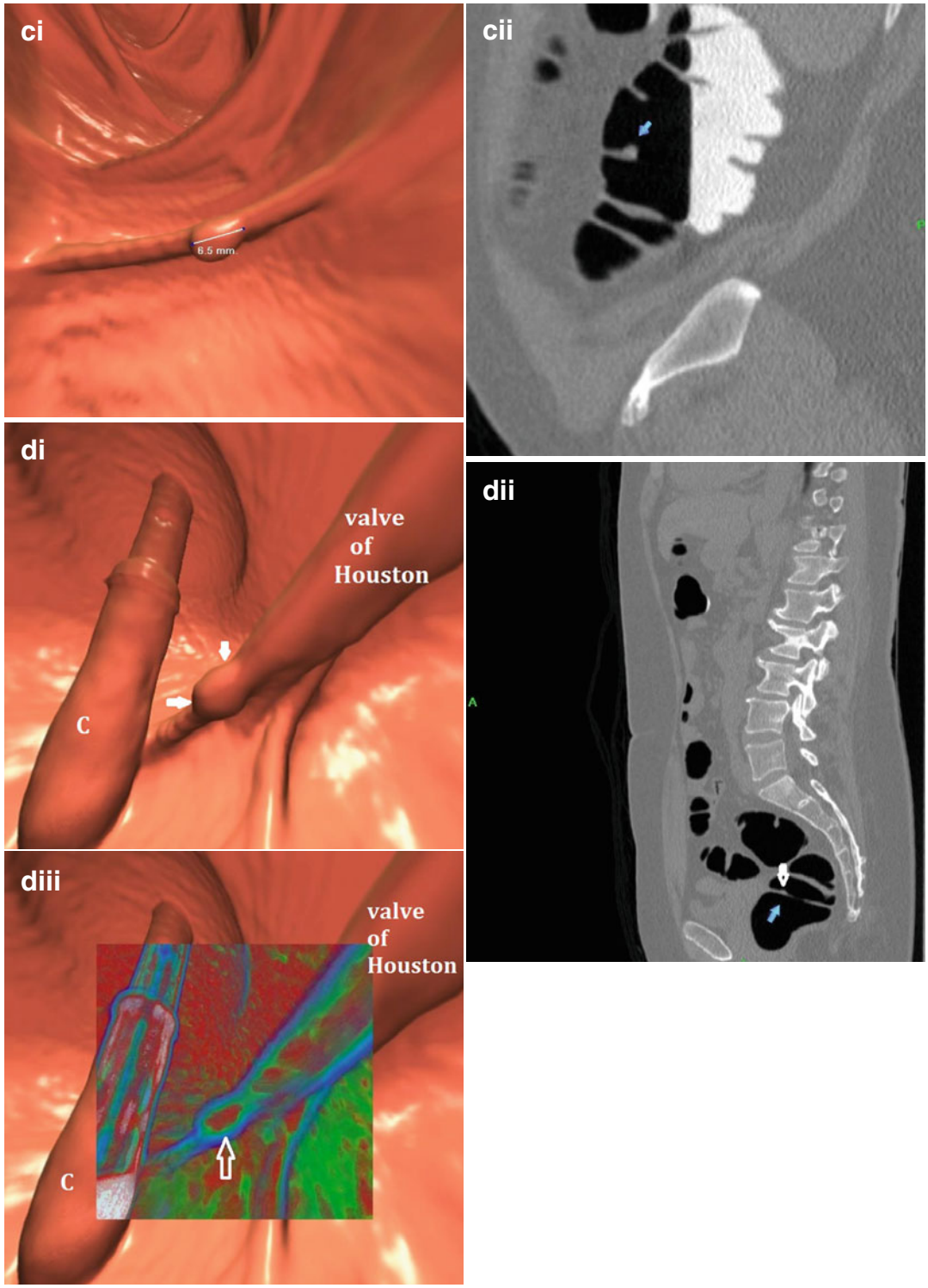

Fig. 14.2 (**c**) (**i**) 3D view showing small polyp (6.5 mm) on haustral fold. (**c**) (**ii**) Sagittal 2D view showing polypoidal density on end of fold (*blue arrow*). (**d**) (**i**) Rectal catheter (*C*). Small sessile polyp on valve of Houston (*white arrows*). (**d**) (**ii**) 2D sagittal view showing small density on inferior haustral fold (*white arrow*). (**d**) (**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*)

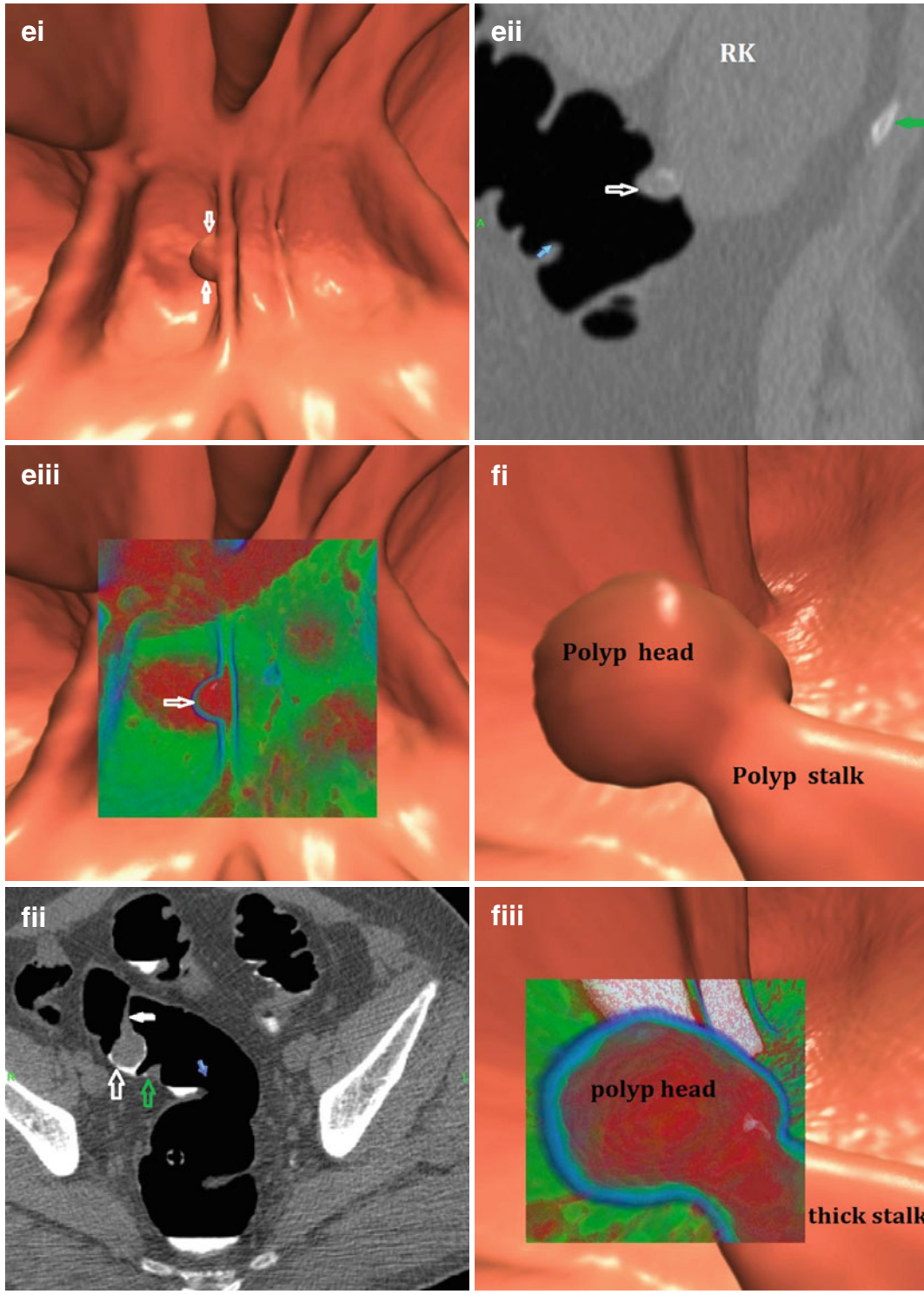

Fig. 14.2 (**e**) (**i**) 3D view of a 9 mm sessile polyp (*open white arrows*) on posterior haustral fold. Polyps on posterior folds are frequently missed on optical colonoscopy. (**e**) (**ii**) 2D sagittal view showing soft tissue polyp on posterior wall of caecum (*open white arrow*). *RK* right kidney. Right rib (*green arrow*). (**e**) (**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. (**f**) (**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*). (**f**) (**iii**) TD showing high intensity (*red*) of polyp head

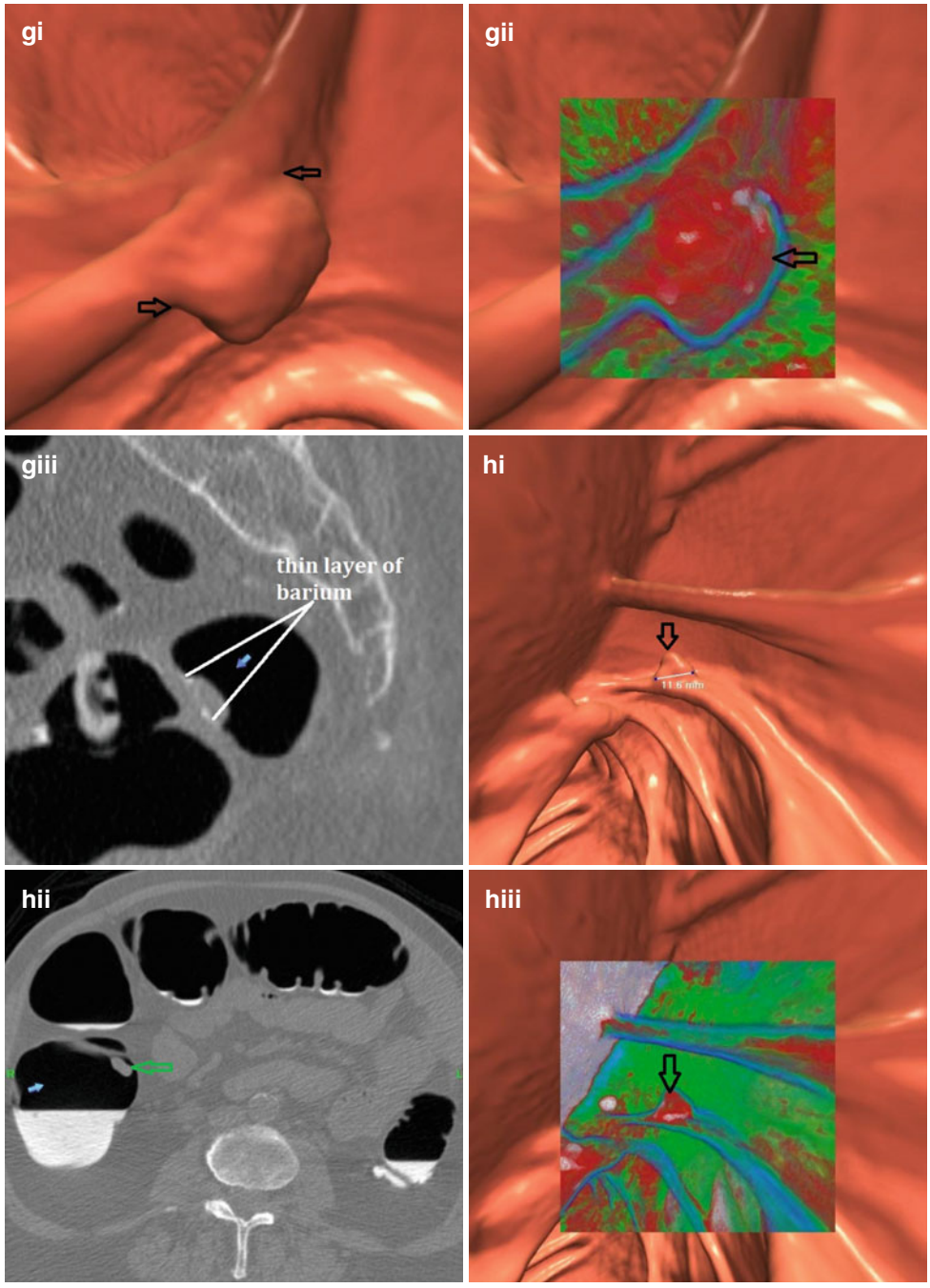

Fig. 14.2 (**g**) (**i**) 3D endoluminal view showing 12 mm advanced adenoma. Note the broad-base sessile polyp attachment (*open black arrows*) on haustral fold with lobulated outline. (**g**) (**ii**) TD showing classical features of a polyp (*open black arrow*). Note large central area of high intensity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

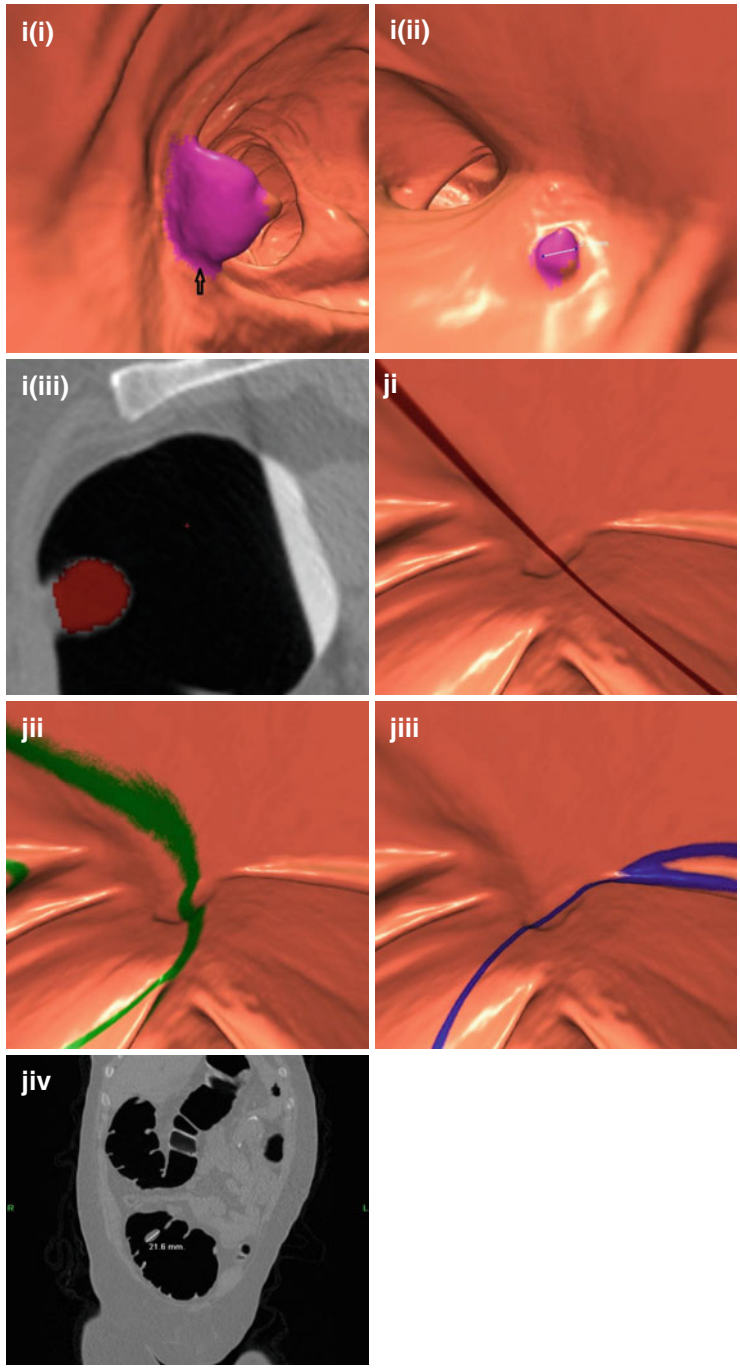

Fig. 14.2 (**i**) (**i**) 3D endoluminal volume measurement of a sessile polyp. Note the slight overflow of purple at the base (*open black arrow*). (**i**) (**ii**) 3D endoluminal head-on view of the polyp (purple). (**i**) (**iii**) 2D view of the polyp that is coloured red for volume measurement. (**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. (**j**) (**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. (**j**) (**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. (**j**) (**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. For example, normal colon or benign lesion would be classified as C1. If a polyp or possibly advanced adenomas were noted on the study, the classification would be C3 [16]. A non-diagnostic study would be C0. Table 14.1 presents the colonic C1 to C4 classifications.

Table 14.1 Colonic classifications

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: e.g. colonic diverticula
C2	Small polyps. Surveillance or colonoscopy recommended Small polyp 6–9 mm, <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 Zalis et al. [16]

14.6 Natural History of Polyps According to Lesion Size

In the vast majority of 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 trend 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. He qualified this statement by stating 'the overwhelming majority cannot possibly represent an important near-term health threat'.

Bond [27] was 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 or less) in size. The majority of diminutive lesions are hyperplastic or tubular adenomas and are of little or no clinical significance [27]. Schoenfeld [28] maintained it was 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 added that it is neither clinically wise nor cost effective to refer diminutive polyps 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. Optical colonoscopy detection of diminutive lesions and matching with CTC findings can be problematic: additional time and costs are incurred, as well as potential complications [24].

In an asymptomatic screening population, the prevalence range for polyps >6 mm 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] were of the opinion that leaving small polyps for 3 years was a safe practice. Pickhardt and Kim [1] concur that many studies have shown that leaving small polyps in place is not a harmful practice.

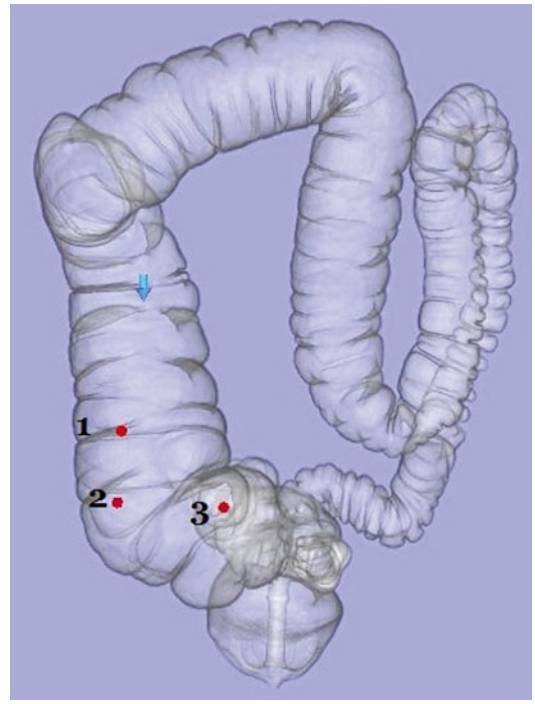

Fig. 14.3 Colon-map showing three lesions. The three *red dots* indicate site of pathology

The clinical management of visualisation of one or two small polyps at CTC is either a same-day optical colonoscopy or a 3-year surveillance period. The working group on virtual colonoscopy stated 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.

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]. Therefore 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 thus 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. However, if a patient has three or more synchronous adenomatous polyps, 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 colonoscopy and polypectomy is recommended. Note that lesions 10 mm or larger, and colonic masses ≥ 30 mm, are referred to colonoscopy.

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 [10]. Despite the overall preponderance of sub-centimetre lesions, only a small minority of advanced adenomas are present, and 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, there is a slow progression to cancer conversion [36].

There are three criteria of an advanced adenoma [10], namely:

- Any adenoma that is large (≥10 mm) and of any histological subtype, namely, tubular, tubulovillous or villous

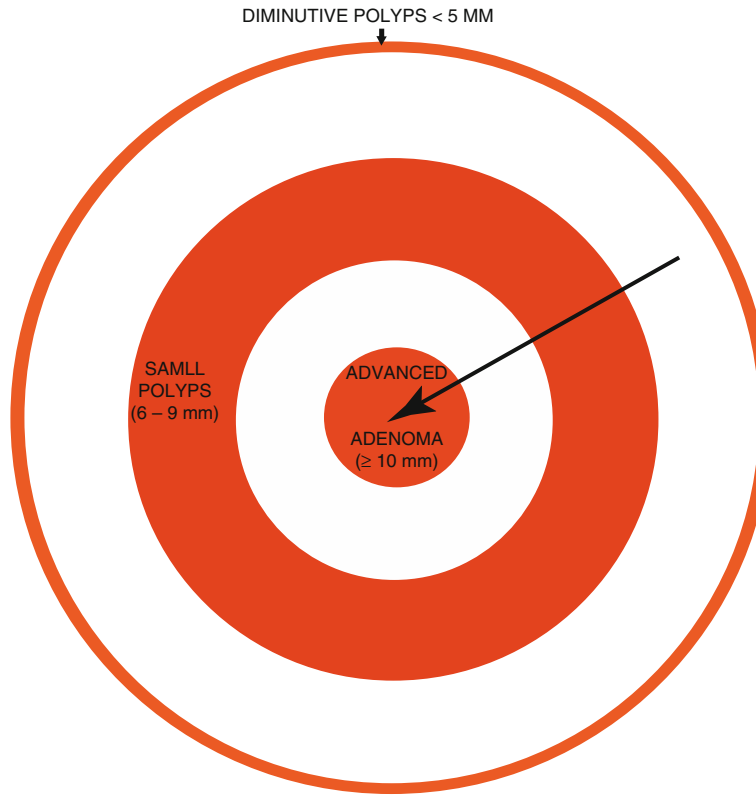

Fig. 14.4 The target is an advanced adenoma

- 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 (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. This table includes some interesting points:

- The number of advanced adenomas ≥10 mm was identical in both groups.
- The total number of advanced neoplasia (includes all advanced adenomas and carcinomas) was almost identical.
- Only 8 % of patients who had CTC studies were referred for OC.
- Out of these patients, a total number of 561 polyps were removed compared with 2434 polyps 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 is that there were seven perforations in the OC group and nil in the CTC group.
- The major revelation in the study being that in an almost equal number of patients, 14 cancers were detected in the CTC group compared with only 4 cancers detected in the OC group.

Table 14.2 Comparison of CTC vs OC for detection of advanced adenoma

	Primary CTC cases $n=3120$	Primary OC cases $n=3163$
Patients referred for OC	$n=246$ (8 %)	$n=3163$ (100 %)
Number of polyps removed at OC	561	2434
Number of advanced adenoma ≥ 10 mm	103	103
Number of advanced adenoma 6–9 mm	5	11
Total number of advanced adenoma 5 mm	1	3
Invasive cancer	14	4
Total advanced neoplasia	123	121
Perforations	0	7 (0.2 %)

Adapted from Kim et al. [10]

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 (e.g. abnormal growth/development of tissue). 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:

- Tubular adenoma (80–85 %)
- Tubulovillous adenoma (10–15 %)
- Villous adenoma (<5 %)

Adenomatous polyps usually contain both glandular and villous components. The percentage of villous component 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 adenomas 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 [37].

An adenoma with high-grade dysplasia has the greatest risk of progressing to cancer [36]. It should be noted that 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:

- 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.

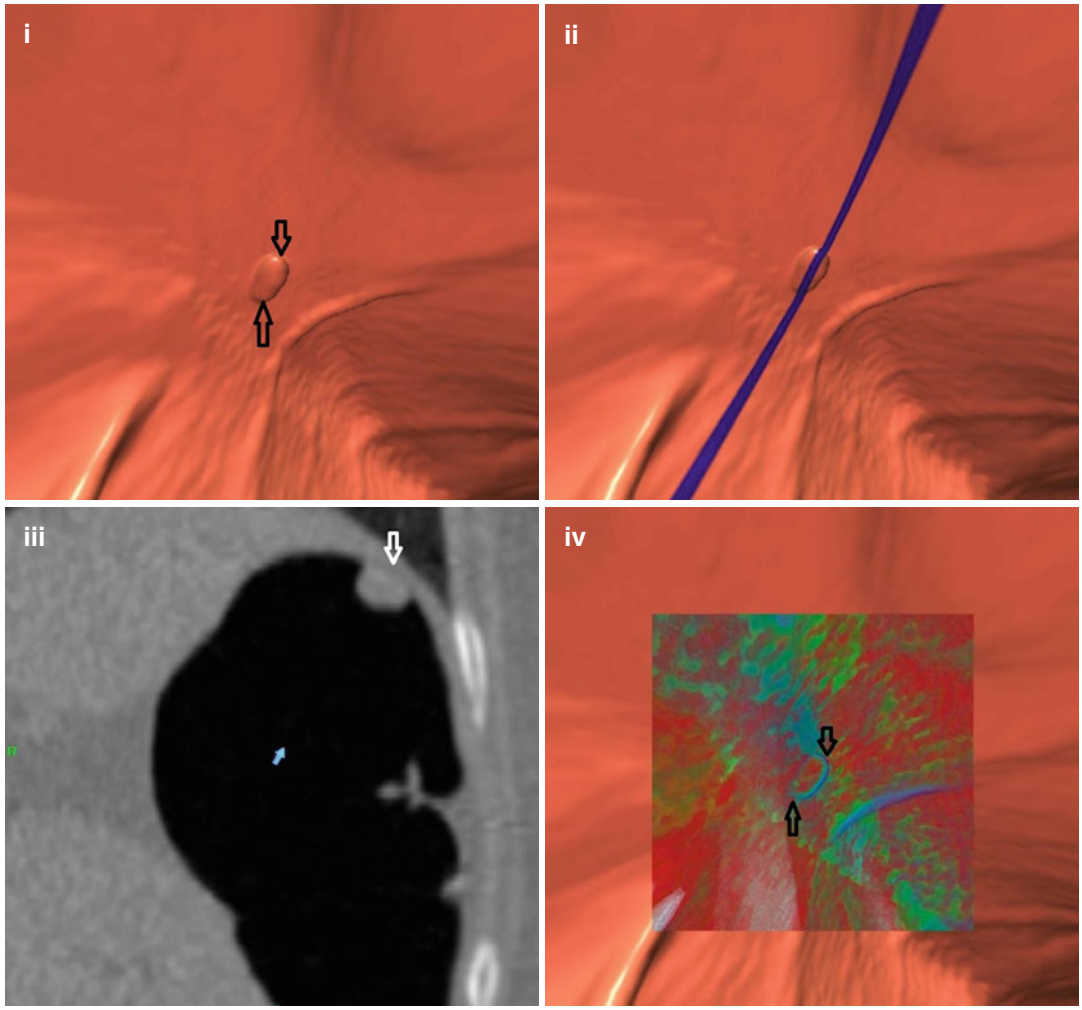

Fig. 14.5 (**i**) 3D endoluminal view of sessile lesion (*open black arrows*). (**ii**) Blue line passes through long axis of lesion. (**iii**) 2D coronal view of sessile lesion (*open white arrow*). (**iv**) Typical features of a polyp (*open black arrows*) on a TD view. High intensity centrally (*red*)

14.9.2 Tubulovillous Adenomas

Their important points are:

- 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 haustral fold. Histology confirmed a tubulovillous adenoma with no high-grade dysplasia.

14.9.3 Villous Adenomas

Their important points are:

- They comprise less than 5 % of all colorectal neoplasms.
- 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 are [38, 39] presented below:

- 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 occur 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.

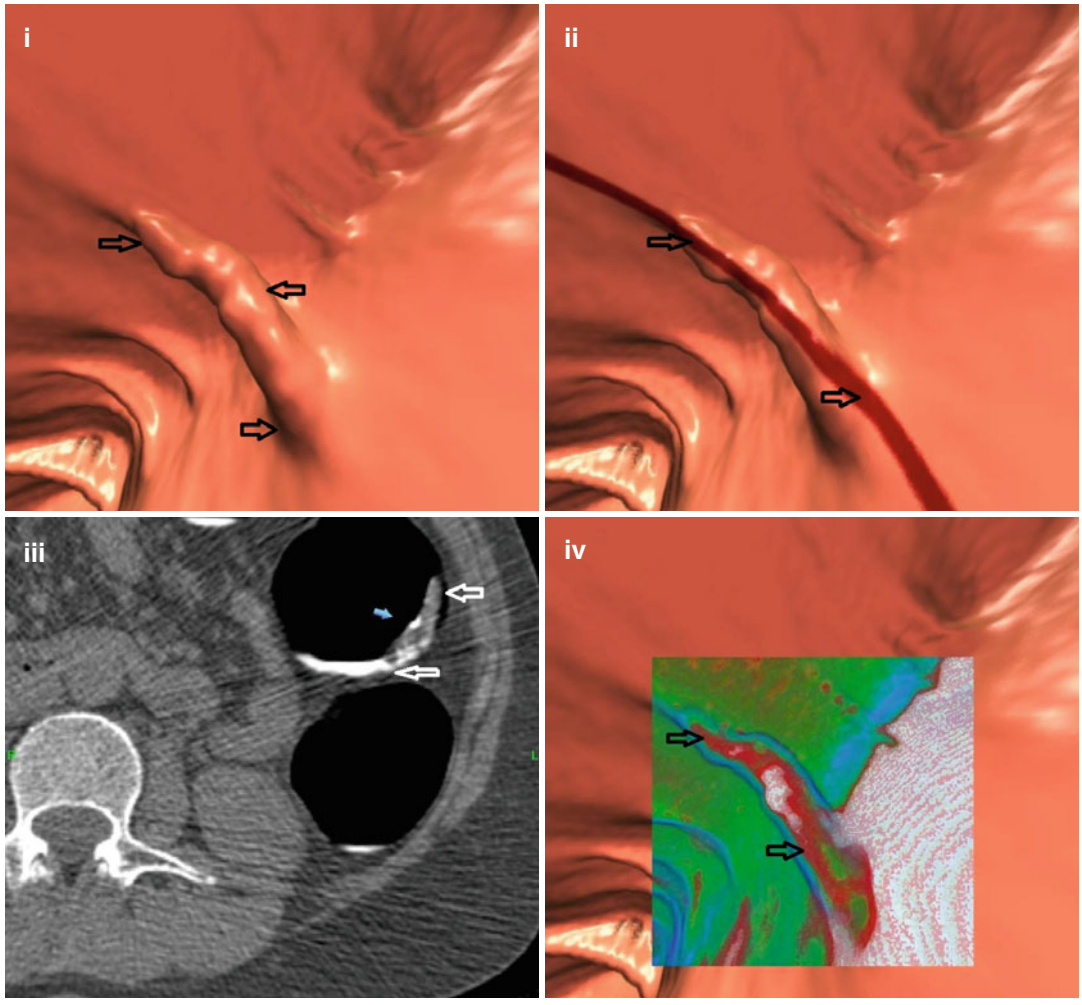

Fig. 14.6 (**i**) Thickened, lobulated haustral fold (*open black arrows*). (**ii**) Red line (*open black arrows*) passes through long axis measurement, i.e. axial on 2D. (**iii**) 2D axial view shows thickened, lobulated fold (*open white arrows*). (**iv**) Thickened, lobulated fold with high intensity (*open black arrows*) and covered in barium on TD

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. These lesions are not difficult to diagnose, provided tagging of stool and retained liquid has been performed. 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 shows examples 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. This makes the use of a cathartic agent, as well as tagging, essential to avoid misdiagnosis [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 the rectum, caecum, sigmoid colon and ascending colon, in other words both the right and left 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].

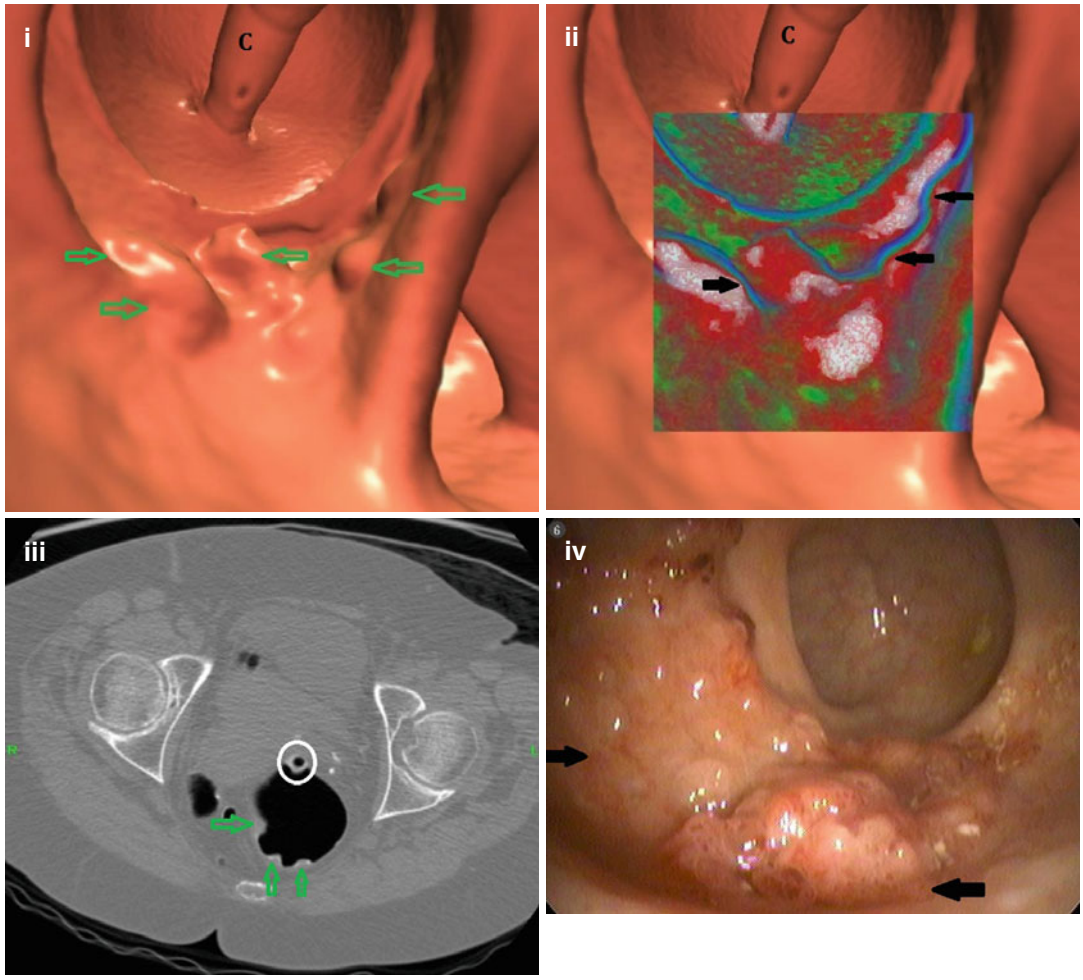

Fig. 14.7 (**i**) 3D endoluminal view of rectum showing rectal catheter (C) and carpet lesion extending for 40 mm (*open green arrows*). Histology confirmed tubulovillous adenoma. (**ii**) TD view showing rectal catheter (C) and lobulated high-intensity regions (*black arrows*) covered with a thin layer 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. There are two major classes of precancerous colorectal lesions: (*1*) adenoma, which consists of tubular, tubulovillous and villous histology, and (*2*) serrated polyps [44–46]. The latter has three subclasses [47, 48], namely:

- 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 (HP) are:

- Typically small and predominantly in the left colon
- Considered to have almost no malignant potential

Traditional serrated adenomas (TSA) are:

- 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.
- Twenty percent 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].

In addition, clinicians treat a proximal colon serrated lesions ≥10 mm as a SSP even if the histological report states hyperplastic polyp. SSP detection can be extremely challenging. A 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:

- 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. Table 14.3 illustrates the clinical features of conventional adenomas and the serrated class.

Table 14.3 Clinical features of conventional adenomas and the serrated class

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

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, namely:

- Hyperplastic polyp
- '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.
  - Twenty-five percent or less of HPs measure more than 6 mm.
- 'Mucosal' polyp
  - Normal epithelium in a 'raised' polypoid appearance
  - Second most frequent nonadenomatous lesion
  - Ninety percent 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 1 and 7 years
  - Tends to be solitary and pedunculated and occurs in the rectosigmoid region
  - Most regress or slough off
  - May occur in isolation or be associated with polyposis conditions, such as the 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 postinflammatory 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. Such lesions manifest as smooth broad-based abnormalities. This allows for them 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 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].

14.14.1 Neoplastic Intramural Submucosal Lesions

(i) 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. 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.

(ii) Carcinoid tumour is uncommon and is usually located in the rectum. When the tumour 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 sub-centimetre lesions. They rarely cause symptoms and are usually in the distal appendix [53]. Figure 14.8b shows a carcinoid tumour.

(iii) 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].

Table 14.4 Neoplastic and non-neoplastic causes of submucosal lesions involving colon and rectum

Neoplastic causes		Non-neoplastic causes	
Intramural origin	Lipoma Carcinoid tumour Lymphoma Haemangioma GIST (GI stromal tumour) Secondary deposits	Intramural origin	Vascular lesions Cystic lesions Haematoma Pneumatosis cystoides
Extramural origin	Invasion by extracolonic tumour Peritoneal carcinomatosis	Extramural origin	Endometriosis Extrinsic impression

Adapted from Pickhardt and Kim [51]

(iv) 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.

(v) GIST (gastrointestinal stromal tumour) typically arise in the muscular 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 i.v. contrast on CT scanning [56].

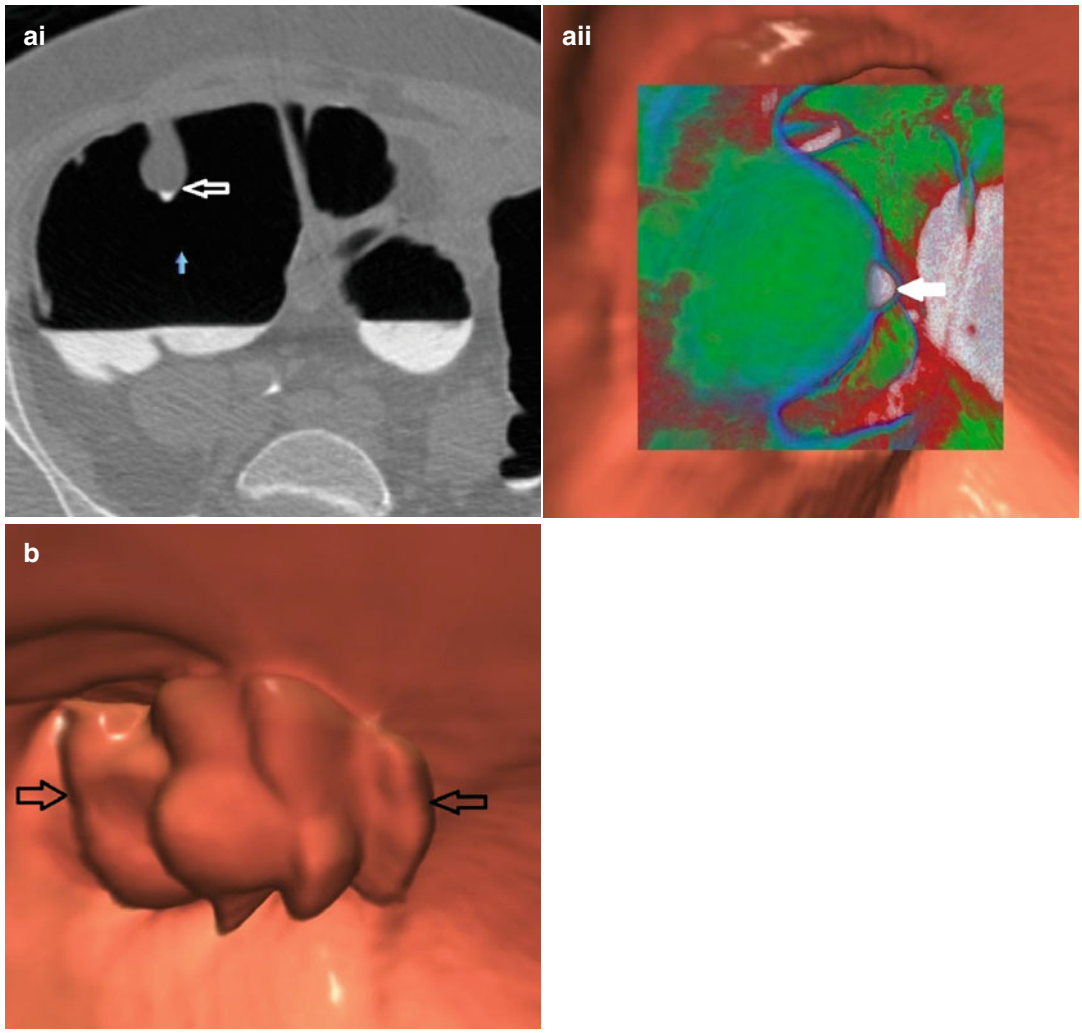

Fig. 14.8 (**a**) (**i**) Axial 2D soft tissue window view showing tip of barium (*open white arrow*) on lipoma. (**a**) (**ii**) Translucent display of lipoma (*green = fat*). Barium (*white arrow*) on tip of lipoma. (**b**) 3D view of distal ileum showing a lobulated mass (*arrows*) on endoluminal fly-through. Histology showed a malignant carcinoid with lymph node involvement

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. Figure 14.9a (i, ii) shows examples of internal haemorrhoids.

Non-neoplastic causes of extramural origin include endometriosis and extrinsic impressions. An extrinsic impression, without mural invasion, may be caused by an abnormal extracolonic lesion:

(i) 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].

(ii) An extrinsic impression is any structure, which may lie adjacent to the colon, and may cause an extrinsic impression on the lumen. 2D multiplanar reformatting allows one to readily differentiate intramural lesions from extracolonic lesions. Common examples of the latter include aorta, uterus, small intestine and kidneys [58, 59]. Figure 14.9b (i, ii) is an example of an extrinsic impression on the colon. See more examples in Chap. 11.

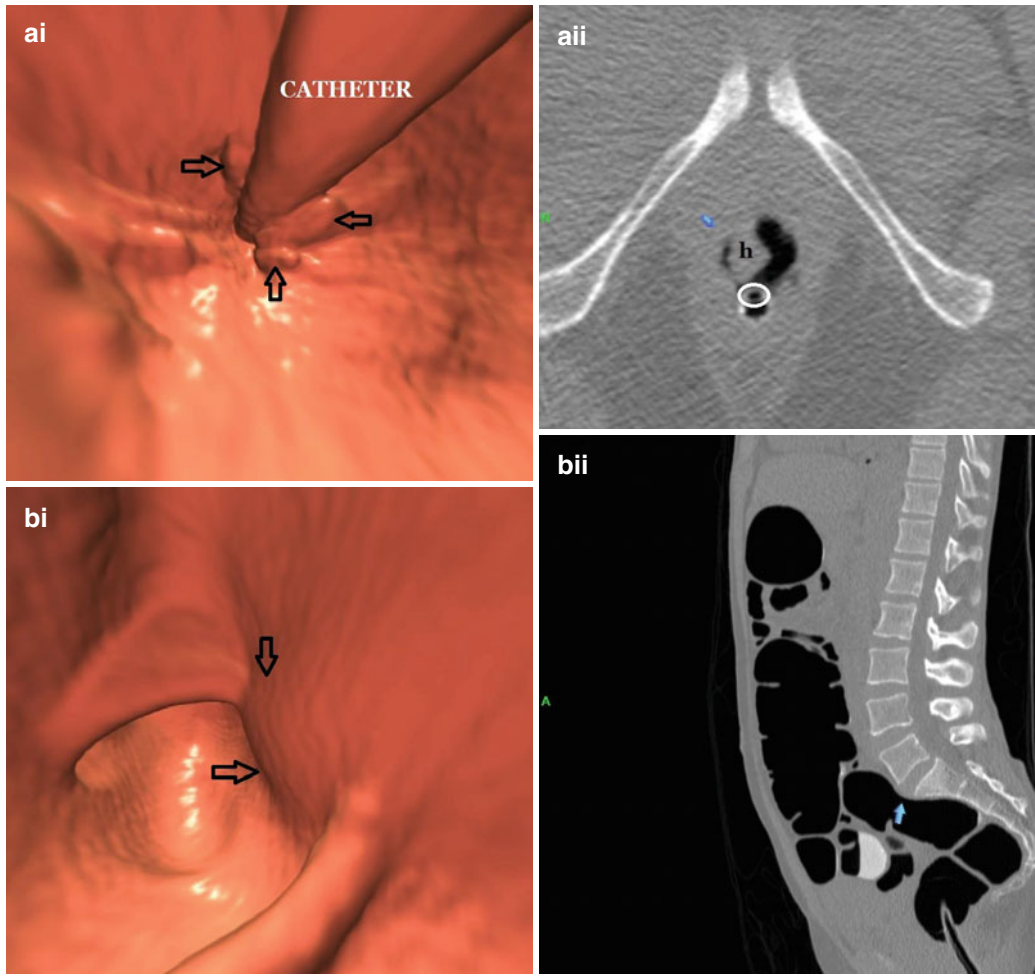

Fig. 14.9 (**a**) (**i**) Internal haemorrhoids (*open black arrow*). (**a**) (**ii**) 2D axial prone view showing internal haemorrhoid (h). Rectal catheter (*white circle*). (**b**) (**i**) 3D endoluminal view showing an external impression from L5 (*open black arrows*). (**b**) (**ii**). 2D sagittal view showing mild spondylolisthesis of L5 on S1 causing posterior extrinsic impression on sigmoid colon (*blue arrow*)

14.15 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 option of a 3-year surveillance may be offered.
- Advanced adenomas (≥10 mm) are sent for same-day OC.
- Beware of right-sided colonic lesions as they may be of the serrated variety.

14.16 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. http://dx.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); http://dx.doi/org/10.4102/sajr. v18i1.607 [www.sajr.org.za].
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. http://dx.doi.org/NEJMoa0800996.
5. Miller-Keane Encyclopedia and Dictionary of Medicine, Nursing, and Allied Health, 7th Ed. 2003. [cited 2015 August 7]. Available from: http://medical-dictionary.thefreedictionary.com/prevalence.
6. Farlex Partner Medical Dictionary. 2012. [cited 2015 August]. Available from: 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. Cancer key facts. [cited 2015 June 25]. Available from: http://www.who.int/mediacentre/factsheets/fs297/en/.
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://dx.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). doi: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. 2015; 150294 (EPUB ahead of print).
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 29th ed. Philadelphia: WB Saunders; 2012.
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(4):940–46. http://dx.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 Endoscopy 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. doi: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. Semin 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. 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.
37. Macari M, Bini EJ. CT colonography: where have we been and where are we going? Radiology. 2005;237(3):819–33. http://dx.doi.org/10.1148/radiol.22373041717.
38. Waye JD, Bilotta JJ. Rectal hyperplastic polyps – now you seen 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. http://dx.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. Colorectal 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://dx.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.

The Adenoma–Carcinoma Sequence, Management and Treatment of Colon Cancer

15

Joel H. Bortz and Hesta Friedrich-Nel

Abstract

Colorectal cancer (CRC) is a leading cause of death, worldwide. Most sporadic cancers arise from the adenoma–carcinoma pathway. This pathway, together with the serrated polyp–carcinoma sequence, constitutes 95 % of cancer of the colon. The hereditary colorectal cancer syndromes represent 5 % of colon cancers. At CTC it is important to describe the size and location of lesions as early detection of cancer precursors is important. Examples of lesions at CTC are presented. The role of imaging modalities in preoperative evaluation of CRC, as well as for staging of tumours, nodes and metastases, is discussed. Management of CRC includes surgery, radiation therapy, chemotherapy and targeted therapy which is either separate or in combination.

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 fifth most common site of cancer in both men and women in 2012. Reduction of cancer by 25 % by 2020 is part of the WHO's global action plan for the prevention and control of noncommunicable diseases [2]. The WHO promotes screening programmes for early detection of CRC [1]. An estimated 93,090 cases of colon cancer and 39,610 cases of rectal cancer are expected to be diagnosed in 2015. The latest CRC statistics for new cases in the United States of America (USA) is expected to decrease to 136,830 from the previous estimate of more than 143,000 cases in 2012 [3–5]. The number of deaths in 2015 is expected to decrease to 49,700 from the previous figure of more than 50,000 deaths per year [3–6]. There has been a gradual decline in the incidence of cancer as well as the number of deaths in the USA; these

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declines have been attributed to CRC screening and removal of potentially harmful polyps [6]. 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 [7]. It is important to detect and remove a polyp, which will ultimately grow and become an underlying cancer [8]. Knowledge of the adenoma–carcinoma sequence is important for reporting of polyps detected during CTC studies [9].

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 [8, 9]. 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. A cancer, which arises from an adenomatous polyp, goes through a pathway known as the adenoma–carcinoma pathway [7, 8]. Cancer from a hyperplastic polyp develops along a different pathway: the serrated polyp–carcinoma sequence. There is another less common pathway: the hereditary colorectal cancer syndromes [10].

15.3.1 Adenoma–Carcinoma Pathway

The adenoma–carcinoma pathway is that of a cancer that arises from an adenomatous polyp [7]. 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 [11]. It takes between 10 and 15 years for an adenoma to develop into a carcinoma [7, 12]. 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 [8]. 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 [8], namely:

- 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 15.1a(i)–f presents a range of examples of polypoidal lesions and colorectal cancer, as well as an example of metastatic lymph nodes.

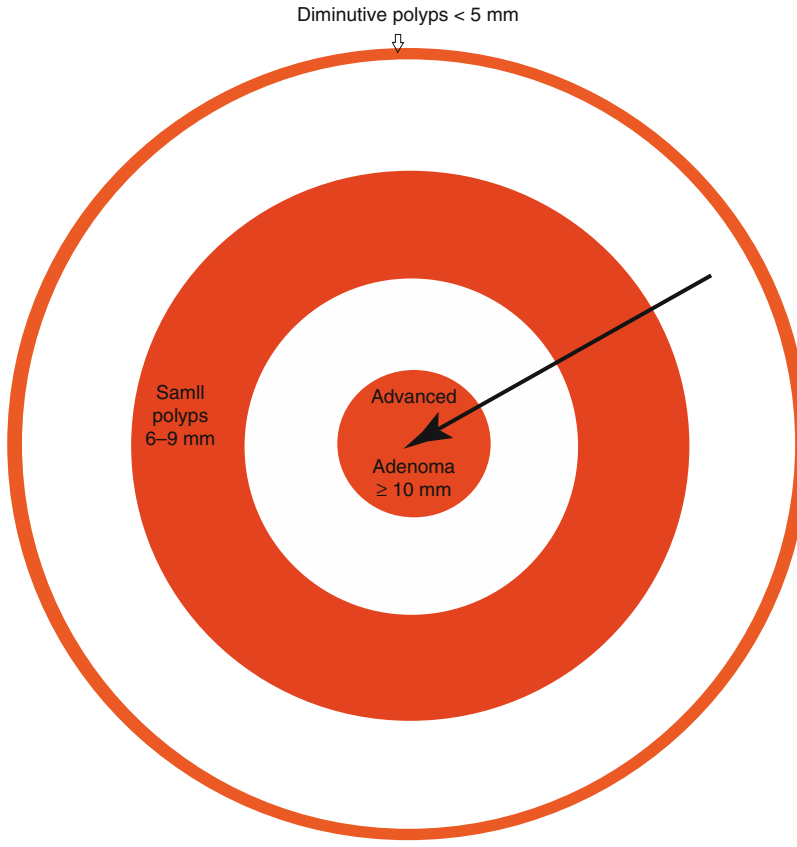

Fig. 15.1 An advanced adenoma is the target lesion

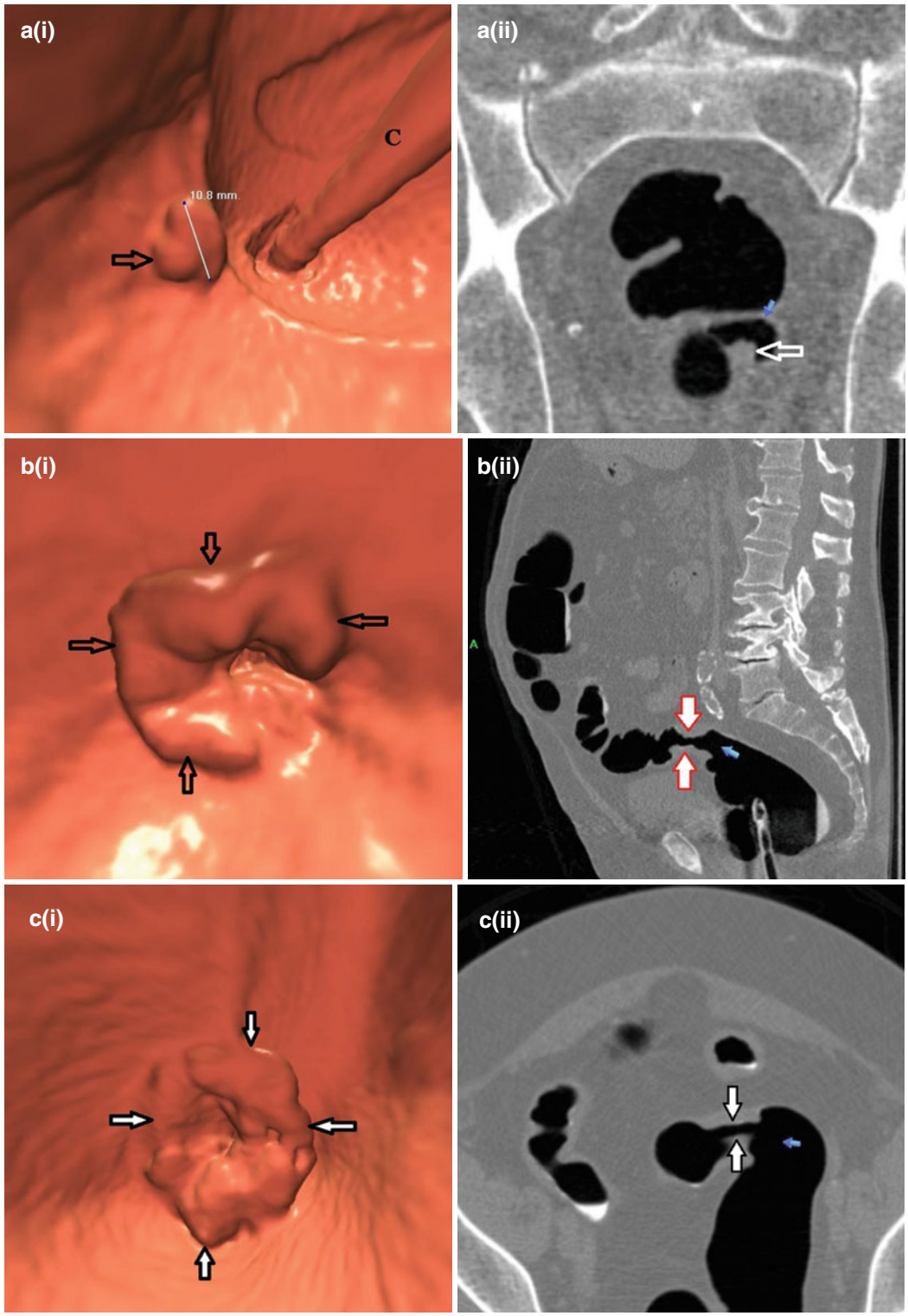

Fig. 15.1 (**a**) (**i**) 3D view of a 10.8 mm polypoidal lesion (*open black arrow*) close to rectal catheter (C). (**a**) (**ii**) 2D coronal soft tissue window showing polyp (*open white arrow*). (**b**) (**i**) 3D endoluminal view showing an almost complete annular carcinoma in the sigmoid colon (*open black arrows*). (**b**) (**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*). (**c**) (**ii**) 2D axial soft tissue view showing annular carcinoma with marked narrowing of lumen (*arrows*)

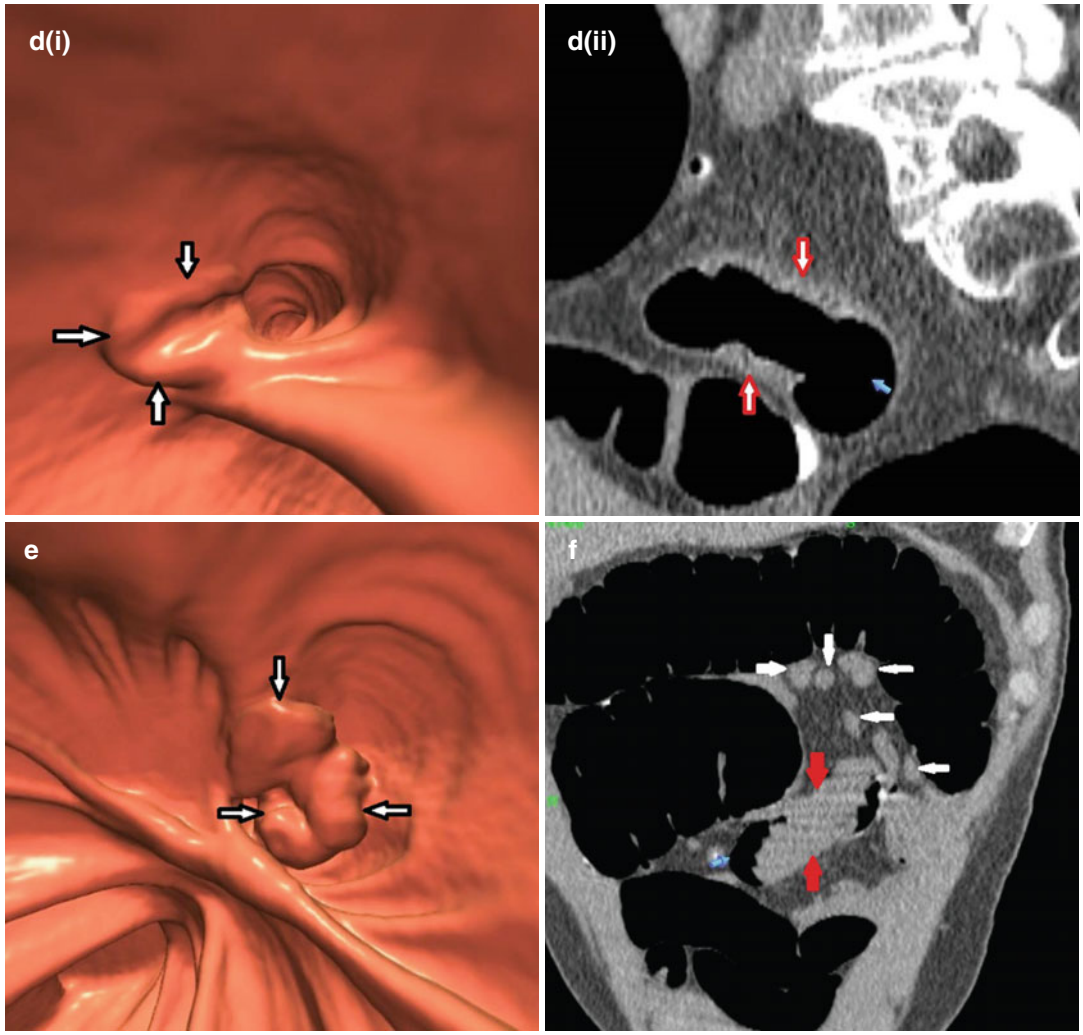

Fig. 15.1 (**d**) (**i**) 3D endoluminal view showing semi-annular carcinoma (*arrows*). (**d**) (**ii**) 2D sagittal soft tissue view showing cancer in the sigmoid colon (*arrows*). (**e**) 3D view showing large fungating caecal pole mass carcinoma (*arrows*). (**f**) Coronal 2D soft tissue view showing a large ileal carcinoid (*red arrows*) and metastatic lymph nodes (*white arrows*)

15.3.2 Serrated Polyp–Carcinoma Sequence

Cancer from a hyperplastic polyp develops along a different pathway, the serrated polyp–carcinoma sequence, and forms between 15 and 20 % of CRCs. It is termed the 'mutator' pathway [13]. 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 [14]. 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 %).

15.4 Hereditary Colorectal Cancer Syndromes

The vast majority of CRC (95 %) arise from pre-existing polyps; the rest (5 %) represent the hereditary colorectal cancer syndromes [10]. 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 twenties (3rd decade) and thirties (4th decade). Colorectal cancer 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. Although related, they are considered under the umbrella of FAP as separate syndromes: 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) [15] 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 %) and ovarian cancer (9–12 %). There are also higher risks of other cancers, namely, pancreatic cancer, kidney cancer, prostate cancer and breast cancer [15].

15.5 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, e.g. the Union for International Cancer Control (UICC) or tumour, node, metastases (TNM classification) or Duke staging [16]. 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), is locally advanced (stages II and III) and/or has spread to distant organs (stage IV). Local CRC (stages I to III) can have a high, moderate or low risk of local recurrence. This information assists in determining the treatment protocol of the patient.

15.5.1 Surgery

Surgery is the most common treatment option but depends on the location of the tumour and is recommended if the tumour is resectable [17]. During a colonoscopy, the surgeon can perform a polypectomy which is a local excision of a polyp. 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 [18].

15.5.2 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 [17].

15.5.2.1 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 [18].

15.6 Radiation Therapy

External beam radiation therapy is commonly used for patients with CRC and can take various forms [19]. 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. The 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 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 [18].

15.6.1 Treatment of CRC by Stage

There are four stages of CRC [18]. 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 the chemotherapy before the surgery. If there is a suspicion of local recurrence, radiation therapy may also be used. Radiation therapy and/or chemotherapy remains 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.

15.7 Imaging Modalities in Preoperative Evaluation of CRC

CTC can play a role in preoperative evaluation of CRC according to Kijima et al. [19]. They compared the effectiveness of different modalities, namely, CT colonography, 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. In terms of CT colonography, 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 3D 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 [20]. 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 CT colonography 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 CT colonography in TNM staging is as follows [19]. Tumour staging (T staging) varies between 73 and 83 %. In terms of the detection of metastatic lymph nodes (N staging), diagnostic CTC, which includes i.v. contrast medium, 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 %. Intravenous (i.v.) contrast media are not used in screening CTC. However, the administration of i.v. contrast medium is mandatory for staging by CT scanning.

MRI is used mainly for staging of rectal cancer (see Chap. 20) and in the evaluation of liver metastases. According to Kijima et al. [19], PET/CT colonography seems a useful tool (i) for the evaluation of CRC in presurgical staging and (ii) 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 [21].

15.8 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.
- Cancer from a hyperplastic polyp develops along a different pathway, the serrated polyp–

carcinoma sequence, and forms between 15 and 20 % of CRCs.

- 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.
- Diagnostic CTC, MRI and PET/CT colonography play a role in TNM staging of CRC.

15.9 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.

Acknowledgement Clinton Bopp is thanked for drawing the target line diagram.

References

1. WHO. Cancer key facts. [cited 2015 June 25]. Available from: http://www.who.int/mediacentre/factsheets/fs297/en/.
2. WHO Global action plan for the prevention and control of noncommunicable diseases 2013–2020 [cited 2015 June 25]. Available from: http://www.who.int/nmh/publications/ncd-action-plan/en/.
3. American Cancer Society. Cancer facts and figures 2015. [cited 2015 June 25]. Available from :http://www.cancer.org/cancer/colonandrectumcancer/detailedguide/colorectal-cancer-key-statistics.
4. 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. http://dx.doi.org/10.7150/jca.5858.
5. Siegel R, Naishadbam D, Jemal A. Cancer statistics, 2012. CA Cancer J Clin. 2012;62:10–29. http://dx.doi.org/10.3322/caac.20138.
6. Johnson DA. Landmark developments in gastroenterology, Medscape June 19, 2015. [cited 2015 June 25]. Available from: http://www.medscape.com.
7. Muto T, Bussey HJR, Morson BC. The evolution of cancer of the colon and rectum. Cancer. 1975;36:2251–70. http://dx.doi.org/10.1002/cncr.2820360944.
8. 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 Am J Roentgenol. 2007;188(4):940–4.
9. Bortz JH. CT colonography: an approach for a successful examination. S Afr J Rad. 2014;18 (1):Art. #607, 11. http://dx.doi/org/10.4102/sajr. v18i1.607 SAJR 2014.
10. Lynch HJ, de la Chapelle A. Hereditary colorectal cancer. N Engl J Med. 2003;348(10):919–32.
11. Robbins DH, Itzkowitz SH. The molecular and genetic basis of colon cancer. Med Clin North Am. 2002;86(6):1467–95.
12. Winawer SJ, Zauber A, Diaz B. The National Polyp Study: temporal sequence of evolving colorectal cancer from the normal colon (abstr). Gastrointest Endosc. 1987;33:167.
13. Pickhardt PJ, Arluk GM. Atlas of gastrointestinal imaging: radiologic-endoscopic correlation. Philadelphia: Saunders; 2007. p. 24.
14. O'Brien MJ. Hyperplastic and serrated polyps of the colorectum. Gastroenterol Clin North Am. 2007;36(4):947–68.
15. Lynch Syndrome approved by the Cancer.Net Editorial Board, 12/2014 .[cited 2015 June 25]. Available from: http://www.cancer.net/cancer-types/lynch-syndrome.
16. Stintzing S. 2014. F1000Prime Rep. 2014; 6: 108. Published online 2014 Nov 4. [cited 2015 July 2]. Available from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4229728/ http://dx.doi.org/10.12703/P6-108.
17. SIGN (Scottish Intercollegiate Guidelines Network) 126. 2011. Diagnosis and management of colorectal cancer. A national clinical guideline. [cited 2015 July 2]. Available from: http://www.sign.ac.uk/pdf/sign126.pdf.
18. Colorectal Cancer: Treatment Options Approved by the Cancer.Net Editorial Board, 09/2014. [cited 2015 July 2]. Available from: http://www.cancer.net/cancer-types/colorectal-cancer/treatment-options.
19. 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.
20. Cunliffe WJ, Hasleton PS, Tweedle DE, Schofield PF. Incidence of synchronous and metachronous colorectal carcinoma. Br J Surg. 1984;71(12):941–3.
21. Heriot AG, Hicks RJ, Drummond EG, et al. Does positron emission tomography change management in primary rectal cancer? A prospective assessment. Dis Colon Rectum. 2004;47(4):451–8.

Diverticular Disease

16

Joel H. Bortz

Abstract

Diverticular disease is considered to be a normal finding as it is the most common benign colonic abnormality in people over the age of 50 years. CTC is contraindicated in patients with acute diverticulitis. Chronic diverticular disease does have known complications, which may be visualised by CTC. There are several criteria that distinguish diverticular disease from underlying cancer. CTC images of diverticular disease are presented to illustrate the features of the pathology.

16.1 Introduction

Diverticular disease 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 (C1 classification – see Chap. 10 Table 10.2) 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 diverticular disease, predominantly in the sigmoid colon, and to a lesser extent in the descending colon and right side of the colon [1]. The incidence of diverticular disease increases with age with equal prevalence in men and women [2]. The prevalence of diverticular disease has increased over the last few decades. Approximately 40 % of adults below the age of 40 years have the disease. This rises to 50–70 % in adults up to the age of 70 years and reaches 85 % in persons 80 years or older [1]. Asians are more prone to develop colonic diverticular disease on the right side of the colon [3].

16.2 CTC Study Is Contraindicated in Acute Diverticulitis

Acute diverticulitis is an absolute contraindication for performance of a CTC study. Acute diverticulitis means that a perforation of a diverticulum has occurred. This may be extremely small. The 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 which results in abscess formation. This is a serious situation which requires use of antibiotics. If there is a large volume of fluid in the abscess cavity,

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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).

16.3 Pathogenesis and Cause of Colonic Diverticular Disease

What is pathogenesis? It is the biologic mechanisms that lead to a disease state. Diverticular disease pathogenesis is thus acquired by herniation (outpouching) of mucosa and submucosa through the muscularis propria in an area of weakness where the nutrient arteries extend through the submucosa [4]. Figure 16.1 shows outpouchings of multiple diverticula.

The cause of colonic diverticular disease is not well understood. Several theories have been mooted [2, 5, 6]. 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 [6].

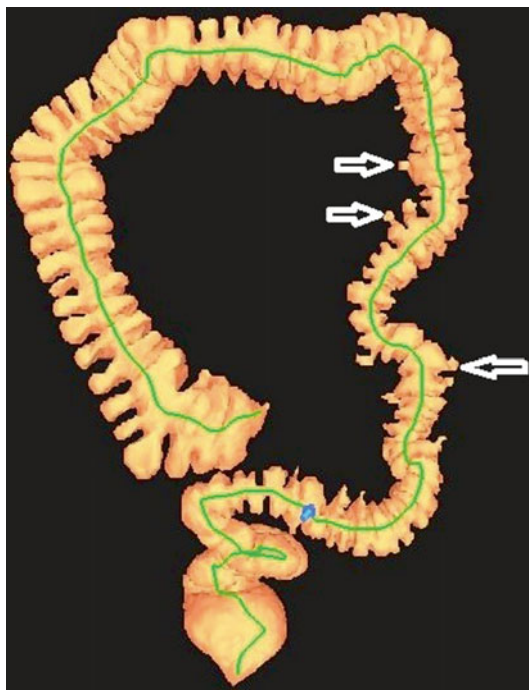

Fig. 16.1 Example of outpouching of diverticula (*open white arrows*) on supine colon-map view

16.4 Pathological Features of Chronic Diverticular Disease

There are several features of the disease [5], namely:

- Myochosis (muscle thickening) and elastin deposition
- Thickening of the circular muscle
- Shortening of the taeniae
- Decreased compliance
- Luminal narrowing

16.5 CTC in Patients with Diverticular Disease

Patients with diverticular disease are usually asymptomatic when presenting for CTC screening for detection of colorectal cancer (CRC). Moderate or advanced severity diverticular disease is diagnosed in at least 50 % of patients who are 50 years or older [7]. The sigmoid colon, followed by the descending colon and then the ascending colon are mainly the areas of involvement. According to Pickhardt and Kim [8], 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 16.8, and thickened folds may cause possible pitfalls, as discussed in 12.2.3 in Chap. 12. 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) shows examples of impacted diverticula.

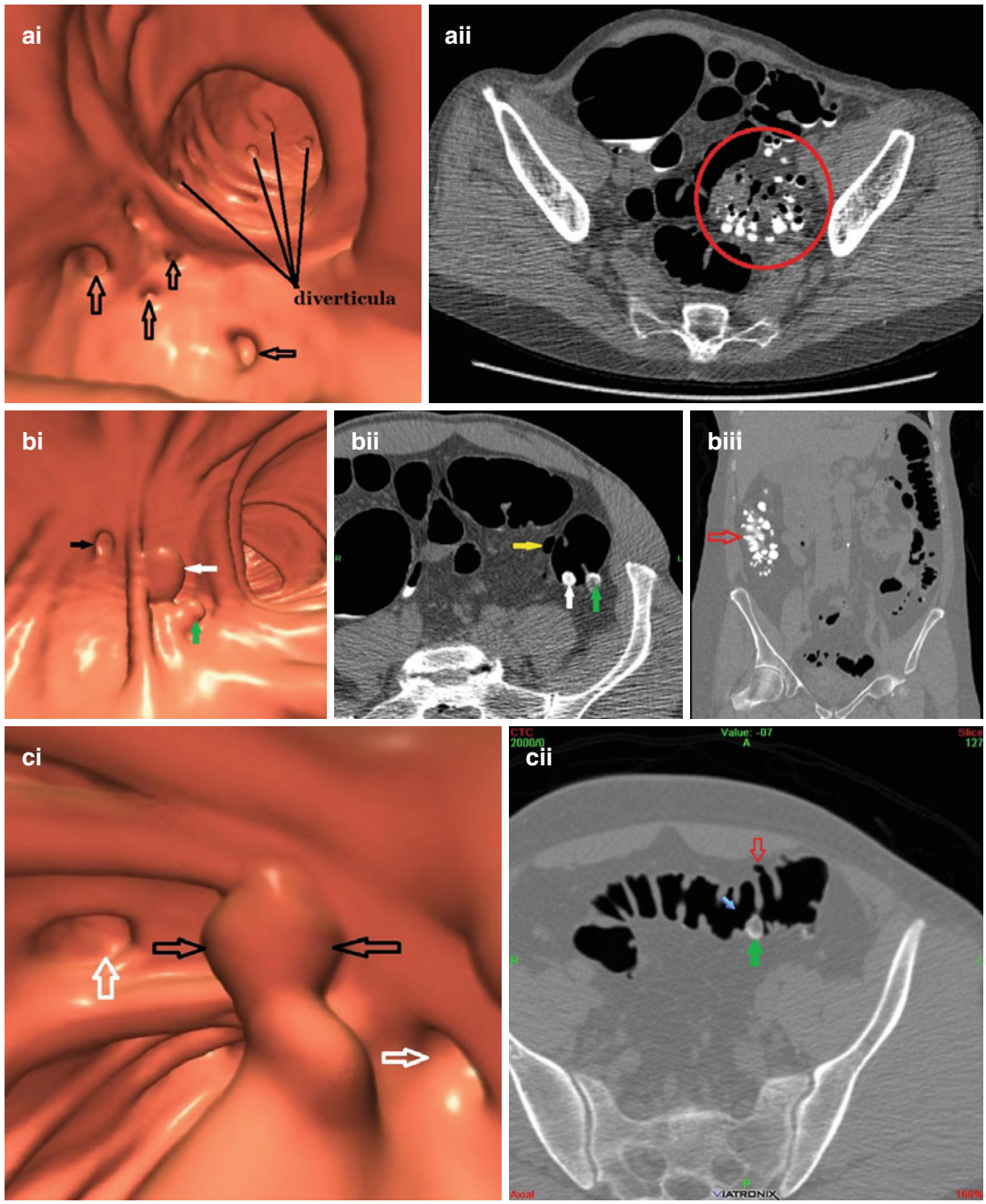

Fig. 16.2 (**a**) (**i**) 3D view of multiple diverticula with black margins (*open black arrows*). (**a**) (**ii**) 2D axial view of multiple diverticula (*red circle*). (**b**) (**i**). 3D view showing diverticulum (*black arrow*) and impacted diverticulum (*green arrow*). Polypoidal defect due to stool (*white arrow*). (**b**) (**ii**) 2D axial view shows stool (*white arrow*) and impacted diverticulum (*green arrow*). *Yellow arrow* shows diverticulum. (**b**) (**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*). (**c**) (**ii**) 2D axial showing impacted diverticulum (*green arrow*) and an air-filled diverticulum (*red arrow*)

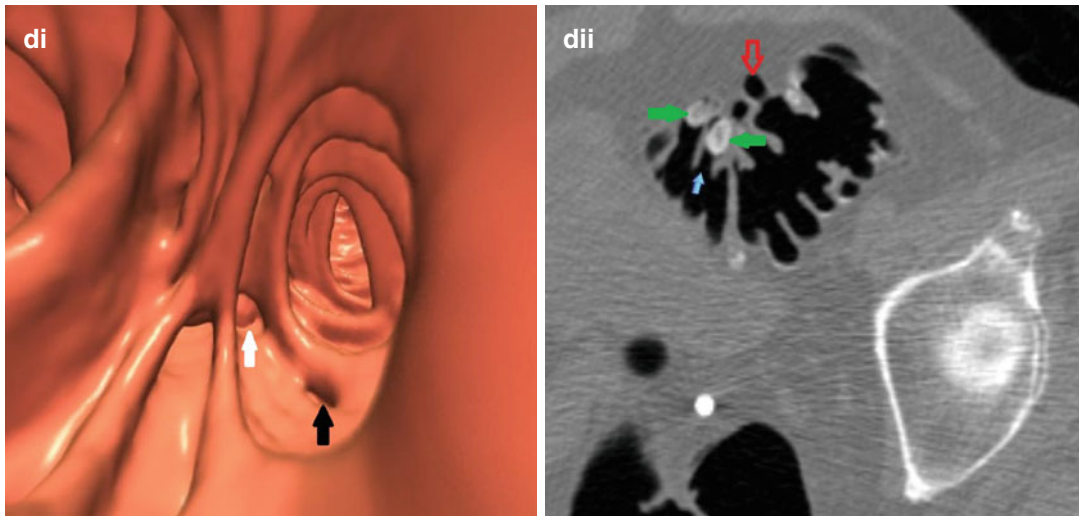

Fig. 16.2 (**d**) (**i**) 3D endoluminal view of impacted diverticulum (*white arrow*) and diverticulum (*black arrow*). (**d**) (**ii**) 2D axial shows impacted diverticula (*green arrows*) and air-filled diverticulum (*red arrow*)

16.6 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' [9]. The thickening of the folds as well as luminal narrowing, due to muscular hypertrophy from diverticular disease, can cause a confusing picture on both 2D as well as 3D visualisation. Thick folds may be interpreted as polyps or even possible masses on both 2D and 3D endoluminal views [10]. 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 an easy recognisable black ring (Fig. 16.3a (i)). On 2D views the diverticulum extends beyond the colon wall and is usually 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 Figure 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.

16.7 Role of Antispasmodics

CTC procedures are not complicated in countries where Buscopan (hyoscine butylbromide) is available [11]. Buscopan does have side effects; it 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

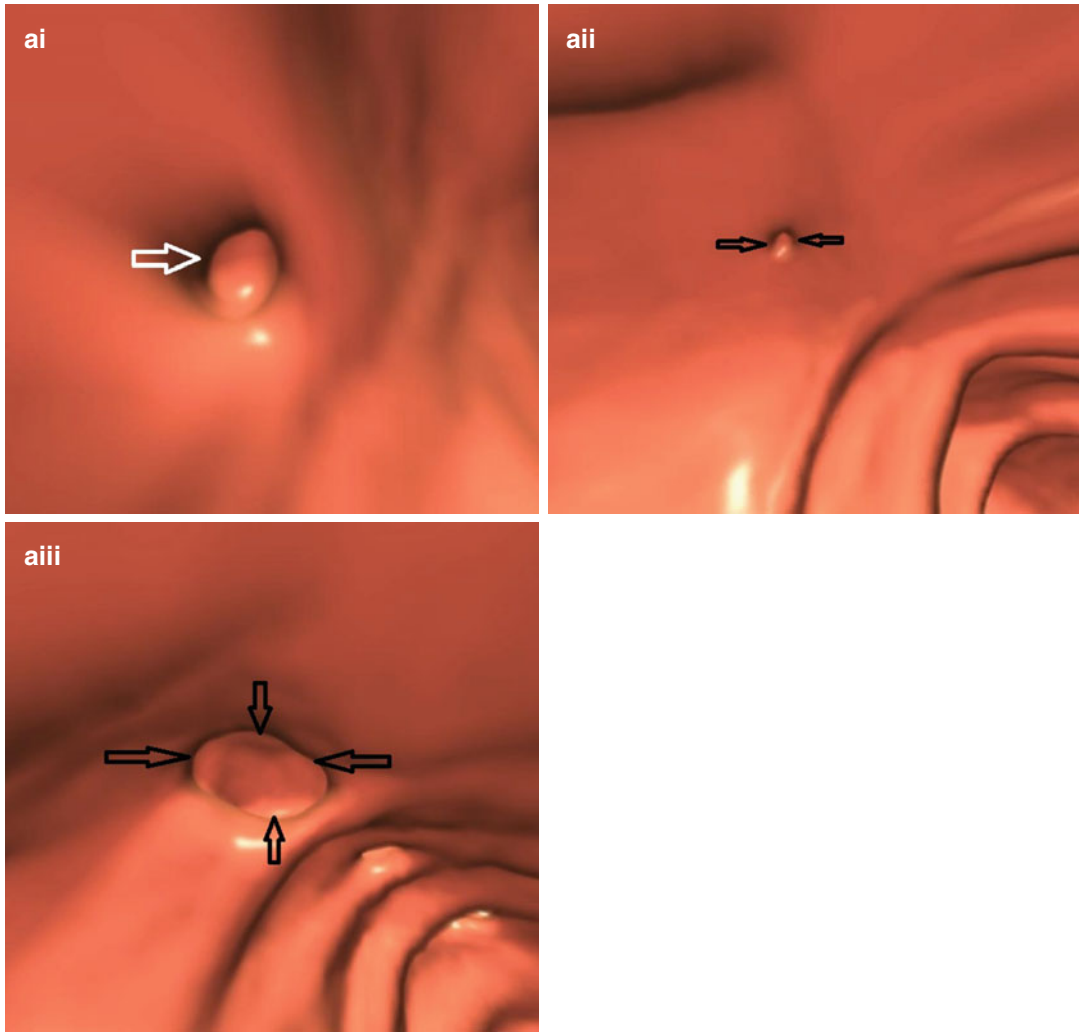

Fig. 16.3 (**a**) (**i**) 3D view shows orifice of diverticulum as a black ring (*open white arrow*). (**a**) (**ii**) 3D view of a narrow neck diverticulum (*open black arrows*). (**a**) (**iii**) 3D view of a wide neck diverticulum (*open black arrows*)

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 [11]; 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 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 distension.

16.8 Inadequate Luminal Distension

A fairly recent publication by Nagata et al. [12] compared the effects of automated CO_2 insufflation, with and without the administration of intravenous (i.v.) 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 the 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 diverticular disease. If adequate distension is not achieved with the use of a 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.

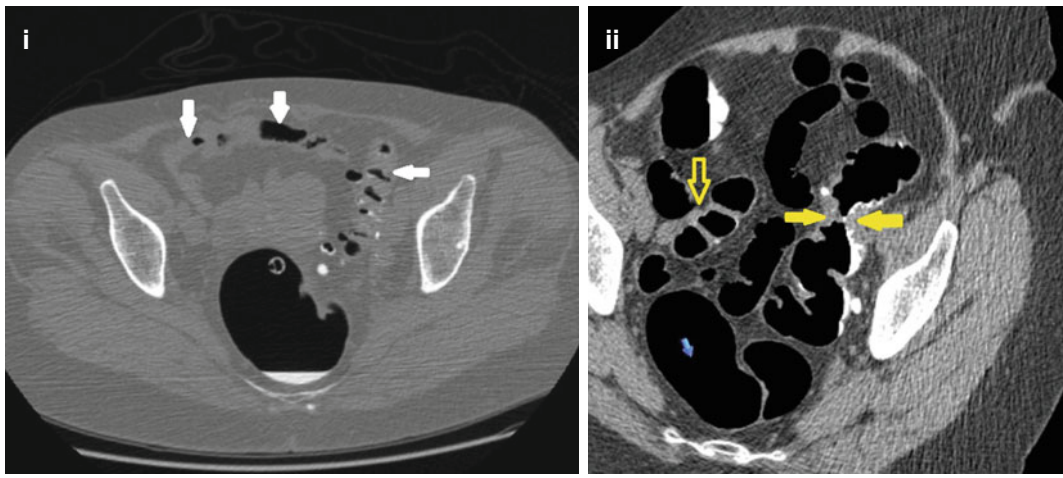

Fig. 16.4 (**i**) 2D axial view shows poor distension of sigmoid colon (white arrows). (**ii**) 2D *left* lateral decubitus view shows stricture (*closed yellow arrows*) and thick colon wall (*open yellow arrow*)

16.8.1 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 [11]. 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 [11].

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.

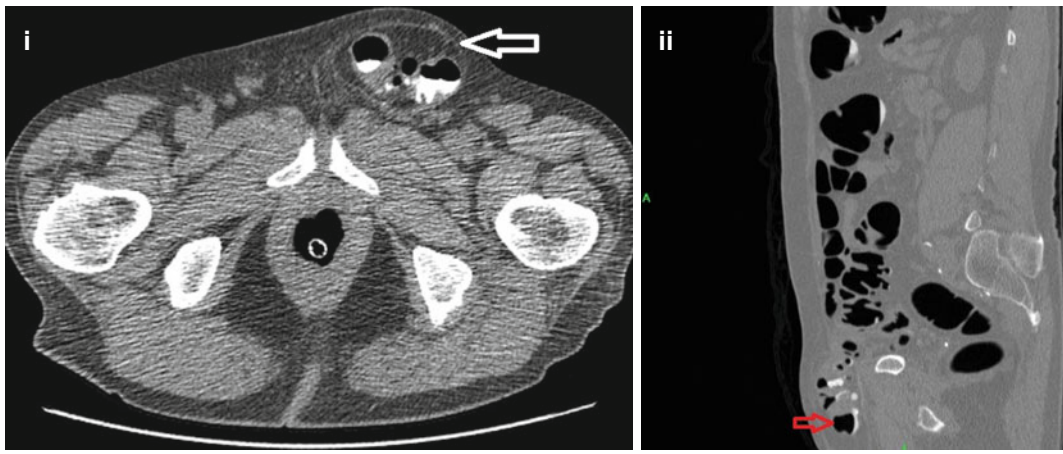

Fig. 16.5 (**i**) 2D axial view of *left* inguinal hernia containing sigmoid colon (*open white arrow*). (**ii**) 2D sagittal view shows *left* inguinal hernia of sigmoid colon (*red arrow*)

16.9 Complications of Diverticular Disease

The most usual complication of diverticular disease is diverticulitis. It affects between 10 and 25 % of patients [13]. How does this inflammation begin? It is similar to that of appendiceal inflammation. A diverticulum becomes obstructed in its neck by inspissated stool [14]. The faecalith (the hard mass inspissated stool) abrades the mucosa of the sac, resulting in:

(i) Inflammation of the mucosa
(ii) Increase in bacterial flora
(iii) 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) is 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 [5].

16.9.1 Clinical Features of Diverticulitis

Diverticulitis most commonly occurs in the sigmoid colon. Therefore 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 suprapubic or even right sided. Lower right-sided pain, particularly in the Asian population, may be due to right-sided diverticula [15]. 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.

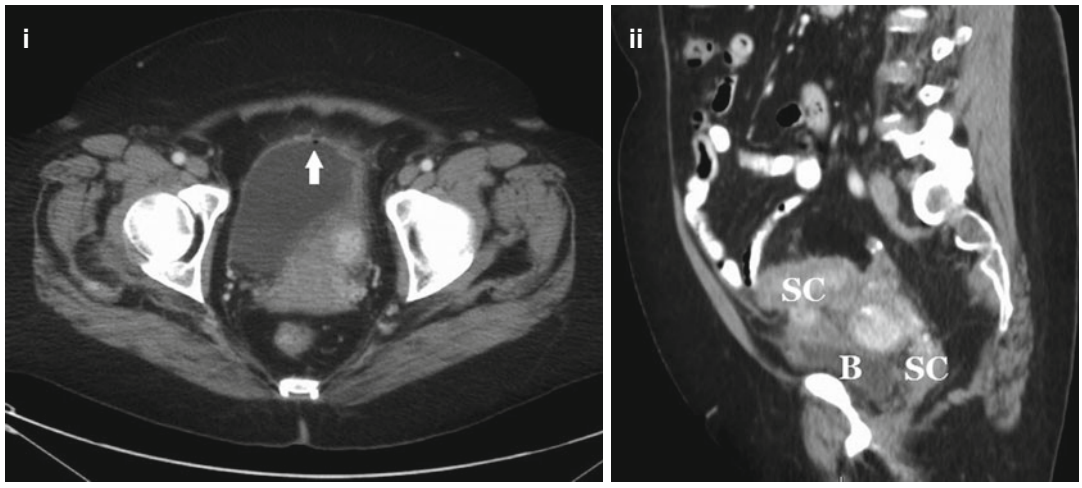

Fig. 16.6 (**i**) 2D soft tissue axial view shows small amount of air in bladder (*white arrow*) due to colo-vesical fistula (Image courtesy of Professor D Kim, University of Wisconsin). (**ii**) 2D sagittal view shows contrast in sigmoid colon (*SC*) in close apposition to bladder (*B*) (Image courtesy of Professor D Kim, University of Wisconsin)

16.10 Diagnostic Modalities for Acute Diverticulitis

The choice of diagnostic modalities changed significantly over the last 25 years [5]. 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 [5]. The imaging modality of choice is a CT scan of the abdomen with or without the use of an i.v. contrast medium, as well as oral and rectal contrast media [5]. CT interpretation has a sensitivity of 99 %, a specificity of 99 %, a negative predictive value (NPN) of 99 % and an overall accuracy of 99 % [16].

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

Figure 16.7 (i and ii) shows CT images of acute diverticulitis showing thick fascia lines and thickening of the bowel wall.

16.10.1 Contrast Enemas

Barium enema was once the diagnostic gold standard in the investigation of suspected diverticulitis [5]. However, contrast-enhanced CT scanning is now the gold standard, with both CTC and optical colonoscopy 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. Positive findings of diverticulitis would include:

- 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 [17].

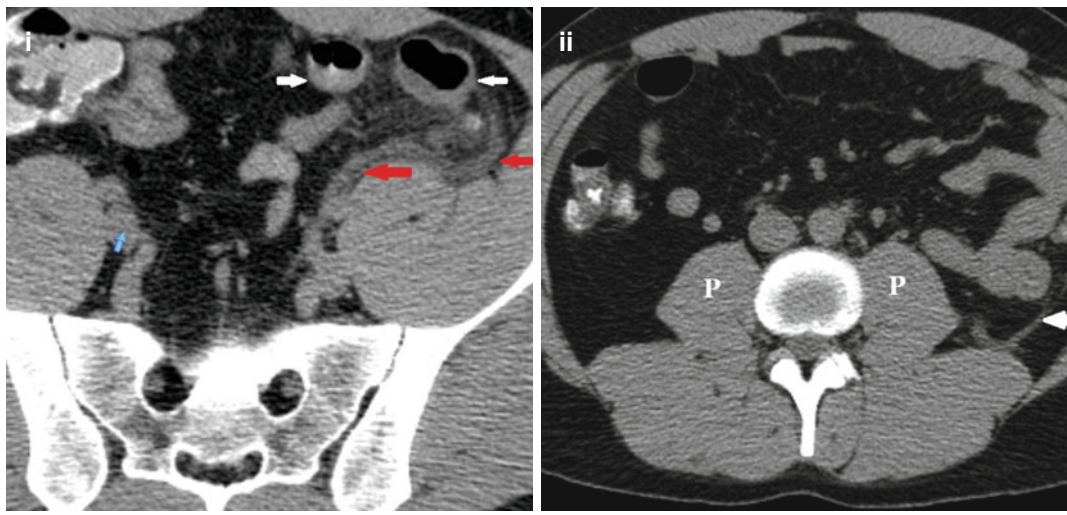

Fig. 16.7 (**i**) 2D axial view showing thick wall (*white arrows*) and thick fascia line (*red arrows*). (**ii**) 2D axial view showing thick fascia line (*white arrow*). Psoas muscle (*P*)

16.10.2 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. Diverticular disease is responsible for 40 % of lower GIT bleeding [18].
- Obstruction can occur. Partial obstruction is not uncommon because of luminal narrowing 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.

16.11 Differentiation of Chronic Diverticular Disease from an Underlying Tumour

Chronic diverticular disease may cause a diagnostic dilemma in distinguishing between an underlying carcinoma versus a chronic diverticular disease mass. What are the distinguishing features at CTC between chronic diverticular disease and tumour? Two recent publications [19, 20] provide criteria to enable a CTC reader to differentiate between chronic diverticular disease and an underlying carcinoma. A summary of the main distinguishing features are presented in Table 16.1 However, we must bear in mind that problem cases will still present at CTC, and optical colonoscopy with biopsy then becomes mandatory.

Table 16.1 Differential diagnosis: chronic diverticulitis versus 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 facia sign (77 %)	Thick facia sign (10 %)
Preserved folds (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 [19, 20]

In brief the features are:

- A thick facia sign is a good discriminator as this is evident in 77 % of patients with chronic diverticular disease, 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 diverticular disease.
- Bowel wall thickening is more pronounced in patients with tumours >20 mm.
- Tapered margins are found in 67 % of chronic diverticular disease 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. 16.8 (i and ii).

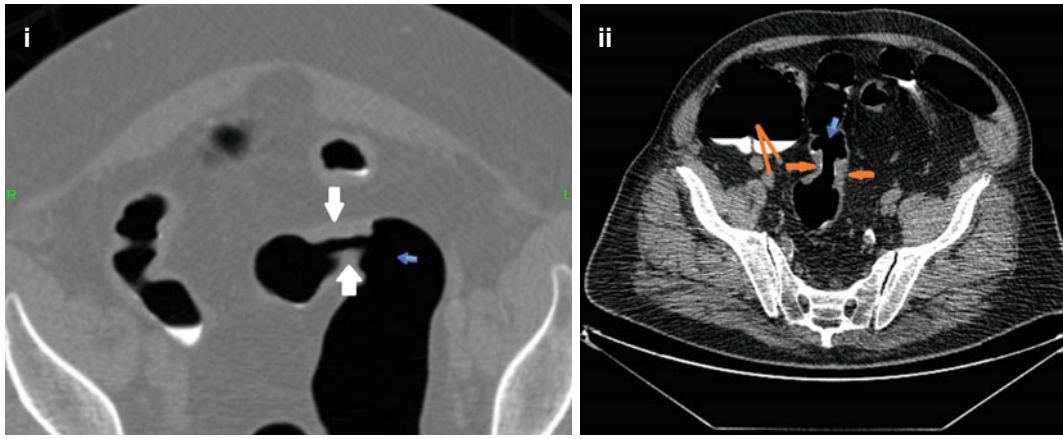

Fig. 16.8 (**i**) 2D axial view shows features of adenocarcinoma. Diverticula not present. Lesion with shoulder phenomenon involves a short segment of bowel (*white arrows*). (**ii**) 2D axial shows small nodes (*orange lines*) and a lesion with shoulder phenomenon in the sigmoid colon (*orange arrows*)

16.12 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 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.

Acknowledgements Professor David Kim from University of Wisconsin is thanked for the colo-vesical CTC images.

References

1. Comparato G, Pilotto A, Franzē A, et al. 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(3):241–52.
3. Jun S, Stollmann N. Epidemiology of diverticular disease. Best Pract Res Clin Gastroenterol. 2002;16:529–42.
4. Morson BC. Pathology in diverticular disease of the colon. Clin Gastroenterol. 1975;4:37–52.
5. Stollman N, Raskin JB. Diverticular disease of the colon. Lancet. 2004;363(9409):631–9.
6. Deckman RC, Cheskin LJ. Diverticular disease in the elderly. J Am Geriatr Soc. 1993;41(9):986–93.
7. Sandford MF, Pickhardt PJ. Diagnostic performance of primary 3-dimensional computed tomography colonography in the setting of colonic diverticular disease. Clin Gastroenterol Hepatol. 2006;4(8):1031–47.
8. Pickhardt PJ, Kim DH. CT colonography: principles and practice of virtual colonoscopy. Philadelphia: Saunders; 2009. p. 272.
9. Yee J. Virtual colonoscopy. Philadelphia: Lippincott, Williams & Wilkins; 2008. p. 138.
10. Macari M, Bini E, Jacobs SL, et al. Filling defects at CT colonography: pseudo and diminutive lesions (the good), polyps (the bad), flat lesions, masses and carcinoma (the ugly). Radiographics. 2003;23(5):1073–91.
11. Bortz JH. An approach for performing a successful computed tomography colonography examination. S Afr J Rad. 2014;18(1); Art. #607, 11 pages. http://dx.doi/org/10.4102/sajrv18i1.607. SAJR 2014
12. Nagata K, Fujiwara M, Shimamoto T, et al. Colonic distension at CT colonography: randomised evaluation of both iv hyoscine butylbromide and automated carbon dioxide insufflation. AJR Am J Roentgenol. 2015;204(1):76–82. http://dx.doi.org/10.2214/AJR.14.12772.
13. Parks TG. Natural history of diverticular disease of the colon. Clin Gastroenterol. 1975;4(1):53–69.
14. Berman LG, Burdick D, Heitzman ER, et al. A critical reappraisal of sigmoid diverticular. Surg Gynecol Obstet. 1965;127:481–91.
15. Markham NI, Li AK. Diverticulitis of the right colon – experience from Hong Kong. Gut. 1992;33(4):547–9.
16. Kircher MF, Rhea JT, Kihiczak D, et al. Frequency, sensitivity, and specificity of individual signs of diverticulitis on thin-section helical CT with colonic contrast material: experience with 312 cases. AJR Am J Roentgenol. 2002;178(6):1313–8.
17. Doringer E. Computerised tomography of colonic diverticulitis. Crit Rev Diagn Imaging. 1992;33:421–35.
18. Perua DA, Lanza FL, Gostout CJ, et al. The American College of Gastroenterology Bleeding Registry: preliminary findings. Am J Gastroenteraol. 1997;92:924–8.
19. 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. http://dx.doi.org/10.1148/radiol.14132829.
20. Gryspeerdt S, Lefere P. Chronic diverticulitis vs. colorectal cancer: findings on CT colonography. Abdom Imaging. 2012;37:1101–9. http://dx.doi.org/10.1007/s00261-012-9858-6.

Lipomas of the Colon

17

Joel H. Bortz

Abstract

Lipomas involving the intestinal tract are rare in clinical practice, but their incidence is the highest in the colon. There are complications associated with lipomas when they reach a certain size, usually greater than 30 millimetres (mm). Colonic lipoma symptoms, morphology, sites and salient points are discussed. CTC images of lipomas are presented.

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].

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Before the advent of CT studies, barium examinations played a major role in the investigation of suspected lipomas in the gastrointestinal tract (GIT) [4]. The upper GIT and small bowel were visualised by barium meal studies; the lower GIT was visualised on barium enema studies. Endoscopy gradually replaced barium enema as the method of choice following the advent of the colonoscope in the mid-1970s [5, 6]. However, 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 noninvasive; and 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

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intussusception or perforation. The latter is a complication of lipoma removal during endoscopy, and small amounts of intraperitoneal air can be readily observed on the CT scans [8]. 3D and 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].

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. Lipomas occur particularly in the sixth decade (50–59 years of age) [11]. There are no associated epidemiological factors for lipomas in the colon nor are there specific predisposing factors. According to Vagholkar and Bendre [12], lipoma incidence has been reported between 0.2 and 4.4 %.

17.4 Anatomical Sites and Morphology of Lipomas

Lipomas have a predilection for the right colon, especially the caecum and ascending colon, followed by the sigmoid and descending colon. The transverse colon is the least common site for lipoma [11]. In 90 % of cases, lipomas arise from the submucosal layer [1]; the remainder arise from the intermuscular layer and subserosal layer [11]. Lipomas may be sessile or pedunculated [13]. 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) [13]. 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.

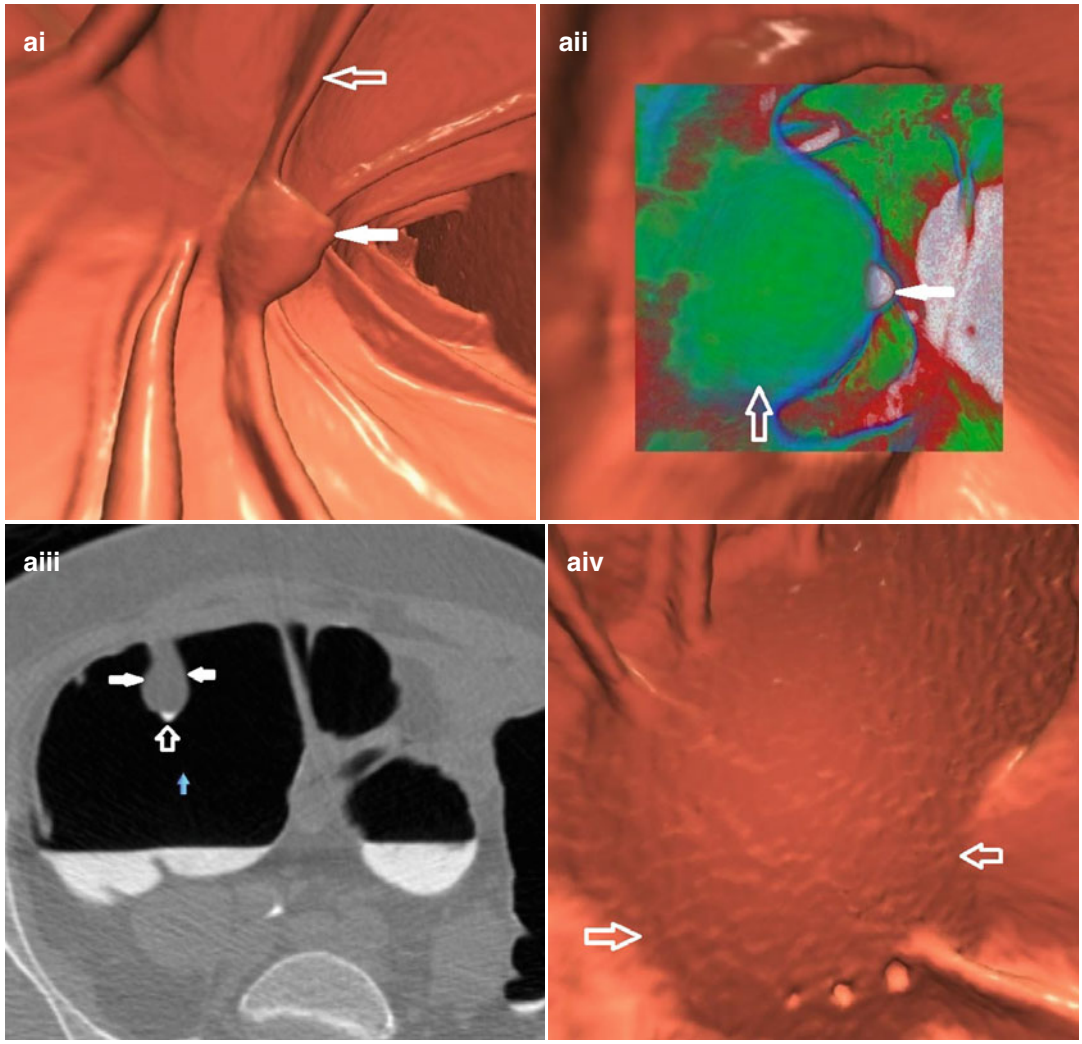

Fig. 17.1 (**a**) (**i**) 3D endoluminal view showing polypoidal lesion (*closed white arrow*) arising from haustral fold (*open white arrow*). (**a**) (**ii**) 3D translucent display of lipoma. Green = fat (*open white arrow*) and barium on tip (*closed white arrow*). (**a**) (**iii**) Axial 2D soft tissue window view showing tip of barium (*open white arrow*) on lipoma (*closed white arrow*). (**a**) (**iv**) 3D prone image shows barium covering lipoma (*open white arrows*)

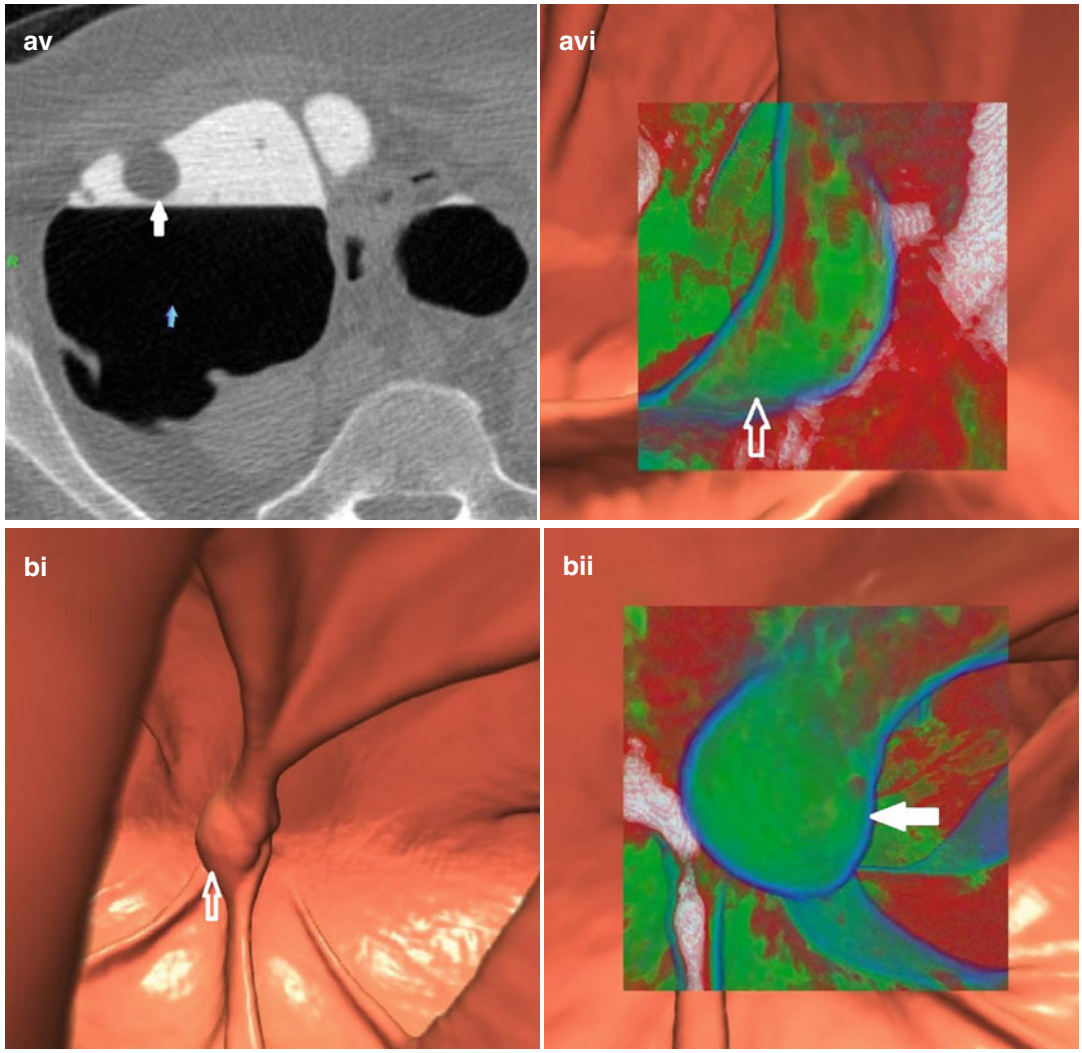

Fig. 17.1 (**a**) (**v**) Prone 2D axial soft tissue window view showing filling defect lipoma (*closed white arrow*) in barium pool. (**a**) (**vi**) Translucent display showing diffuse infiltration of ICV (*open white arrow*) indicating caecal lipomatosis with minimal high tissue intensity (*red*). (**b**) (**i**) 3D view shows a lipoma on ICV (*open white arrow*). (**b**) (**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.

(i) The 'tenting' sign means gripping the mucosa with forceps and 'pulling' or 'tenting' it away from the underlying mass [4].
(ii) 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 [14].
(iii) 'Naked fat sign' means the adipose tissue may protrude through the biopsy site which reveals the fatty characteristic of the tumour [15].

17.6 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 mm 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.

17.7 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 then 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 2015 June 10]. Available from: www.wignet.com.
3. Agrawal A, Singh KJ. Symptomatic intestinal lipomas: our experience. MJAFI. 2011;67(4):374–6. doi:http://dx.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. Br J Radiol. 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. Int J Gastroenterol. 2008;8(1). [Cited 2015 May 31]. Available from: 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. http://dx.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://dx.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 Republic Iran. 2006;20(3):151–4.
11. Nallamothu G, Adler DG. Large colonic lipomas. Gastroenterol Hepatol. 2011;7(7):490–2.
12. Vagholkar K, Bendre M. Lipomas of the colon: a surgical challenge. Int J Clin Med. 2014;5:309–13. http://dx.doi.org/10.4236/ijcm.2014.56046.
13. Jiang L, Jiang L, Li F, et al. Giant submucosal lipoma located in the descending colon: a case report and review of the literature. World J Gastroenterol. 2007;13(42):5664–7. [Cited 2015 June 2]. Available from: www.wjgnet.com.
14. 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.
15. Notaro JR, Masser PA. Annular colon lipoma: a case report and review of the literature. Surgery. 1991;110(3):570–2.

Extracolonic Findings

18

Joel H. Bortz

Abstract

CTC is generally performed in patients 50 years or older. Intra-abdominal and pelvic organs are visualised at CTC, and extracolonic lesions may be identified. The majority of these lesions are not considered to be of clinical importance. However, the potential benefit of detecting an extracolonic lesion of high clinical importance means earlier detection and subsequent intervention. The additional cost of evaluation of follow-up studies of extracolonic lesions is relatively low. A classification system is used when reporting extracolonic findings (ECFs). It is essential to report ECFs even if a CTC study is considered to be of a non-diagnostic quality. Examples of extracolonic images are presented in terms of their clinical importance classification.

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.

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CTC is an acknowledged method of investigation of asymptomatic individuals for colorectal cancer (CRC) who are 50 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 reported that approximately 20 % of indeterminate renal masses detected with CTC were ultimately malignant [6].

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Since the extracolonic abdomen and pelvis are screened with a low-dose technique without the use of an intravenous (i.v.) 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 presymptomatic 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 % (2/1000); and the prevalence of ECFs was 0.35 %. A disclaimer should be in CTC reports, namely, that the lack of i.v. contrast material and low-dose technique limit the evaluation of CT findings outside the colon.

The costs of investigating ECFs have been debated for many years. Concern has been expressed that if multiple benign ECFs are investigated, then costs will be driven-up significantly without influencing the final outcome. 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 [10] resulted in the following information: (1) out of the 41 % of the patients with ECFs, 115 were considered significant findings, and (2) the additional cost of the workup of the ECFs was $28 per CTC examination. ECFs were identified in 69 % of patients in a study of 681 asymptomatic patients, and 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 i.v. 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 i.v. 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 i.v. contrast medium is not routinely used in CTC screening for several reasons, namely:

(i) It does not increase polyp detection.
(ii) It adds to the cost of the examination.
(iii) It extends the time of examination.
(iv) 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, i.v. 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]. To put it differently, 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, while a small percentage (7–11 %) of patients undergo further testing

because of the initial ECF [5, 12, 13]. In a 2010 study of 2277 patients undergoing CTC screening, an almost equal number of extracolonic cancers as intracolonic cancers were identified [14]. Extracolonic detections increased with age, and Macari et al. reported 74 % of patients >65 years had extracolonic abnormalities compared with 55.4 % in younger patients [15]. In a UK study, 67 % of older symptomatic patients had extracolonic abnormalities [16].

18.2 Benefits of Visualising Extracolonic Organs and Tissues at CTC

In approximately 10 % of cases, significant pathology may be identified, such as early cancers of the kidney and ovary, as well as abdominal or pelvic lymphadenopathy in underlying lymphoma. Abdominal aortic aneurysms >50 mm in transverse diameter may be detected incidentally [11, 14]. Visualisation of such pathology is not possible with the 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 diagnoses 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, respectively. 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 infrarenal 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 workup
- Significant importance (= medically important)

The ECFs may be either clinically insignificant or significant, depending on whether additional workup 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. Table 18.1 lists examples of ECFs for each level of clinical importance.

Table 18.1 E classification

E1	*Not of clinical importance* Normal examination or anatomic variant	No extracolonic abnormalities visible Anatomic variant, e.g. retroaortic left renal vein
E2	*Low clinical importance* Clinically unimportant findings	No workup indicated, e.g. 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
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 workup 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 Fatty liver (non-alcoholic fatty liver disease) Pleural effusions Cardiomegaly Splenomegaly Complicated hiatus hernias
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 aneurysm >50 mm Lung: non-uniformly calcified pulmonary nodule ≥10 mm Irreducible inguinal hernia containing large bowel

Adapted from Zalis et al. [21]
It must be remembered that an extracolonic evaluation is limited by lack of i.v. contrast and the low-dose CT technique.

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, i.e. E2. Only a few are classified as E4, i.e. of significant clinical importance.

18.5.1 E1: Not of Clinical Importance

Figures 18.1a–g are examples of ECFs that are not of clinical importance.

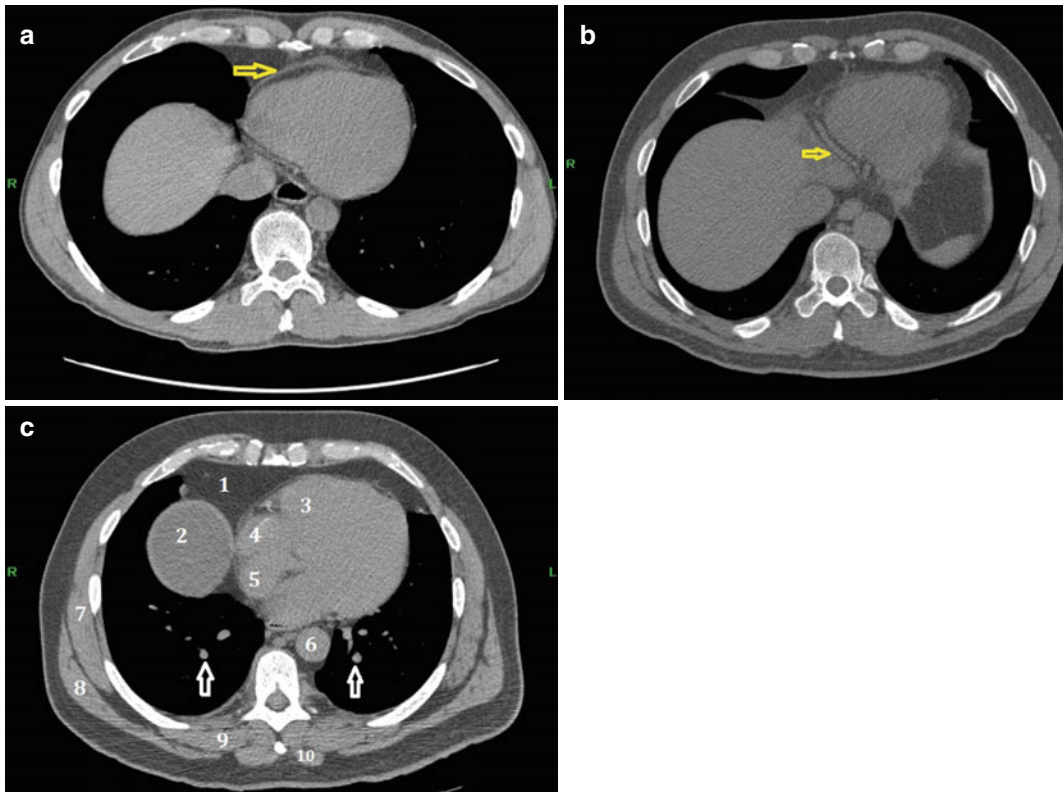

Fig. 18.1 (**a**) 2D axial shows normal pericardium surrounding the heart (*yellow arrow*). (**b**) 2D axial showing normal right posterior descending coronary artery (*yellow arrow*). (**c**) 2D axial view showing pulmonary vessels (*open white arrows*). *1* anterior mediastinal fat, *2* liver, *3* 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

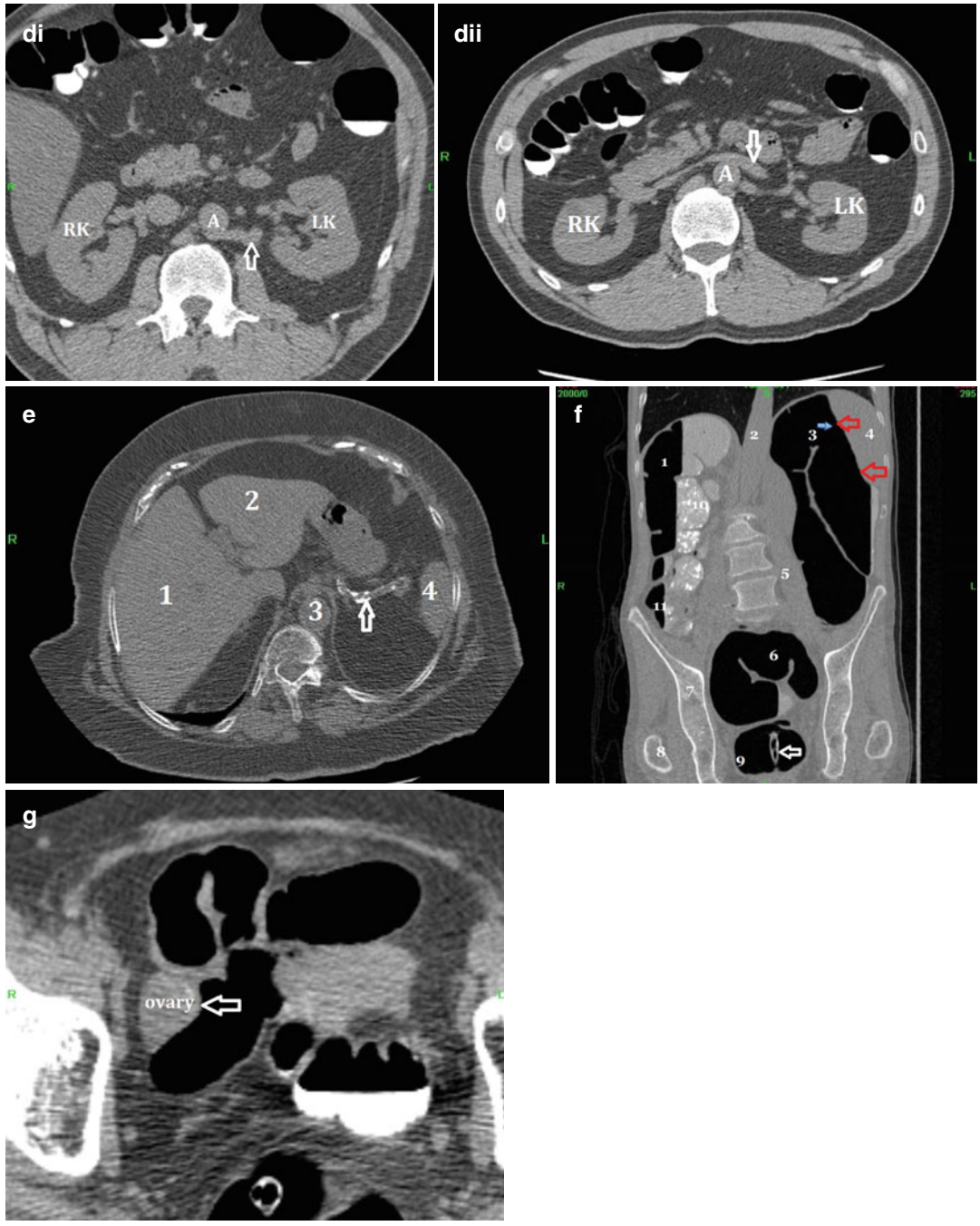

Fig. 18.1 (**d**) (**i**) 2D axial view showing retroaortic left renal vein (*open white arrow*). *LK* left kidney, *RK* right kidney, *A* aorta. (**d**) (**ii**) 2D axial view showing normal renal vein (*open white arrow*). *RK* right kidney, *LK* left kidney, A aorta. (**e**) *1* right lobe of the liver, *2* left lobe of the liver, *3* aorta, *4* spleen, *open white arrow* splenic artery calcification. (**f**) 2D coronal view of the 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

Figures 18.2a–aZ (ii) are examples of ECFs that are of low clinical importance.

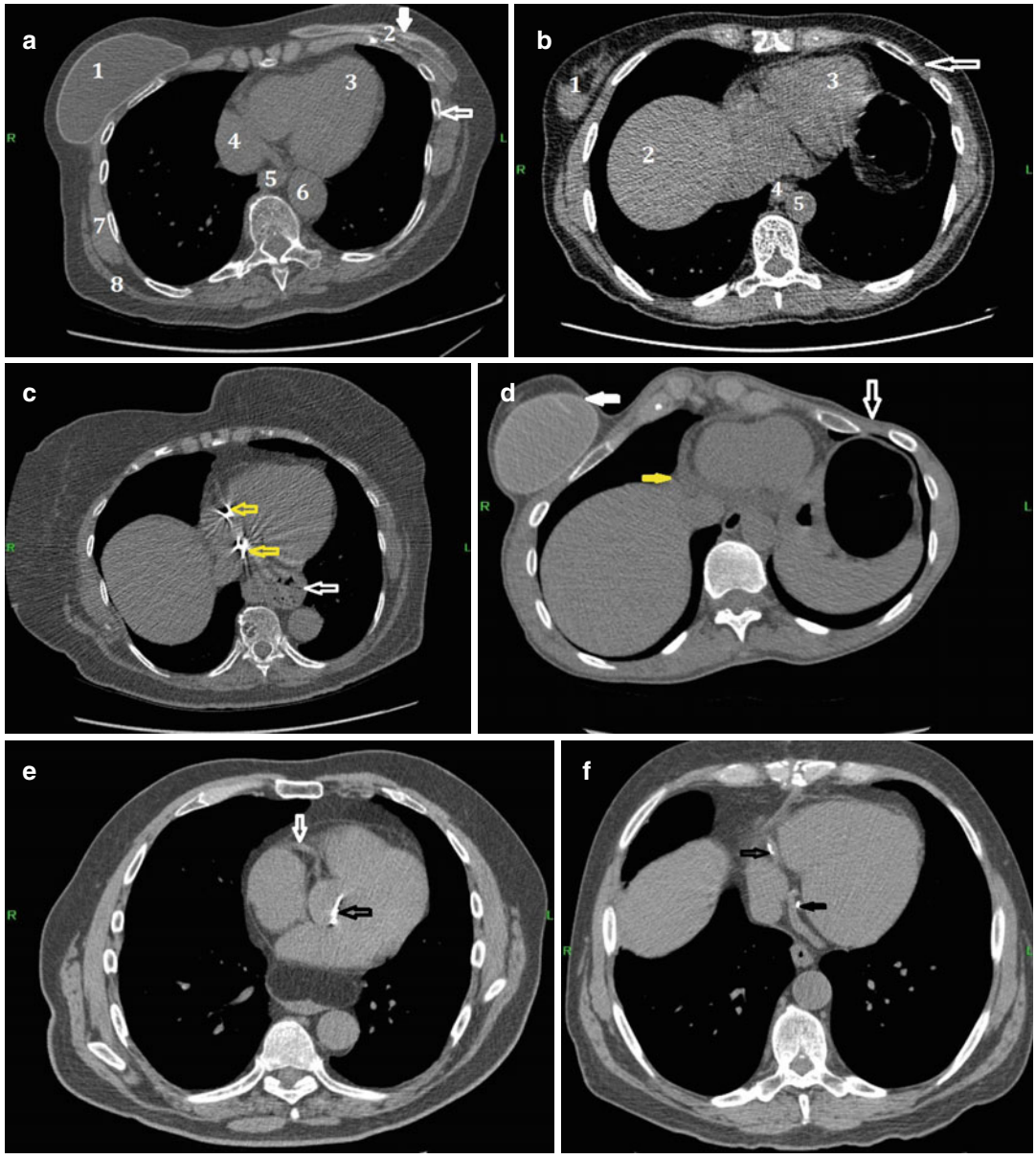

Fig. 18.2 (**a**) 2D axial view. *1* breast implant, *2* collapsed left breast prosthesis (*closed white arrow*), *3* left ventricle, *4* right atrium, *5* distal oesophagus, *6* descending aorta, *7* serratus anterior muscle, *8* latissimus dorsi muscle. Rib *open white arrow*. (**b**) 2D axial view 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 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 the right posterior descending coronary artery (*open black arrow*) as well as mild calcification of the circumflex artery (*closed black arrow*)

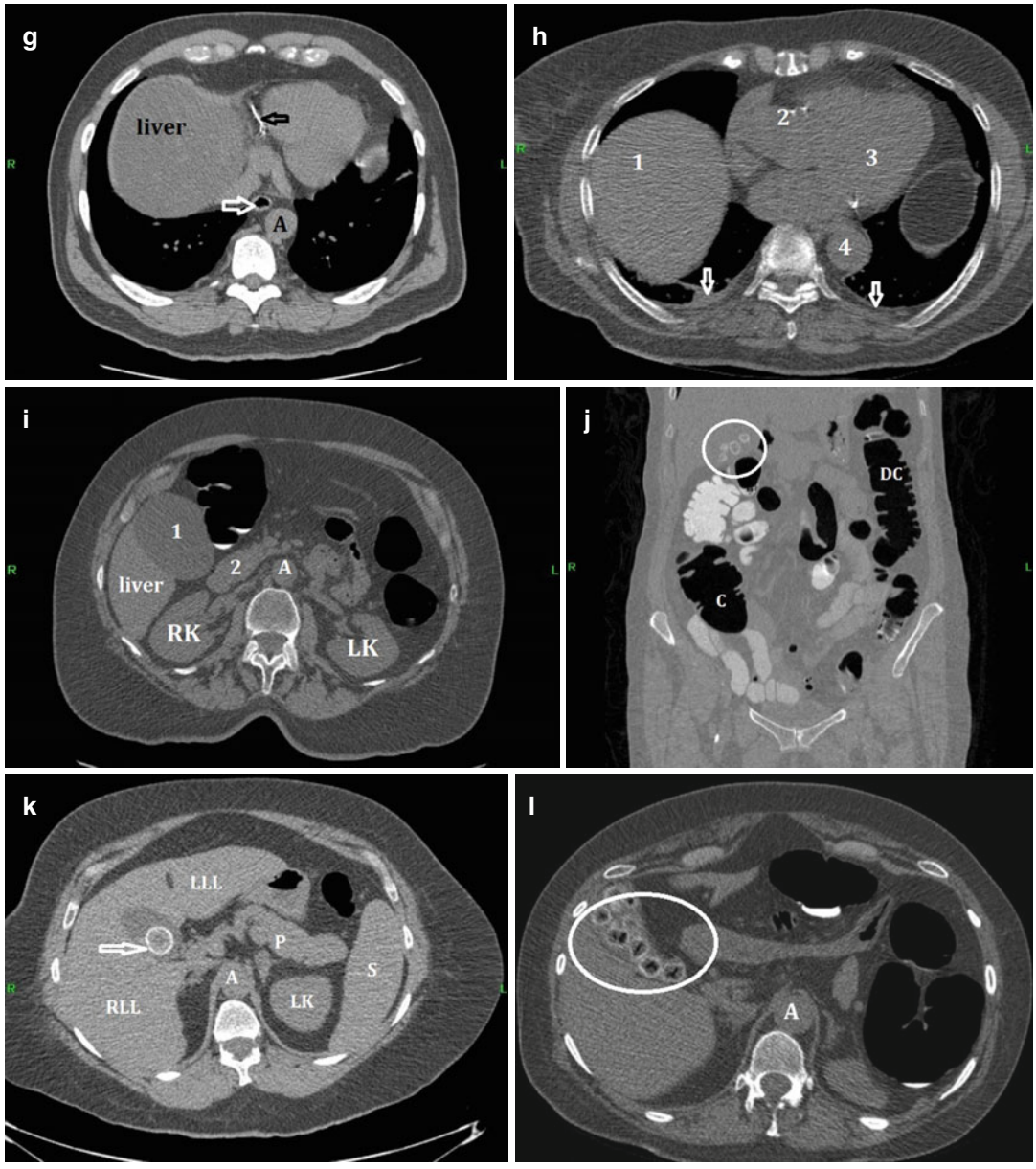

Fig. 18.2 (**g**) 2D axial shows calcification of the right posterior descending coronary artery (*open black arrow*) and fatty liver. *A* aorta. Distal oesophagus (*open white arrow*) (**h**) 2D axial view showing pleural thickening base of lungs (*open white arrows*). *1* liver, *2* right ventricle, *3* left ventricle, *4* aorta. (**i**) *1* Distended gallbladder, *2* duodenum, *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 the liver, *RLL* right lobe of the liver, *P* pancreas, *A* aorta, *LK* left kidney, *S* spleen. (**l**) Multiple gallstones with gas (*circle*). *A* aorta

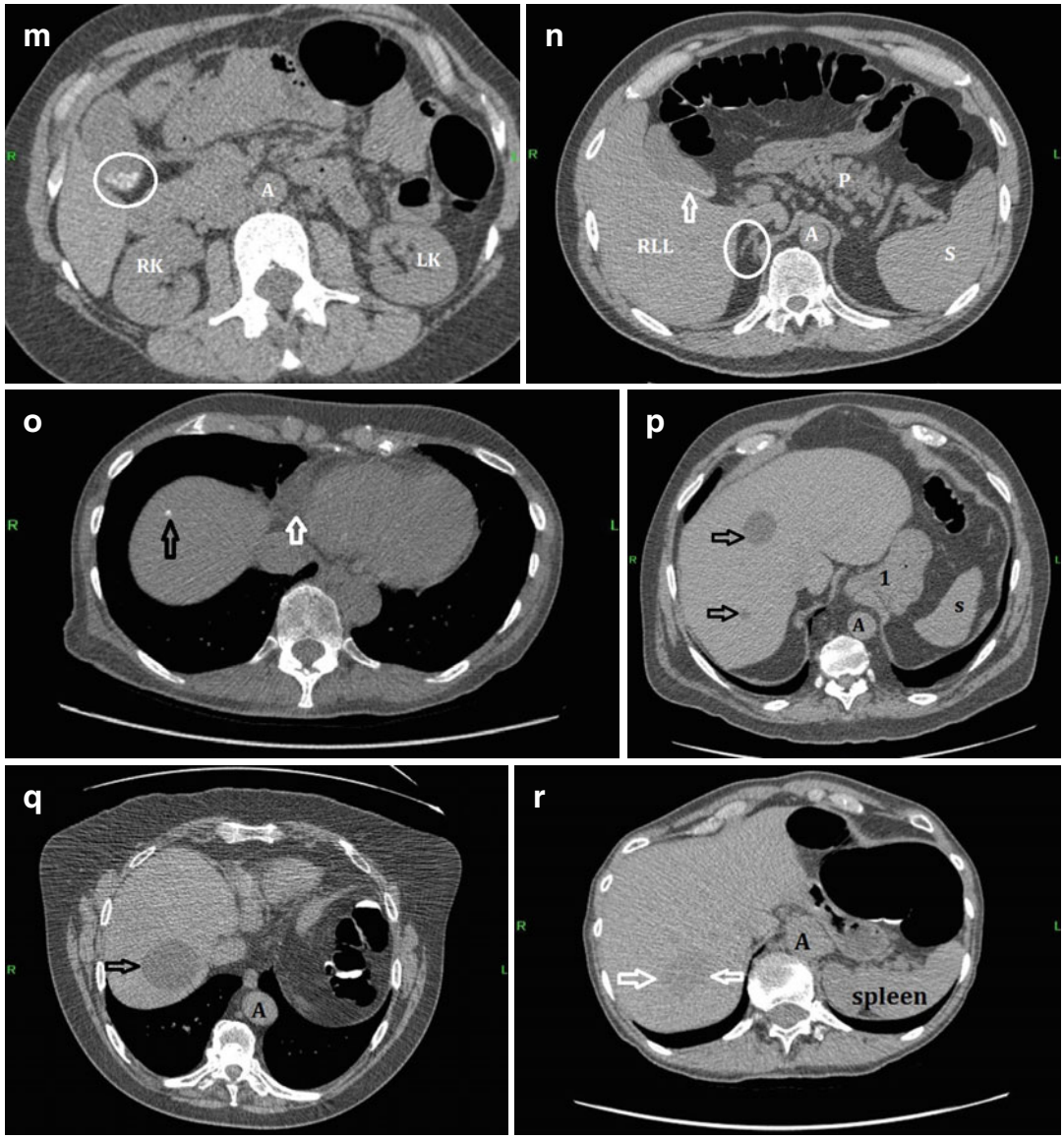

Fig. 18.2 (**m**) Multiple calcified gallstones (*circle*). *RK* right kidney, *LK* left kidney, *A* aorta. (**n**) Milk of calcium bile (*open white arrow*). Right adrenal gland (*circle*). *RLL* right lobe of the liver, *P* pancreas, *A* aorta, *S* spleen. (**o**) Liver granuloma (*open black arrow*). 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

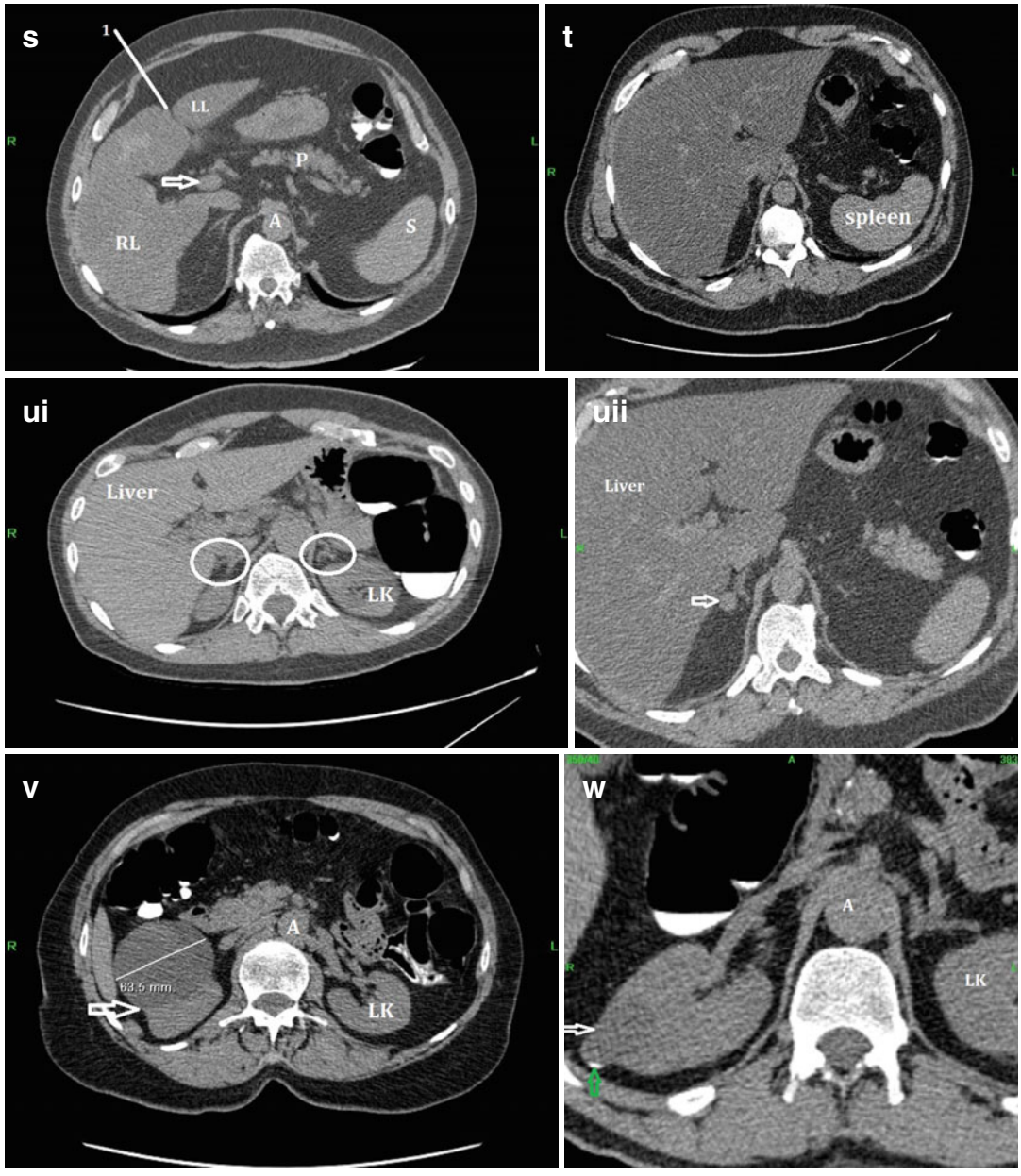

Fig. 18.2 (**s**) Fatty infiltration of the liver. *LL* left lobe of the liver, *RL* right lobe of the liver, *1* fissure for ligament, *P* pancreas, *S* spleen, *A* aorta. Right adrenal gland (*open white arrow*). (**t**) Fatty infiltration of the liver. Note marked decrease in liver density compared with spleen. (**u**) (**i**) Normal adrenal glands E1 (*circles*). *LK* left kidney. Compare the right adrenal with the one in (**u**) (**ii**). (**u**) (**ii**) Nodule on the right adrenal gland (*open white arrow*). Fatty liver. (**v**) 2D axial showing 65mm cyst in the 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

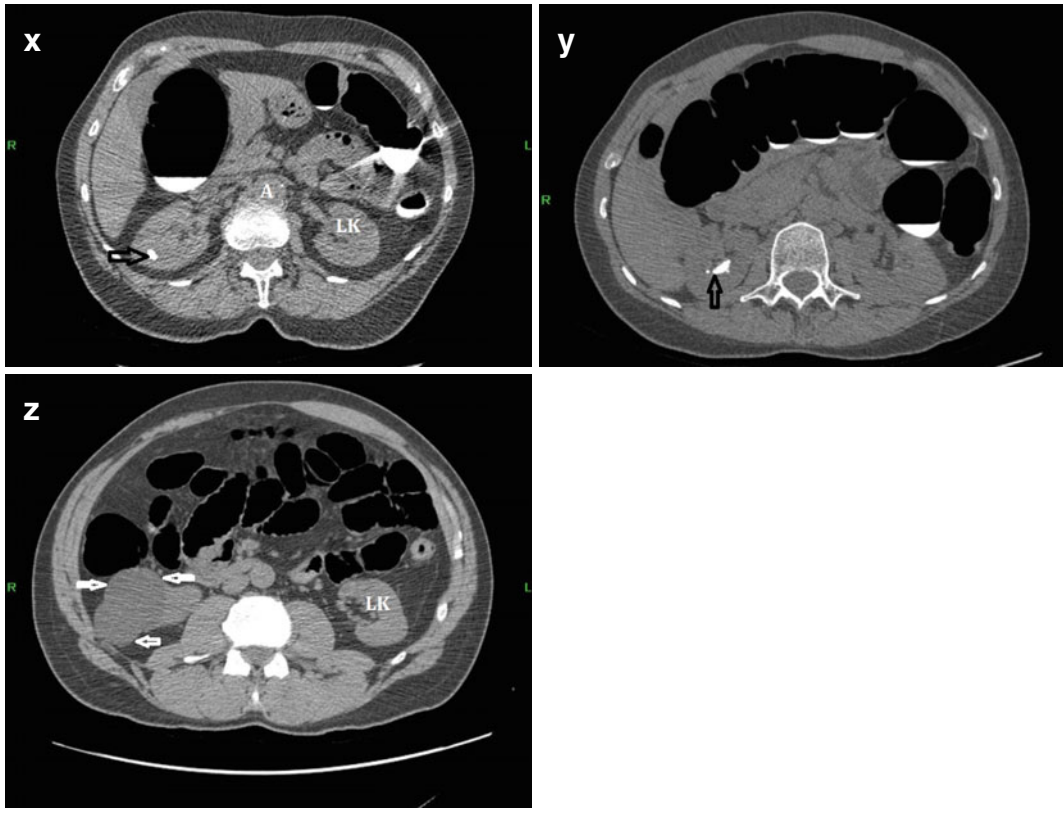

Fig. 18.2 (**x**) Right lower pole renal calculus (6 mm). *A* aorta, *LK* left kidney. (**y**) Large calculus right kidney (*open black arrow*). (**z**) Lobulated cyst right kidney (*open white arrows*). *LK* left kidney

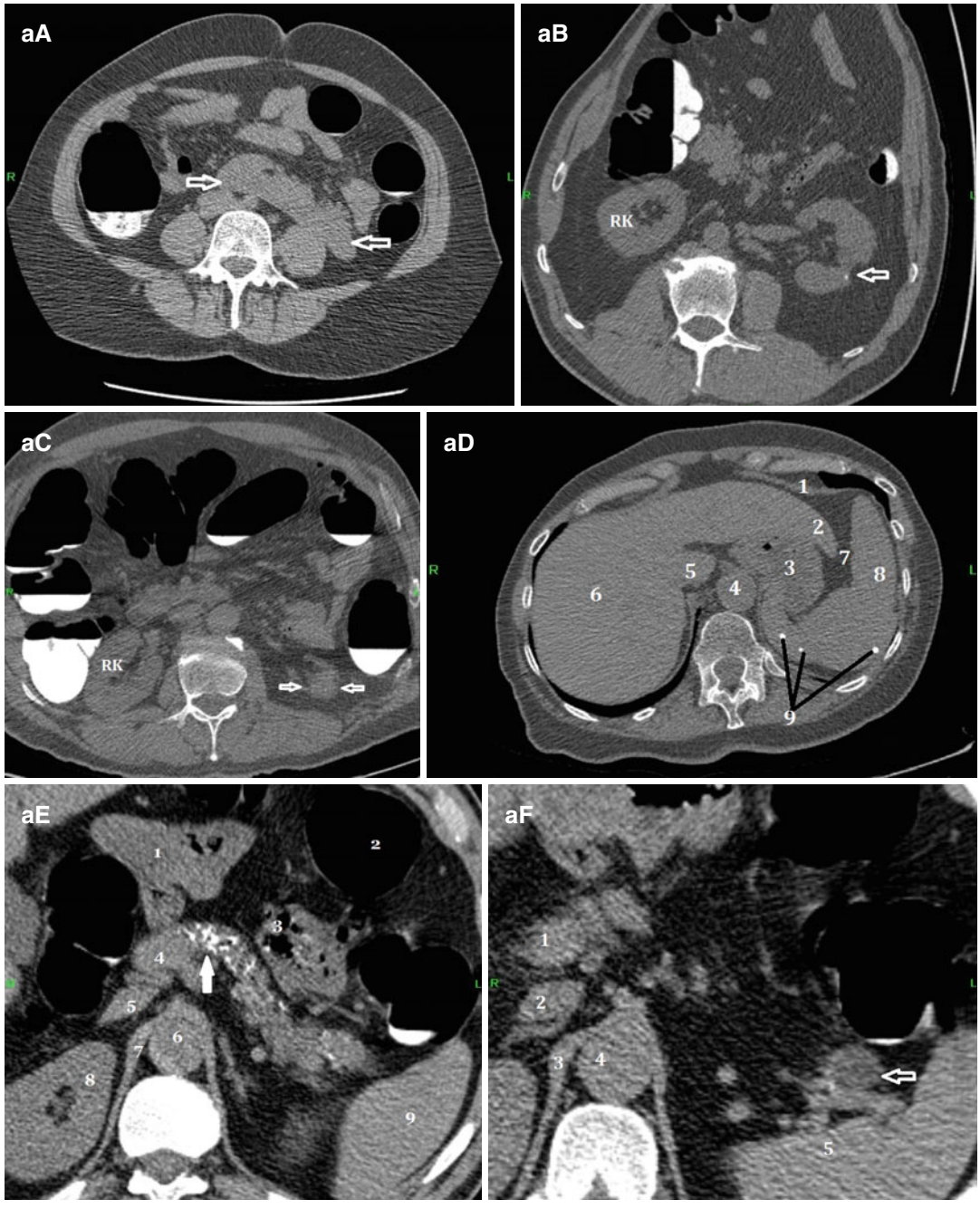

Fig. 18.2 (**aA**) Horseshoe kidney (*open white arrows*). (**aB**) Pyelonephritic scarring left kidney with a small focus of dystrophic calcification (*open white arrow*). *RK* right kidney. (**aC**) Atrophic left kidney (*open white arrows*). *RK* right kidney. (**aD**) 2D axial view. *1* crus of diaphragm, *2* left lobe of the liver, *3* stomach, *4* aorta, *5* caudate lobe of the liver, *6* liver, *7* peritoneal space, *8* spleen, *9* granulomata. (**aE**) 2D axial view showing calcification of the body of the pancreas (*white arrow*) due to previous pancreatitis. *1* small bowel, *2* gas in the large bowel, *3* air in the 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 the tail of the pancreas (*open white arrow*). *1* small bowel, *2* IVC, *3* crus of the right diaphragm, *4* aorta, *5* spleen

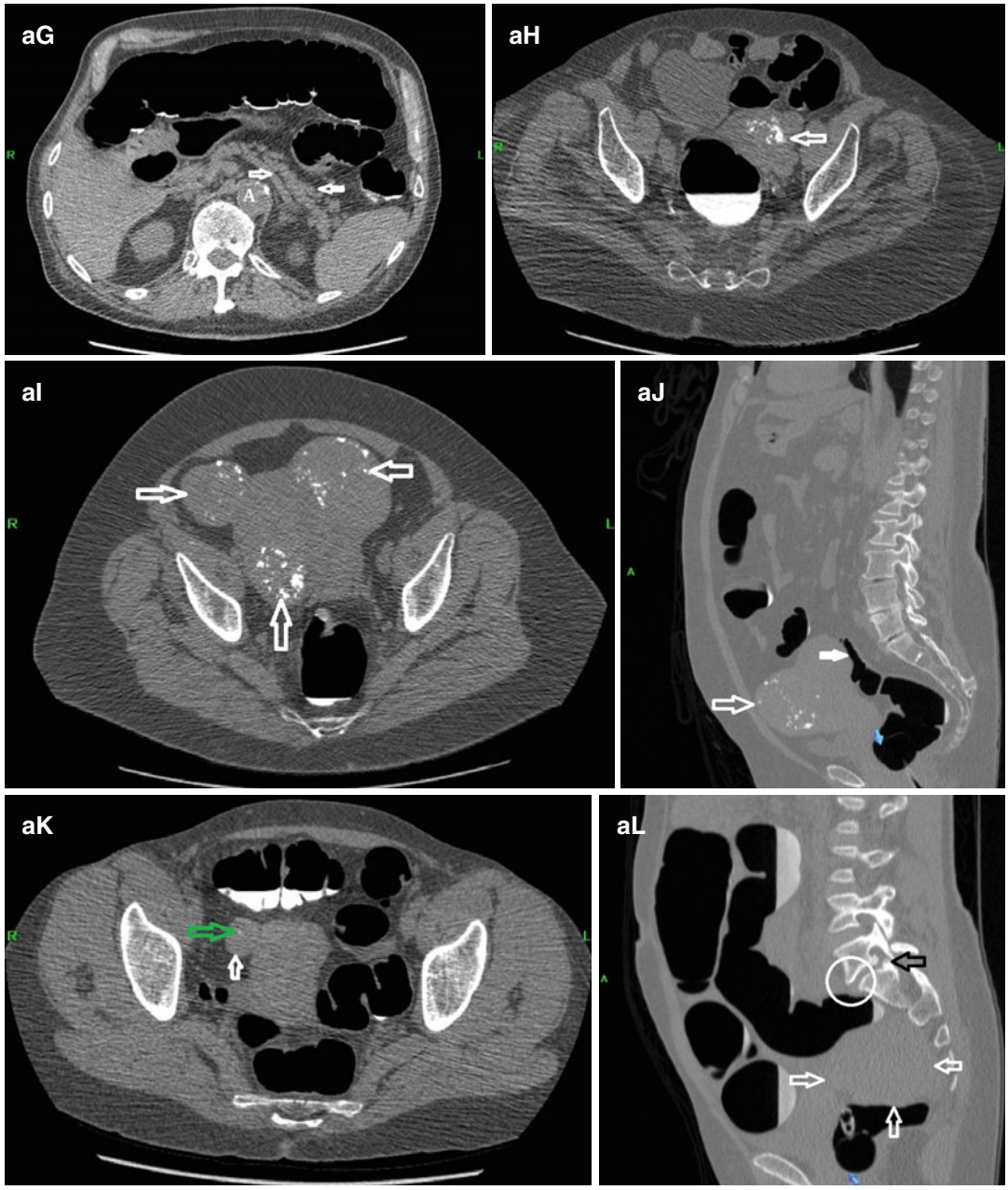

Fig. 18.2 (**aG**) 2 D axial view showing an atrophic pancreas (*open white arrow*). *A* aorta. (**aH**) 2 D axial view shows a calcified fibroid (*open white arrow*). (**aI**) 2D axial view shows three calcified fibroids (*open white arrows*) giving a 'Mickey Mouse' appearance. (**aJ**) 2D sagittal view shows anterior calcified fibroid (*open white arrow*). Non-calcified fibroid 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*)

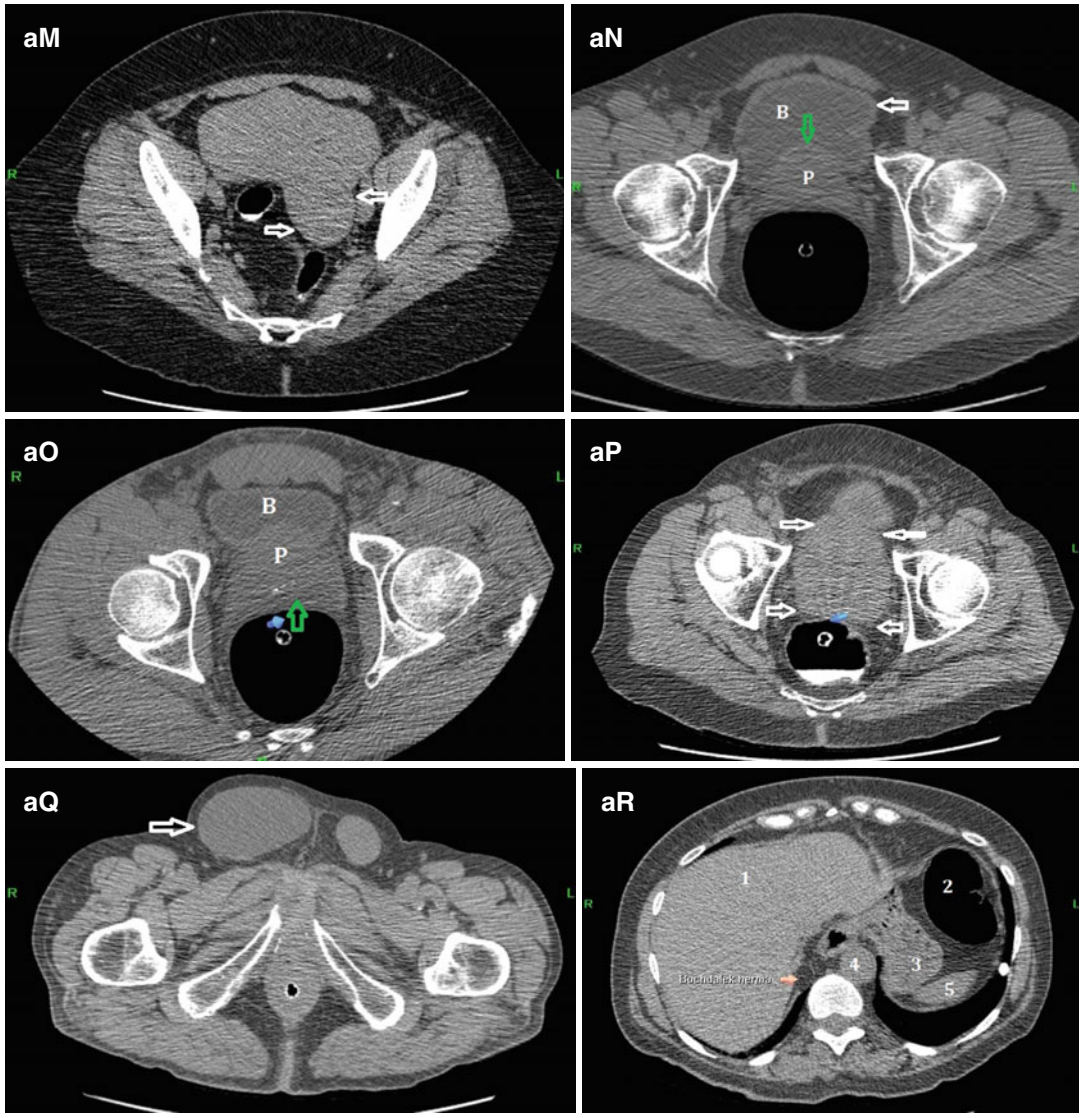

Fig. 18.2 (**aM**) 2D axial shows a prolapsed fibroid (*open white arrows*). (**aN**) *Open green arrow* shows enlarged prostate (*P*) pressing on the bladder (*B*). Note bladder wall thickening (*open white arrow*). (**aO**) Enlarged prostate (*P*) pressing on the base of the bladder (*B*). Mild dystrophic 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

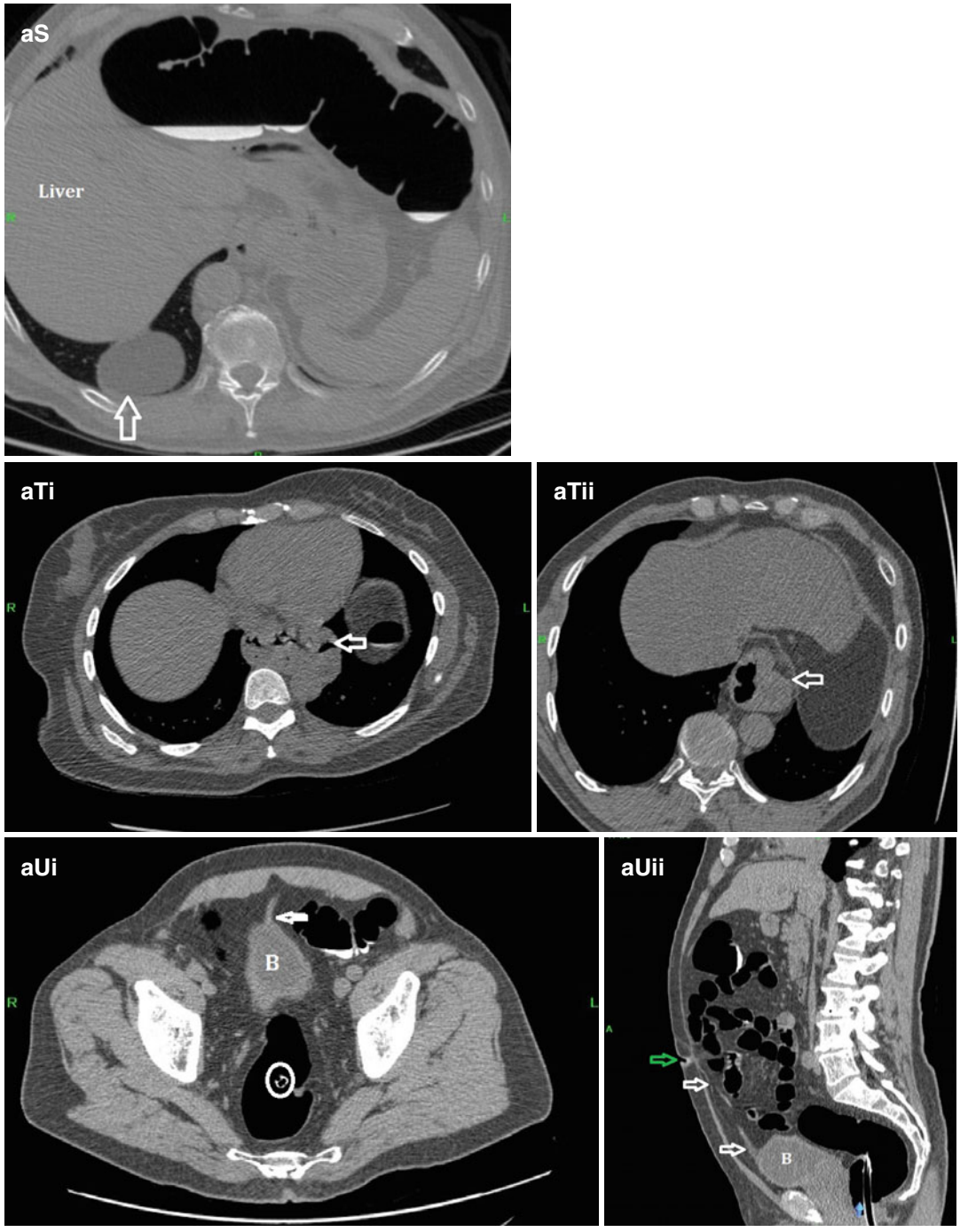

Fig. 18.2 (**aS**) Bochdalek hernia containing fat (*open white arrow*). (**aT**) (**i**) Moderate hiatus hernia (*open white arrow*). (**aT**) (**ii**) Small hiatus hernia (*open white arrow*). (**aU**) (**i**) 2D axial showing urachal remnant (*open white arrow*). *B* bladder. Rectal catheter (*circle*). (**aU**) (**ii**) 2D sagittal showing urachal tract (*open white arrows*) from the bladder (*B*) to the umbilicus (*open green arrow*)

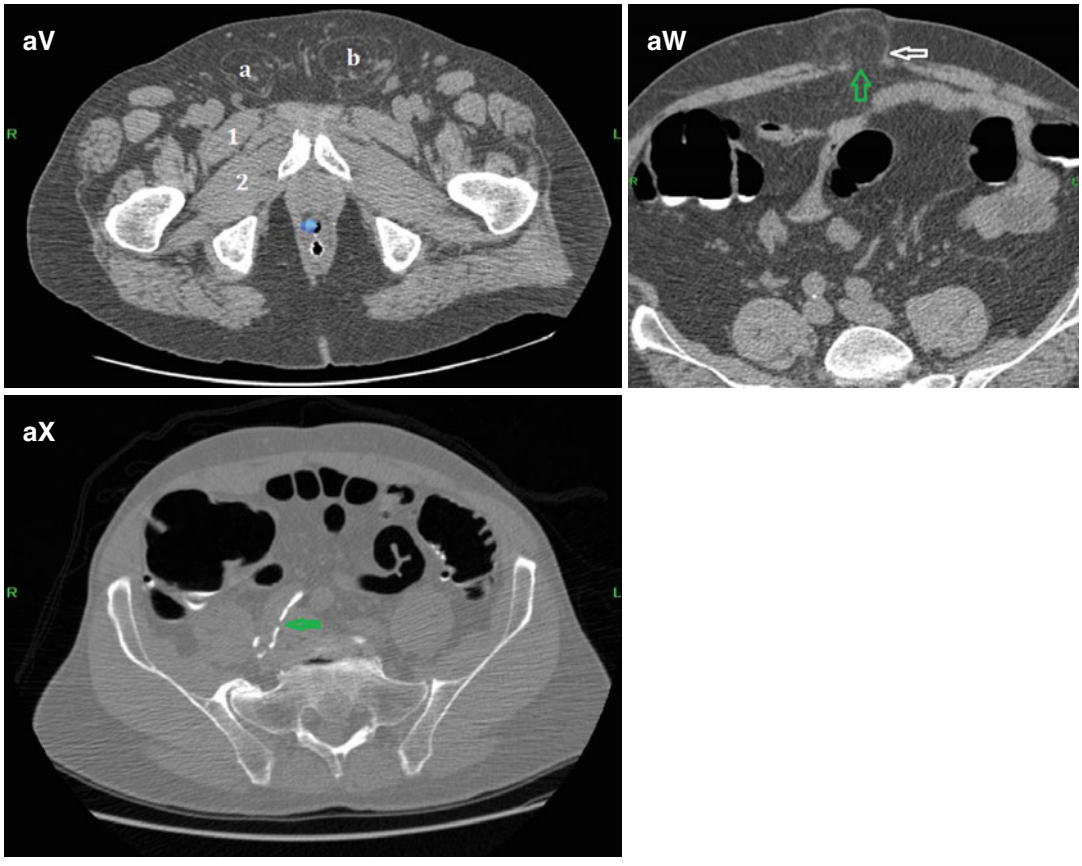

Fig. 18.2 (**aV**) Bilateral small inguinal hernias (*a* and *b*) containing fat, but no loops of bowel. *1* pectineus muscle, *2* obturator externus. (**aW**) Small umbilicus hernia. *Open white arrow* shows margin of the hernia. *Open green arrow* shows defect in musculature. (**aX**) Calcification of the right iliac artery (*open green arrow*)

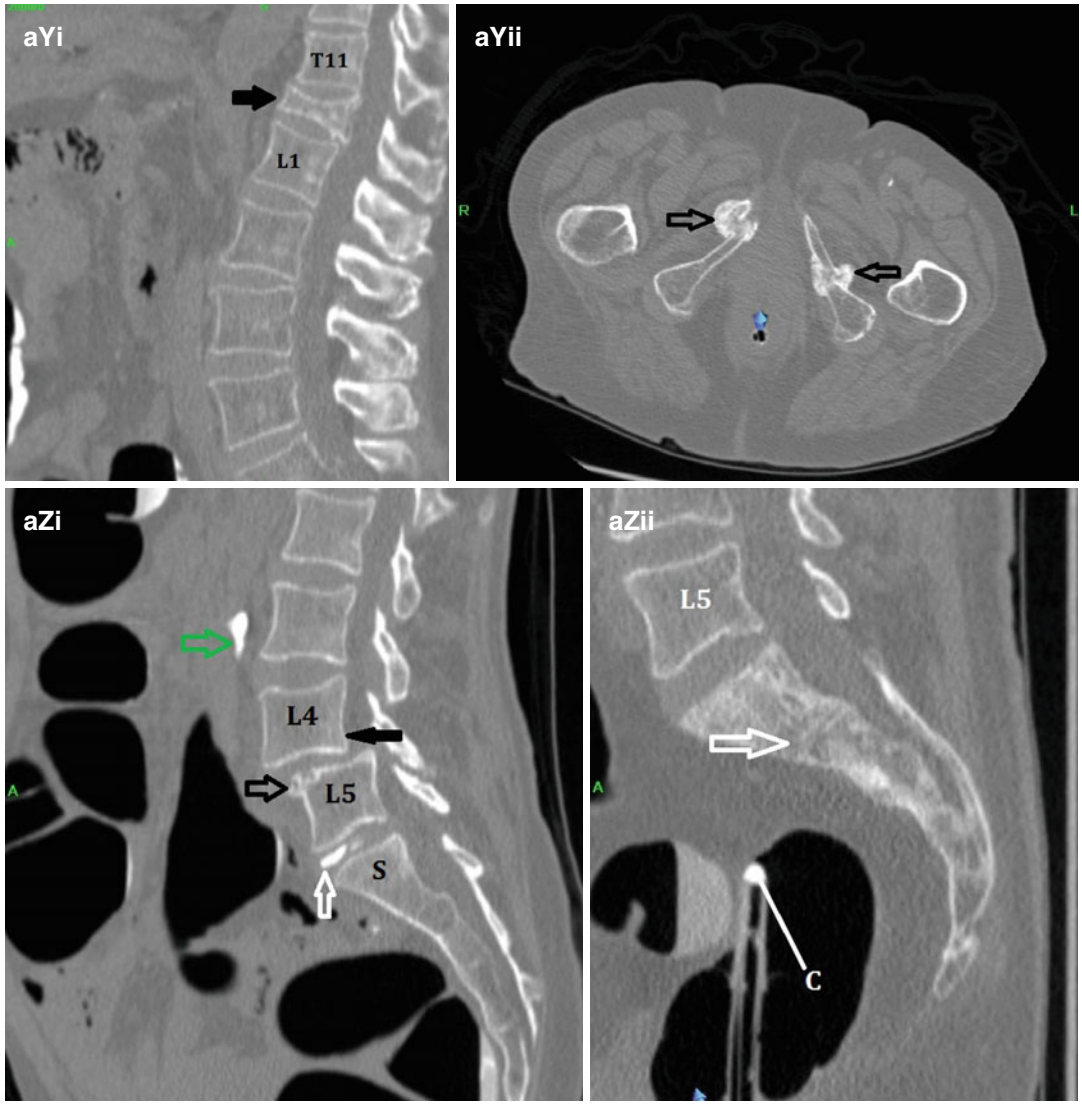

Fig. 18.2 (**aY**) (**i**) Compression fracture T12 (*arrow*). (**aY**) (**ii**) Healed osteoporotic fractures (*open black arrows*). (**aZ**) (**i**) Spondylolisthesis L4 on L5 (*closed black arrow*). *Open black arrow* ununited apophysis of L5. *S* sacrum. *Open white arrow* shows calcified L5/S1 disc. *Open green arrow* shows calcification of aorta. (**aZ**) (**ii**) Lesion sacrum (*open white arrow*) shows Paget's disease. *C* rectal catheter

18.5.3 E3: Moderate Clinical Importance

Figures 18.3a–l are examples of ECFs of moderate clinical importance.

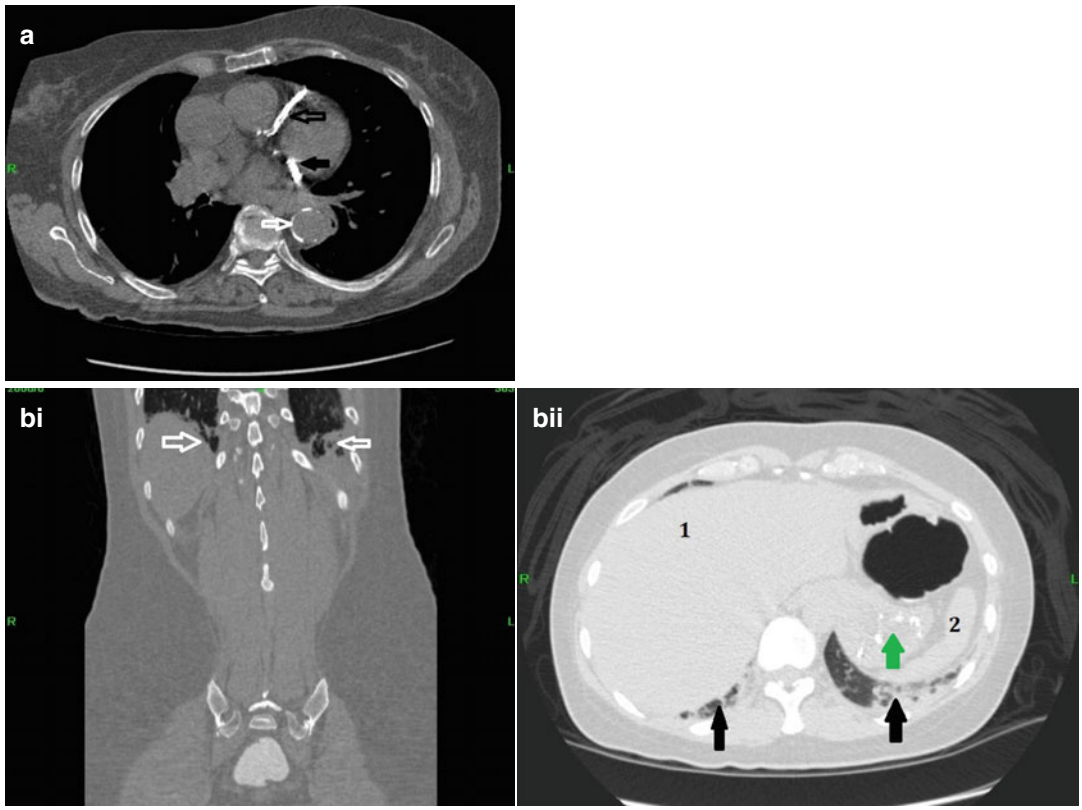

Fig. 18.3 (**a**) 2D axial view shows heavy calcification of the left anterior descending artery (*open black arrow*) and circumflex coronary artery (*closed black arrow*) and calcification of the thoracic aorta (*open white arrow*). (**b**) (**i**) 2D coronal view showing basal lung infective changes bilaterally (*open white arrows*). (**b**) (**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*)

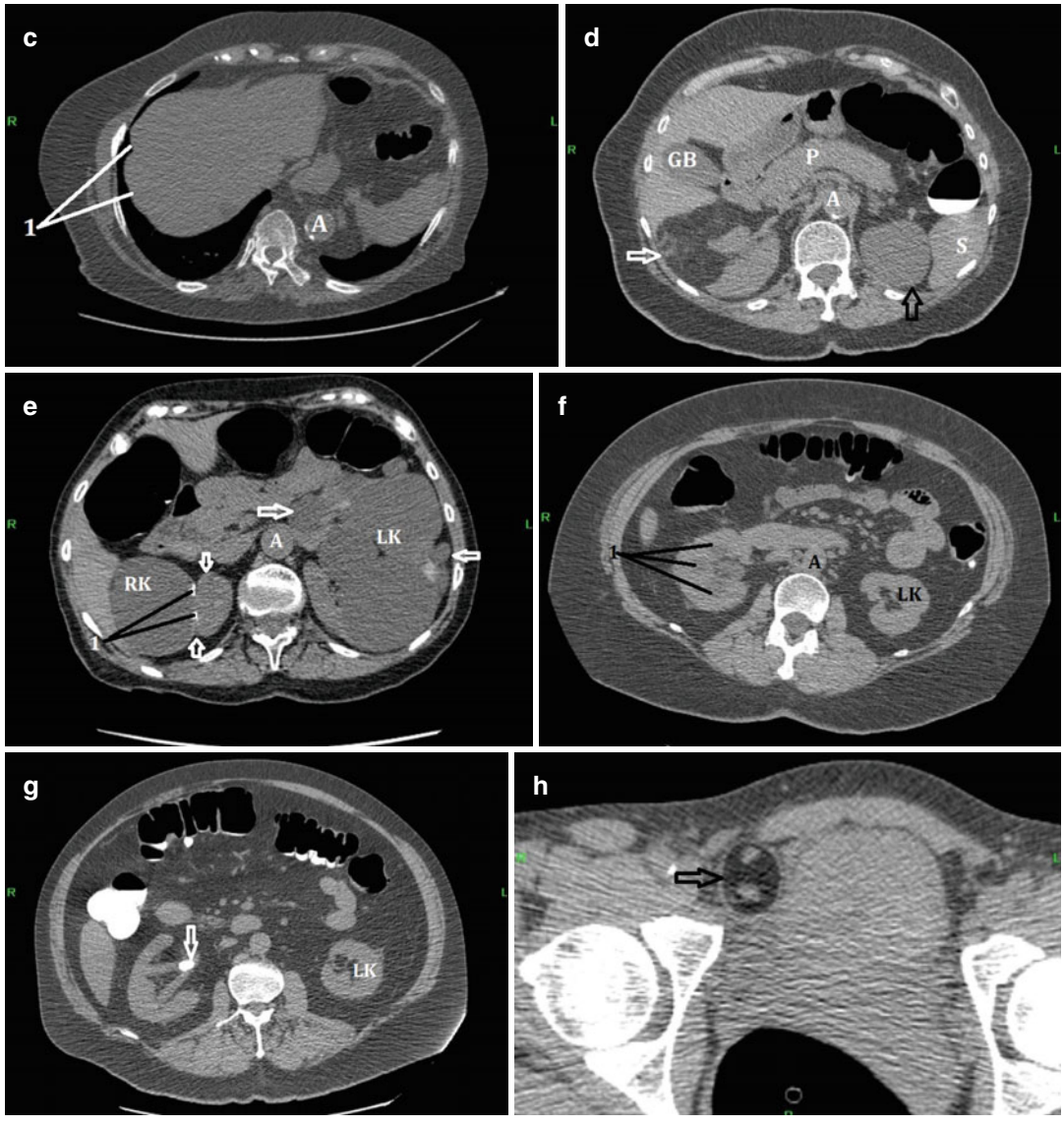

Fig. 18.3 (**c**) Lobular liver (*1*) due to cirrhosis. *A* aorta. (**d**) Angiomyolipoma (*open white arrow*) showing a 'rat-eaten appearance' due to invasion by fatty tissue, vascular and muscle tissue. Cyst of the left kidney (*open black arrow*). *GB* gallbladder, *P* pancreas, *S* spleen, *A* aorta. (**e**) Polycystic kidneys (*open white arrows*) with rim calcification (*1*) in the right kidney (*RK*). *LK* left kidney. (**f**) Hydronephrotic change of the right kidney (*1*), *A* aorta, *LK* left kidney. (**g**) Calculus in ureteropelvic junction (UPJ) of the 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

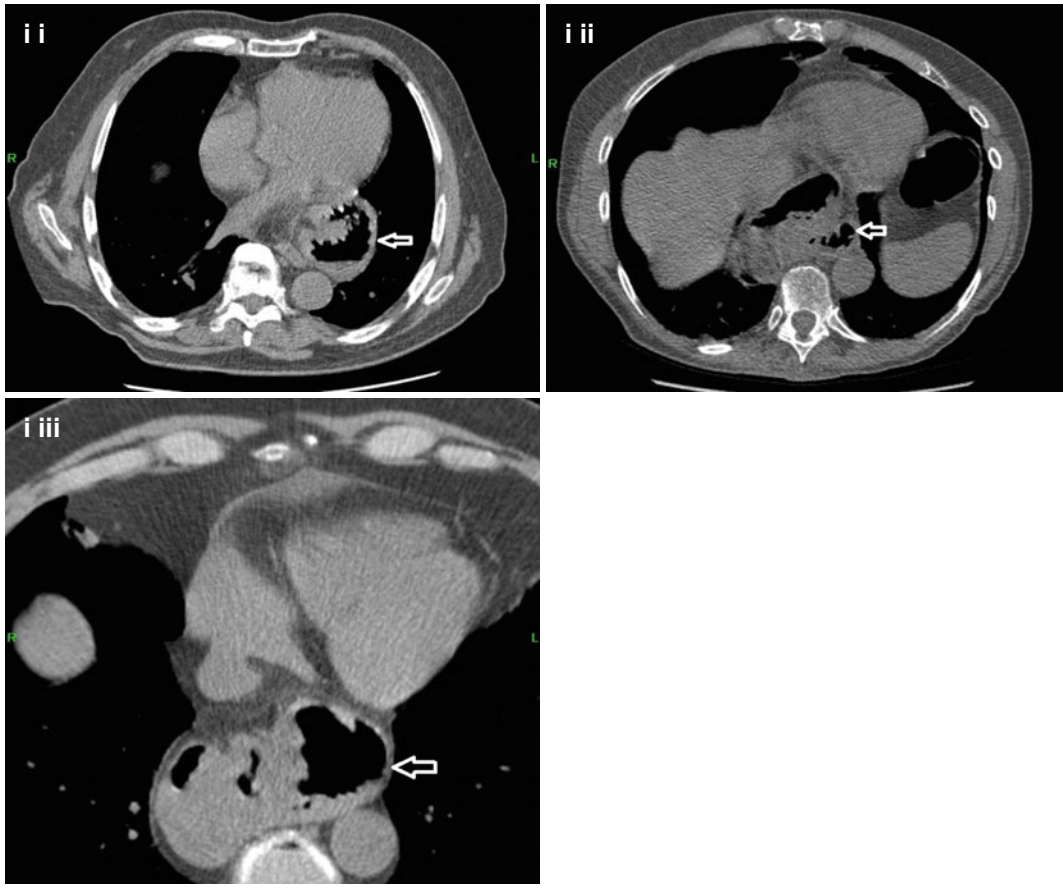

Fig. 18.3 (**i**) (**i**) Incarcerated hiatus hernia (*open white arrow*). (**i**) (**ii**) Large incarcerated hiatus hernia containing part of the stomach (*open white arrow*). (**i**) (**iii**) Large hiatus hernia (*open white arrow*)

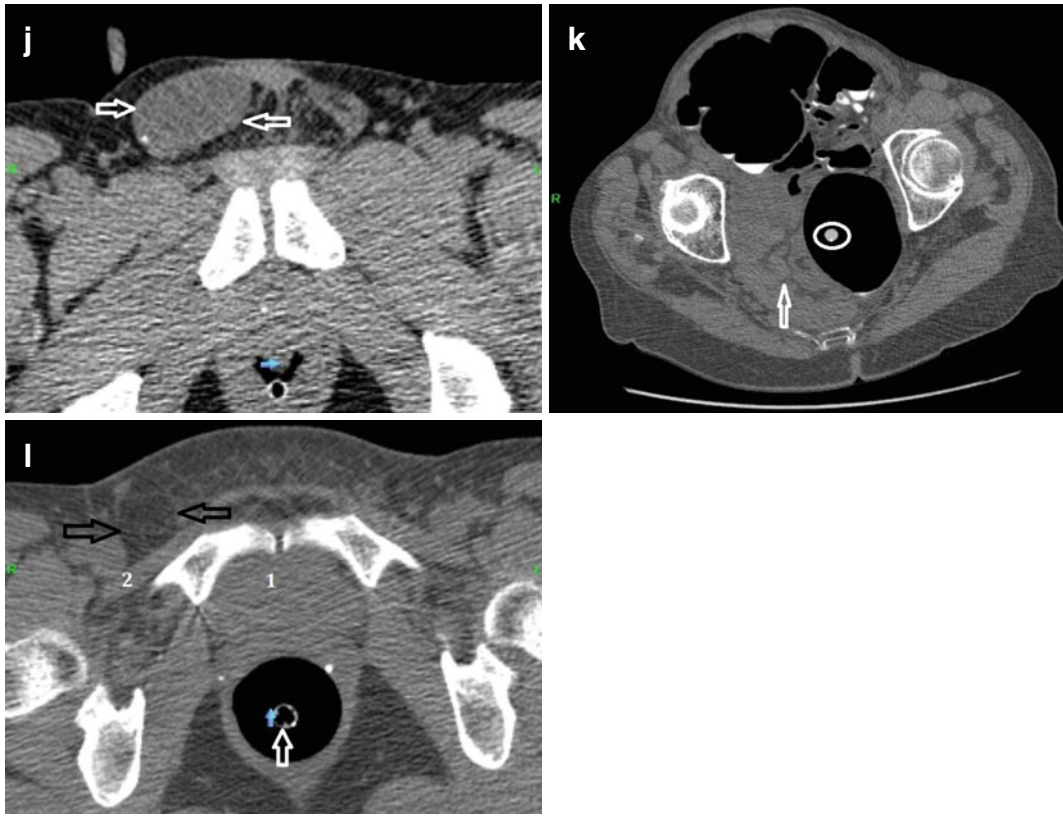

Fig. 18.3 (**j**) Density inguinal canal (*open white arrows*) due to testis. (**k**) 2D axial showing enterocoele (*open white arrow*) post hysterectomy. Rectum displaced to the left. Rectal catheter (*circle*). (**l**) Femoral hernia (*open black arrows*). Rectal catheter (*open white arrow*). *1* bladder, *2* pectineus muscle

18.5.4 E4: High Clinical Importance

Figures 18.4a (i)–i (ii) are examples of ECFs of high clinical importance.

A recent study focused on a comprehensive analysis of potentially important (E4) ECFs of asymptomatic patients (n = 7952) who underwent first time screening CTC for colorectal cancer

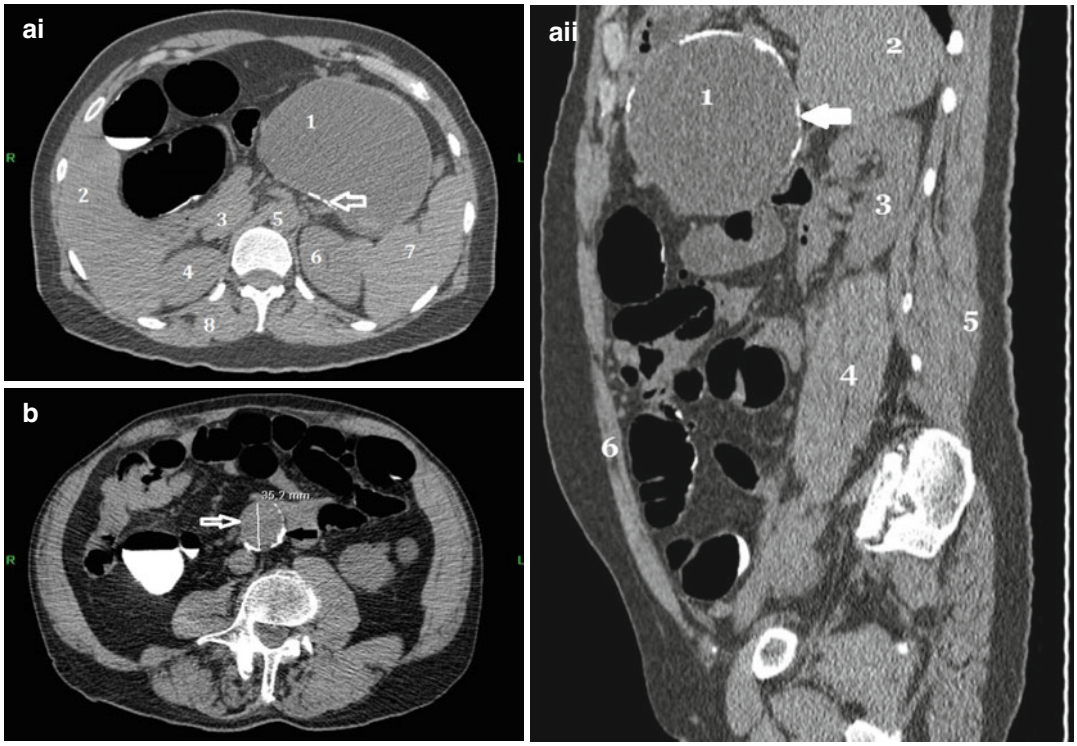

Fig. 18.4 (**a**) (**i**) 2D axial view showing pancreatic mass (*1*) with calcification of the part of the wall (*open white arrow*). *2* right lobe of the liver, *3* inferior vena cava, *4* right kidney, *5* abdominal aorta, *6* left kidney, *7* spleen, *8* quadratus lumborum muscle. (**a**) (**ii**) 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*)

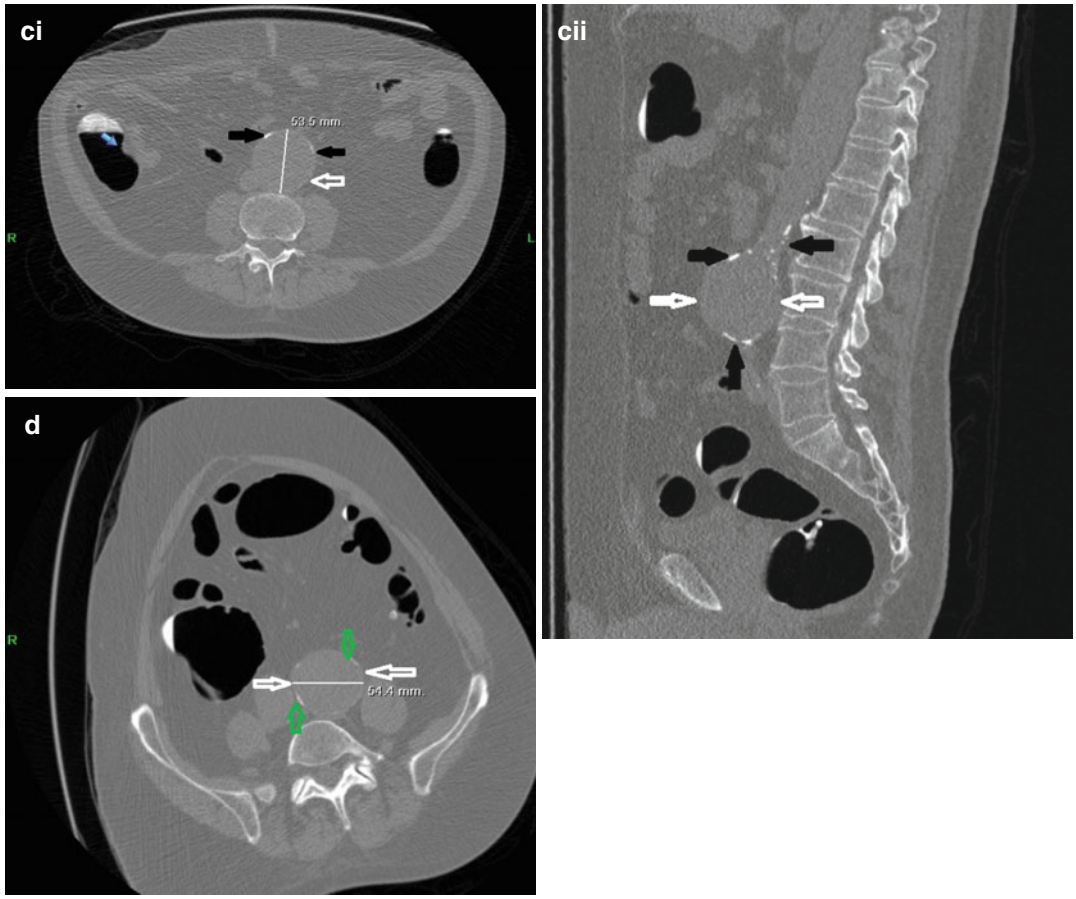

Fig. 18.4 (**c**) (**i**) AAA (*open white arrow*) measuring 53 mm (5.3 cm) with partial calcification (*closed black arrows*). (**c**) (**ii**) Sagittal view of the AAA (*open white arrows*) showing partial calcification (*closed black arrows*). (**d**) Left iliac artery aneurysm (*open white arrows*) measuring 54.4 mm (5.44 cm) with slight calcification (*open green arrows*)

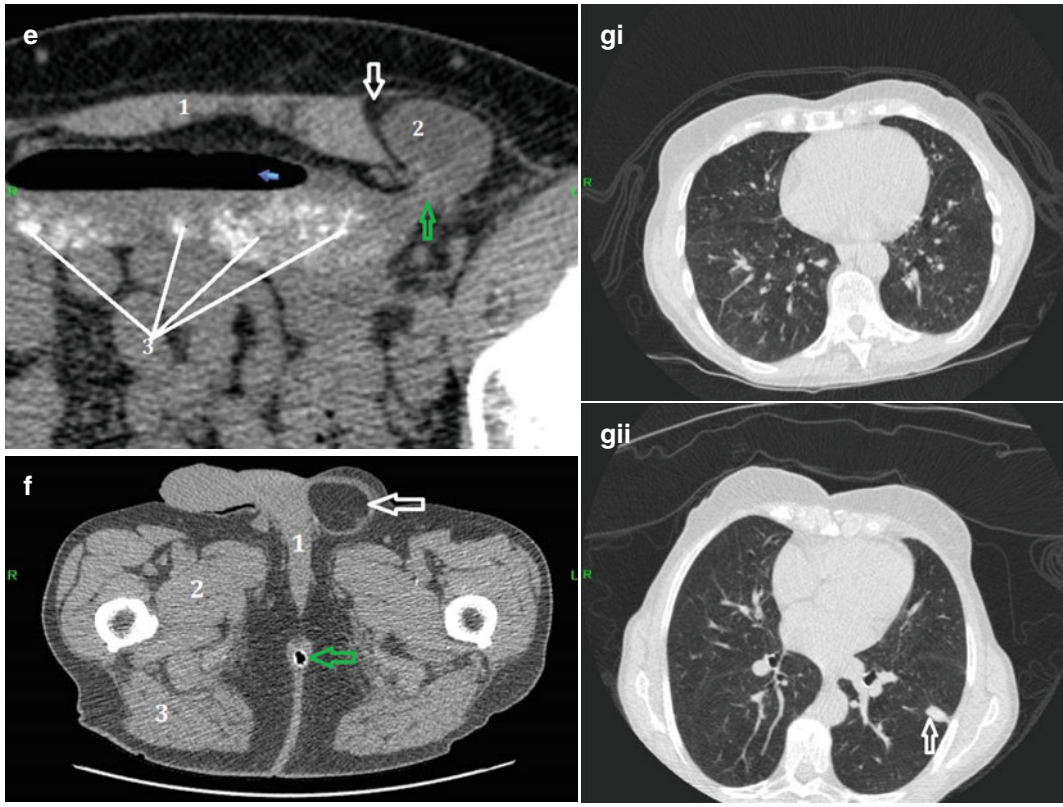

Fig. 18.4 (**e**) 2D axial view showing pressure effect on rectus abdominis muscle (*1*). Dilated small bowel (*2*) trapped in a direct inguinal hernia causing obstruction. *Green arrow* transition point. Granules from ingested tablets (*3*). (**f**) Loop of bowel in scrotum (*open white arrow*). Rectal catheter (*open green arrow*). *1* corpus cavernosum, *2* obturator externus, *3* gluteus maximus. (**g**) (**i**) No pathology evident on 2D axial supine view. (**g**) (**ii**) 2D axial prone view of same patient showing a non-calcified lesion in the left lung (*open white arrow*). This is due to greater coverage of the lung fields in the prone position

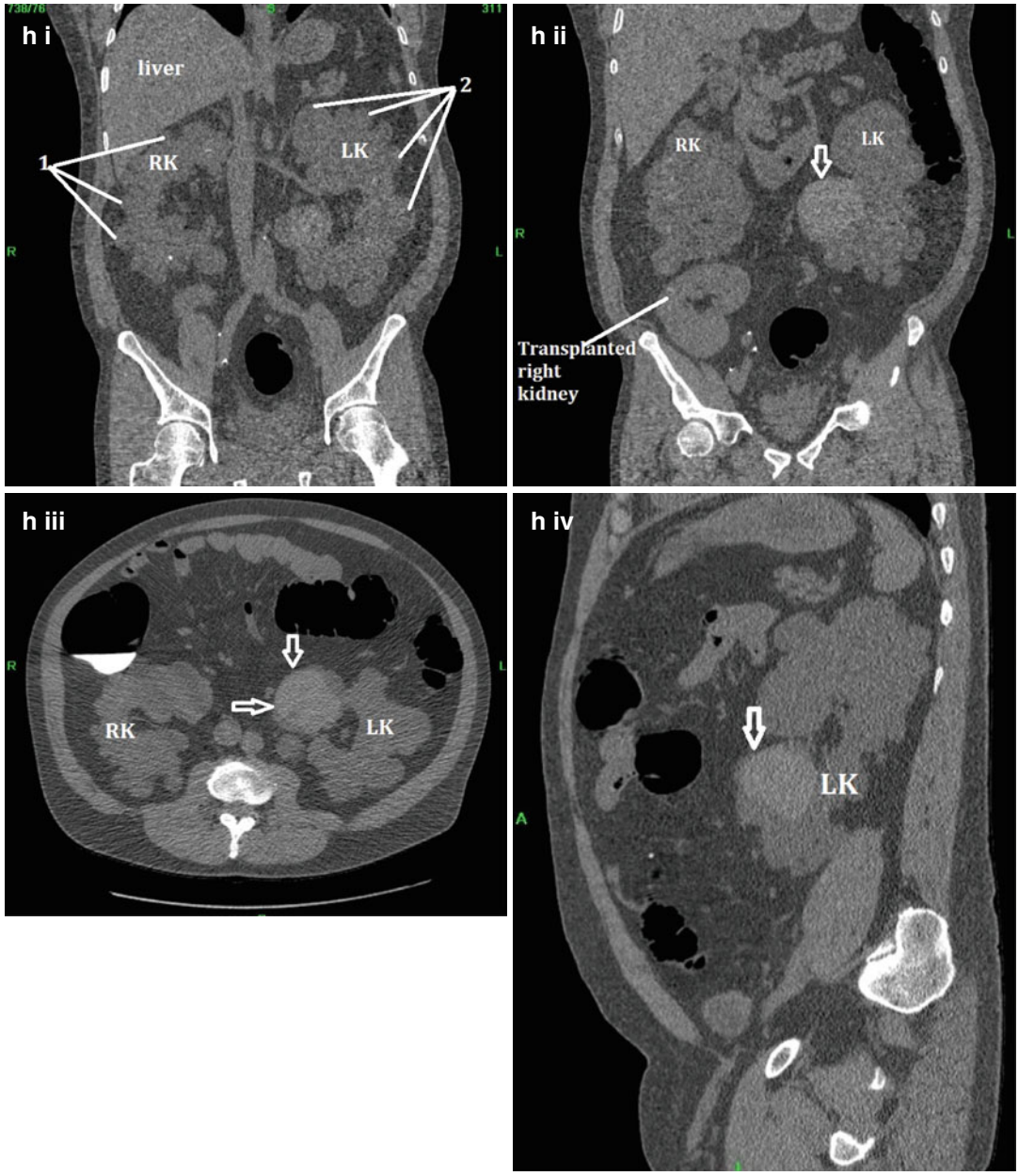

Fig. 18.4 (**h**) (**i**) This patient presented with pain in his right inguinal region, and left kidney area. He declined an optical colonoscopy, and chose to undergo a screening CTC study. 2D coronal view shows multiple cysts (*1* and *2*) in polycystic kidneys. *RK* right kidney, *LK* left kidney (**h**) (**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. (**h**) (**iii**) 2D axial view shows the haemorrhagic cyst (*open white arrows*). *RK* right kidney, *LK* left kidney. (**h**) (**iv**) 2D sagittal view shows the haemorrhagic cyst (*open white arrows*) in the left kidney (*LK*)

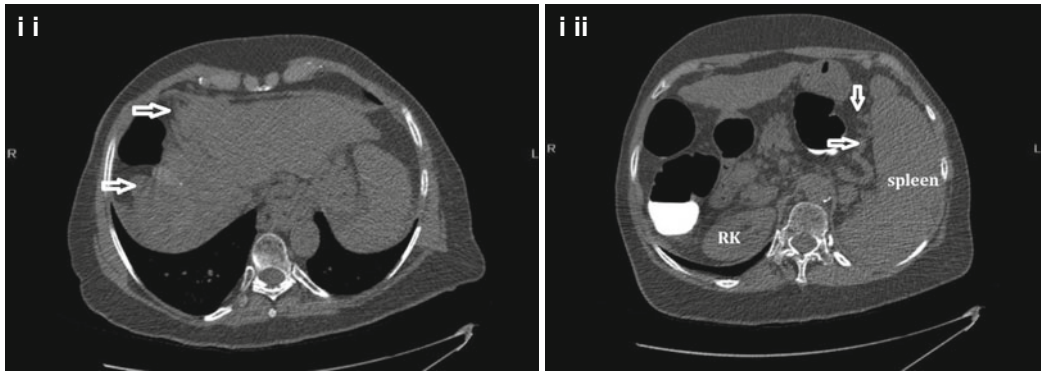

Fig. 18.4 (**i**) (**i**) 2D axial view of liver showing shrunken and lobulated right lobe of liver (*open white arrows*). The lobulated appearance of the liver margin is secondary to infarction of the liver following selective catheterisation of the hepatic artery with chemotherapeutic agents for hepatocellular carcinoma. (**i**) (**ii**) 2D axial view shows a markedly enlarged spleen (splenomegaly) due to portal hypertension with associated splenic varicosities (*open white arrows*). *RK* right kidney

from 1 April 2004 to 30 June 2012 [23]. The results of the retrospective study showed that only 2.5 % of the patients had a significant ECF, i.e. E4 classification (see Table 18.1 above). Almost 70 % of the findings proved to be clinically significant and required treatment or surveillance, for example, malignancies and aneurysms [23]. A summary of the findings of the study is presented in Table 18.2.

Table 18.2 Main organs and systems in the E4 findings*

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 %

*Adapted from the text of Pooler et al. [23]

18.6 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 is 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.

18.7 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 are not subjected to 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.

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), September 2014. (Cited 2015 July 15). Available from: 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. http://dx.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 Endosc 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. [http://dx.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. [http://dx.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(sic).doi: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 data from a clinical screening program. AJR. 2016;206:313–8. (cited 2016 February 21). Available from: www.ajronline.org http://dx.doi.org/10.2214/AJR.15.15193.

Good Practice in CTC Reporting

19

Joel H. Bortz

Abstract

Reporting the findings of a CTC should be done by competent readers, such as radiologists or appropriately trained radiographers. Knowledge of normal colon anatomy and variants is essential in order to recognise intra- and extracolonic pathology. Potential pitfalls, such as stool simulating a polyp, should be recognised. To ensure that a CTC report covers all aspects of the study, a template should be used. The report should include a disclaimer regarding detection of diminutive polyps. A disclaimer regarding extracolonic findings should also be included in the report. If a CTC study is non-diagnostic due to poor quality, it is essential to report on extracolonic findings.

19.1 Introduction

A reader should check both intracolonic and extracolonic structures when reporting on a 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 (i.v.) contrast. It is indicated when there is a known colonic or extracolonic malignancy; nonionic agents should be used. As discussed in Chap. 8, some centres may administer an antispasmolytic; hyoscine 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. Figure 19.1 (i–iii) shows examples of a non-diagnostic study due 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 extracolonic findings even if a patient is rescheduled for a repeat CTC.

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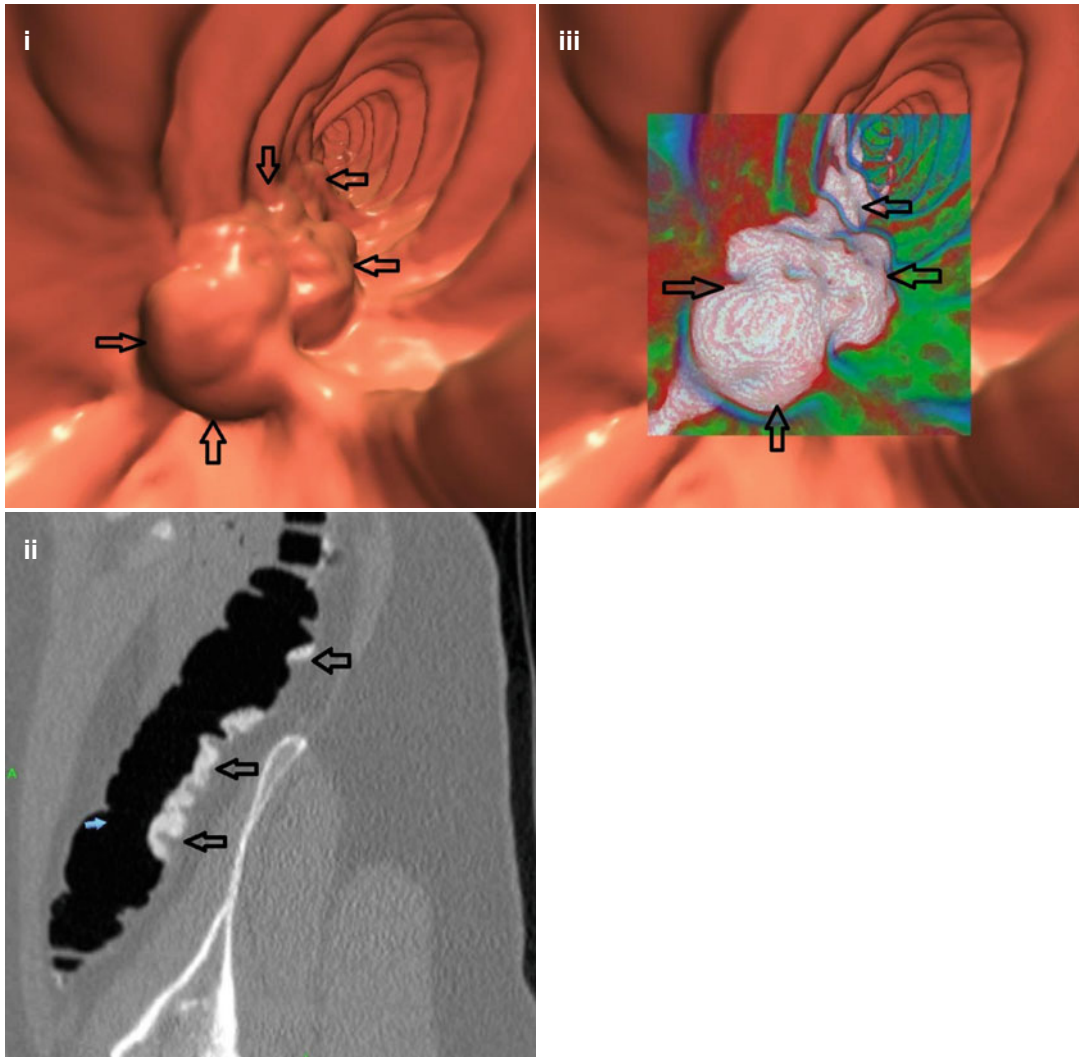

Fig. 19.1 (**i**) 3D view showing stool (*arrows*), (**ii**) 2D view showing stool (*arrows*), (**iii**) TD view showing stool (*arrows*)

19.2 Reading and Interpretation Requirements

Accurate reading and interpretation requires the radiologist, or an appropriately trained radiographer, to be familiar with normal colon anatomy and variants, such as the different appearances of the ileocaecal valve (ICV). Figure19.2a–e (ii) depicts variations of ileocaecal valves (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 require knowledge of the various pathologies that occur within the colon wall, as well as extracolonic findings. 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 were introduced for reporting both asymptomatic screening studies and diagnostic studies. Suggested feature descriptors for polyps and masses are presented in Table19.1 [1].

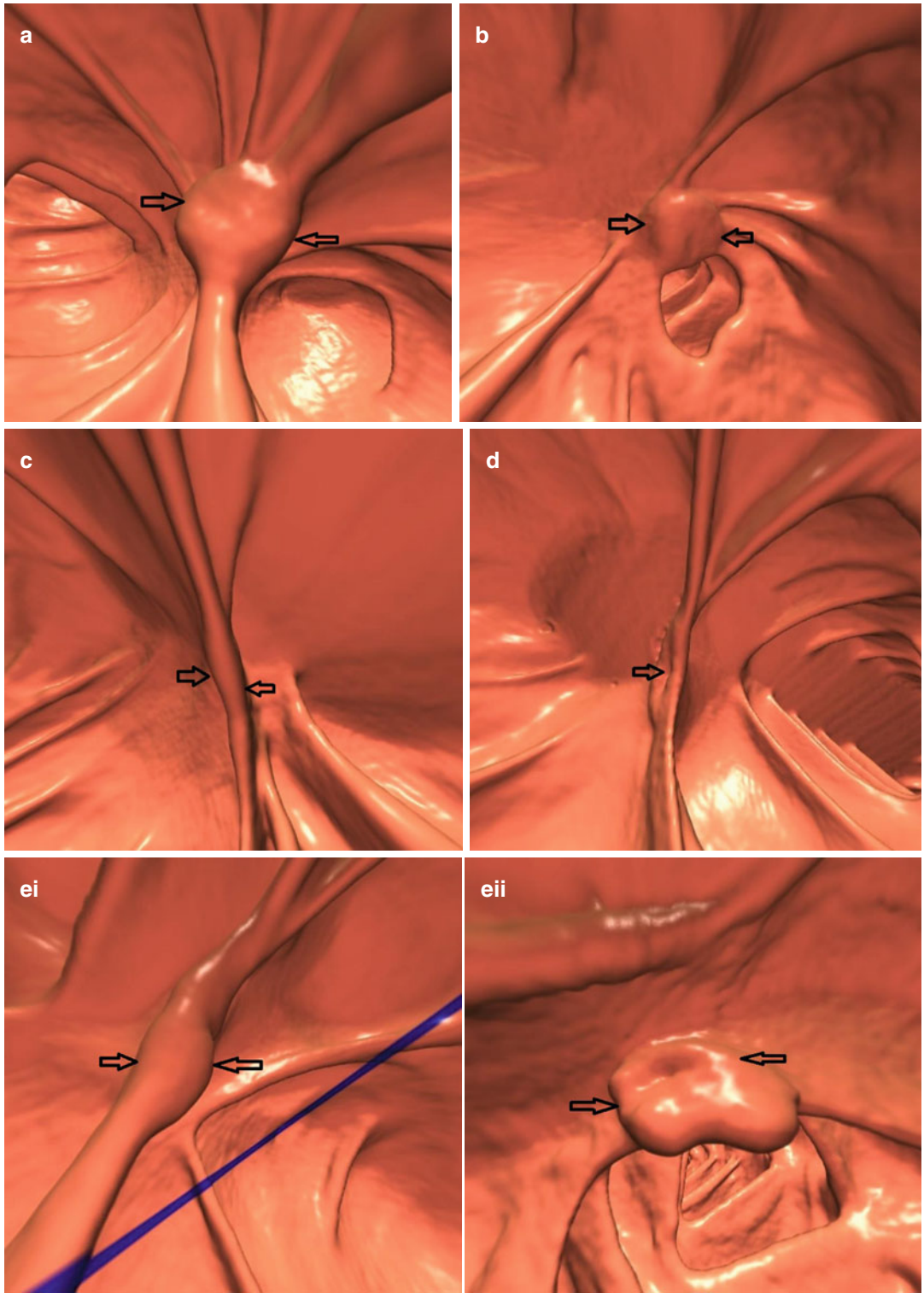

Fig. 19.2 (**a**) Bulbous ICV (*arrows*), (**b**) bulbous (polypoidal) ICV (*arrows*), (**c**) vulval type ICV (*arrows*), (**d**) partially patent ICV (*arrow*), (**e**) (**i**) 3D endoluminal supine view showing ICV (*arrows*), (**e**) (**ii**) 3D endoluminal prone view of the same patient shows change of shape of the ICV (*arrows*)

Table 19.1 Suggested feature descriptors for polyps and masses

Size (mm)	For lesions ≥6 mm: the single largest diameter of the polyp. NB not the stalk of pedunculated polyps
	Measure 3D and any multiplanar reconstruction (MPR). State view used for measurement
Morphology (form/shape)	Sessile: broad-based lesion width >height (W >H)
	Pedunculated: polyp with a stalk – only measure the polyp head
	Flat: polyp with vertical height <3 mm above surrounding normal colonic mucosa
	Carpet lesion is a subset of a flat lesion. Usually ≥30 mm in size with superficially elevated mucosa which can reach a height of 4–14 mm. Edges tend to be superficially elevated from surrounding mucosa
Location	Refer to the six colonic segments (see Chap. 11)
	Rectum
	Sigmoid colon
	Descending colon
	Transverse colon
	Ascending colon
	Caecum
Attenuation	Soft tissue
	Fat

Adapted from Zalis et al. [1]

The 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. To use the C-Rads system requires knowledge of definitions of polyps and colonic masses, for example. See Chap. 14 for a detailed discussion of polyps including definitions.

19.3 CTC Interpretation Tools

CT colonography (CTC) interpretation uses a combination of a 3D-2D approach in which 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. 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: stool and polyp
- Measurement
- Volume measurement
- Electronic cleansing

CAD (computer-aided diagnosis) may also be used [2, 3].

These tools allow a user to segment out the colorectum to create the 3D model and fly-through. An automated centreline 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 centreline 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, whereas the 120° FOV 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. 19.3a). 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 19.3b (i–vi) shows examples of breaks in the colon. The reasons for 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 may occur into the terminal ileum, and in some patients it may track all the way up to the stomach as evident in Fig. 19.3c (i). These areas are excluded from the colon-map view in the automatic centreline creation which results in a 3D map view of the colon only as shown in Fig. 19.3c (ii).

When a polyp is detected, manual navigation is possible by holding down the left button on the

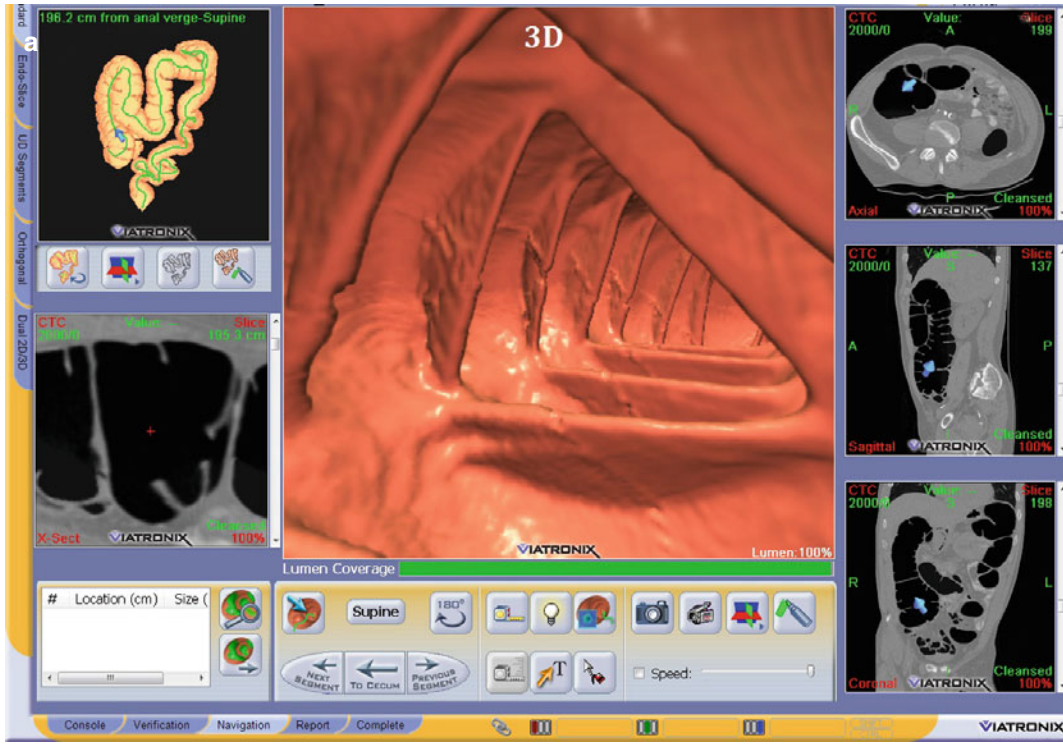

Fig. 19.3 (**a**) Viatronix V3D workstation showing images of a patient and icons. A 3D image must always be in the centre when we commence viewing. *Right side* shows 2D views (axial at the *top*; sagittal in the *middle* and coronal at the *bottom*). Each 2D view can be viewed separately by clicking 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 image are used, for example, for direction of flow and speed (Image courtesy of Viatronix, Stony Brook, New York)

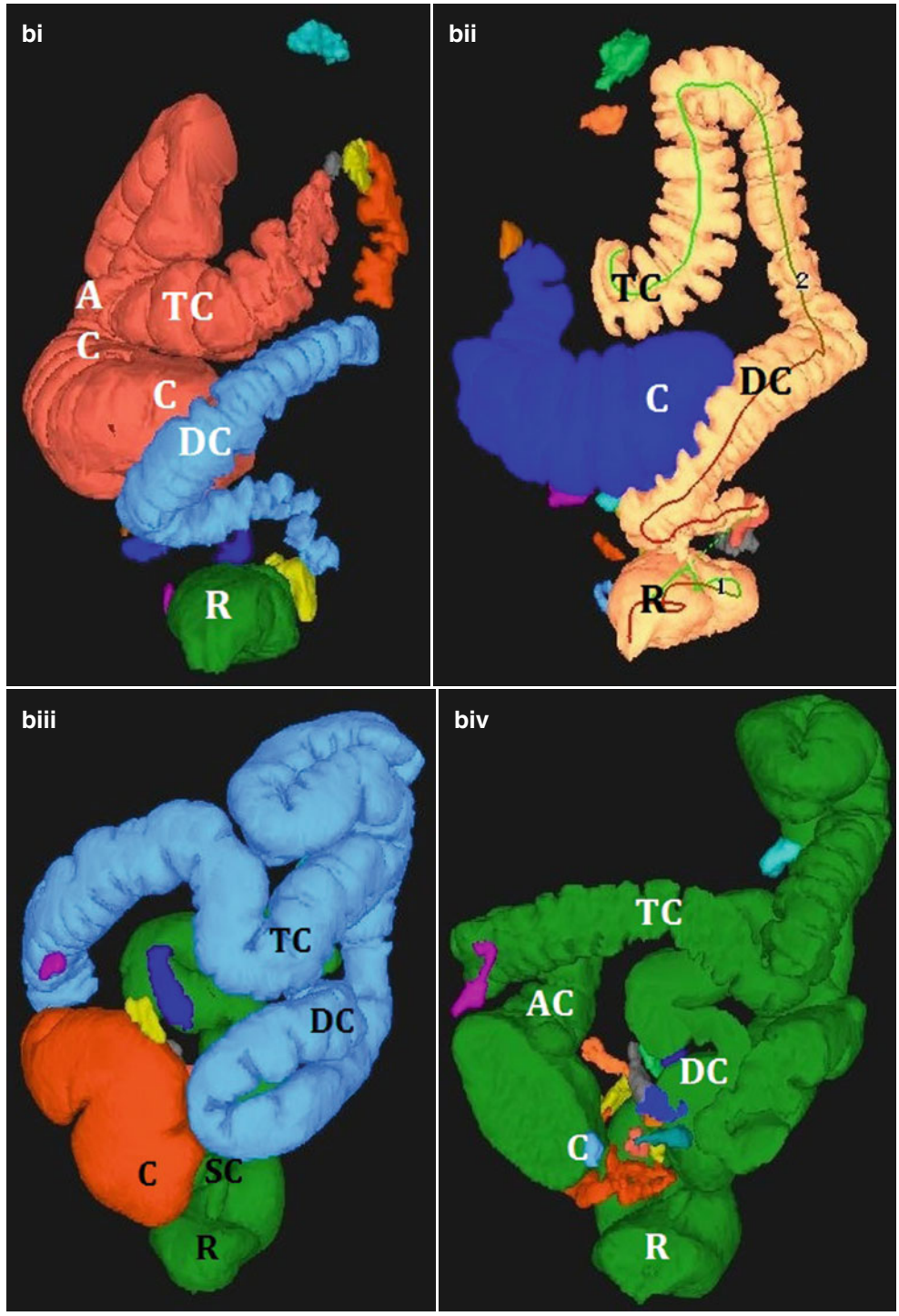

Fig. 19.3 (**b**) (**i**) Supine with four breaks. *R* rectum, *DC* descending colon, *TC* transverse colon, *AC* ascending colon, *C* caecum. (**b**) (**ii**) Prone view shows a break in proximal TC and gap in bowel. This is fully covered in the supine in (**b**) (**i**) therefore the study is complete. (**b**) (**iii**) Supine two breaks. *R* rectum, *SC* sigmoid colon, *DC* descending colon, *TC* transverse colon, *C* caecum. (**b**) (**iv**) Prone showing entire colon distended. *R* rectum, *DC* descending colon, *TC* transverse colon, *AC* ascending colon, *C* caecum

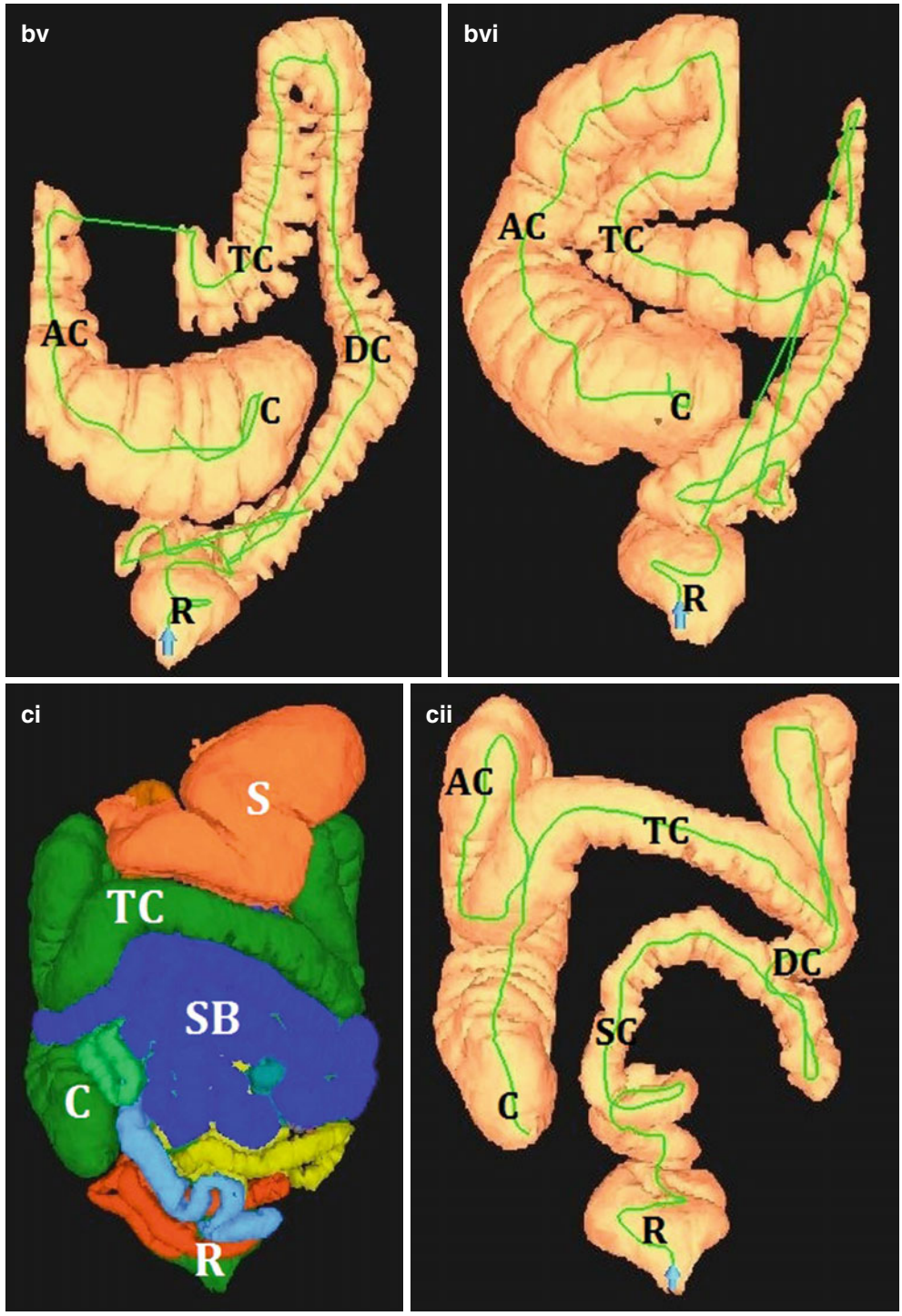

Fig. 19.3 (**b**) (**v**) Gap proximal transverse colon in LLD view. *C* caecum, *AC* ascending colon, *TC* transverse colon, *DC* descending colon, *R* rectum. (**b**) (**vi**) Gap proximal transverse colon covered in RLD view thus study complete. *C* caecum, *AC* ascending colon, *TC* transverse colon, *R* rectum. (**c**) (**i**) Reflux of CO_2 into the stomach (*S*). *TC* transverse colon, *SB* small bowel, *C* caecum, *R* rectum. (**c**) (**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

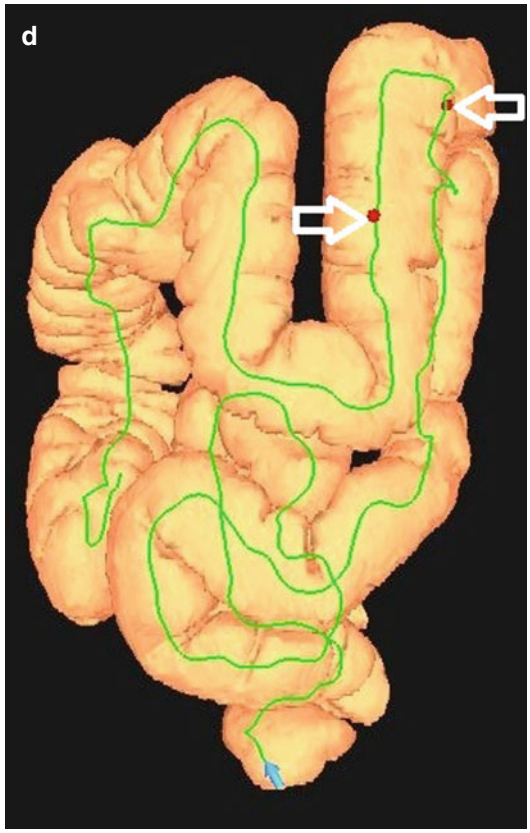

Fig. 19.3 (**d**) Colon-map showing two red dots indicating the site of lesions (*open white arrows*)

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. 19.3d. 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 centreline measurement from the anorectal region 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 extracolonic findings in the report as underscored in Chap. 18.

19.4 Dictation Template

A dictation template should be used to ensure that all aspects of the CTC study are recorded and reported. Medical terminology must be used in all CTC and extracolonic findings reports. Table 19.2 is a recommended dictation template.

Table 19.2 Dictation template

Patient's name: Date: Name of referring physician:	
Indications	Routine CRC screening
	Diagnostic study, e.g. bleeding or change in bowel habit, etc.
	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 diatrizoate. 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 i.v. 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.
	NB: in some countries it is mandatory to provide patient dose report. Recommend always include in the CTC report
Findings	*Colon*
	(i) Comment on quality of bowel preparation (e.g. presence of stool)
	(ii) Comment on degree of distension
	(iii) Comment on presence or absence of diverticular disease
	(iv) Comment on presence of small polyps (6–9 mm) and large polyps (≥10 mm). Provide accurate measurements
	(v) Describe location of polyp
	(vi) Describe morphology of polyp
	Add disclaimer: note 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
	Extracolonic
	Tabulate the most significant findings; comment on any additional workup needed
	Add disclaimer: note that extracolonic evaluation is limited by the low-dose CT technique and lack of i.v. contrast

19.5 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.

19.6 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.

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(1): 3–9. [http://dx.doi.org/10.1148/radiol.2361041926].
2. 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. [http://dx.doi.org/10.1148/radiol.10092292].
3. 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. [http://dx.doi.org/10.1148/radiol.10100354].

20 Ultrasound, Magnetic Resonance Imaging and Positron Emission Tomography in the Evaluation of Colon Cancer

Kalpesh Mody and Fozy Peer

Abstract

With the increasing incidence of colorectal cancer (CRC), diagnostic imaging provides an important complementary role to colonoscopy in the management of colorectal pathology. As surgical and oncological therapies have improved, the importance of highly accurate and reproducible imaging has also grown. Further research has gone into the role other modalities may play in patient work-up and management. Transrectal ultrasound and magnetic resonance imaging (MRI) of the rectum provide high-definition imaging of the local spread of rectal tumours, but cannot assess the proximal bowel or more distant metastatic disease. Abdominal ultrasound is used to identify metastatic involvement of the solid abdominal viscera, but cannot evaluate the primary lesion. MR colonography (MRC) depicts all segments of the colon and can identify visceral and nodal metastases. However, staging of the primary lesion, particularly of early tumours, is limited by the resolution of MRC. In CRC PET-CT studies are useful for 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. PET-CT may be used to detect recurrence of disease and to manage ongoing patient care. PET-CT imaging assists treatment planning 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 may be determined as related to the response to specific drugs and ongoing therapy. Based on changes in cellular activity observed on PET-CT images, treatment regimens may be changed. MR and PET-CT images are presented to illustrate these modalities' role in CRC management.

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20.1 Introduction

Imaging has a crucial role in all aspects of the approach to colorectal neoplasms, namely, screening, diagnosis, staging and surveillance. Accurate and reproducible imaging is necessary to determine the appropriate course of clinical management. 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 [1, 2]. In this chapter we discuss ultrasound, magnetic resonance imaging (MRI) and nuclear medicine, in terms of their respective role as alternative imaging techniques for screening, diagnosis and staging of CRC.

20.2 Ultrasound

Abdominal ultrasonography is not used for evaluation of the primary neoplasm due to bowel gas shadowing and limited depth of imaging. It is performed for detection of visceral metastatic disease, abdomino-pelvic fluid and lymphadenopathy. The term 'endoscopic ultrasonography' refers to the procedure whereby an ultrasound probe is introduced into a hollow organ such as the gastrointestinal tract. Transrectal ultrasound (TRUS) is a type of endoscopic ultrasonography which may be used as an alternative modality in imaging of rectal tumours. TRUS 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]. It provides high-resolution detail of tumour infiltration of the rectal wall, making TRUS the best imaging modality for staging of early rectal carcinoma, particularly if confined to the rectal wall [1, 3–5]. TRUS also allows for assessment for local nodal involvement by evaluating the morphology of the adjacent nodes [1, 2]. If available, the addition of 3D software and US elastography may further improve the accuracy of T and N staging [2, 3]. As with all imaging modalities, there are advantages and disadvantages.

20.2.1 Advantages [4]

- Lack of ionising radiation
- Less expensive
- Easier accessibility
- Shorter examination time
- Allows for simultaneous imaging and biopsy

20.2.2 Disadvantages

- Operator dependent
- Stenotic lesions may limit passage of the probe and inhibit accurate imaging (use of microprobes may alleviate this) [3]
- Limited accuracy in evaluation of upper rectal lesions
- Does not evaluate the remainder of the colon 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 the mesorectal fascia [2]

20.3 Magnetic Resonance Imaging (MRI), MR Colonography (MRC) and MRI of the Rectum

MRI has advantages and disadvantages as an alternative imaging technique for screening, diagnosis and staging of CRC.

- Advantages of MRI
  - 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
  - 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 noncompatible metallic objects due to the magnetic field which will result in obvious patient discomfort and even severe burns. It is important to also remember that although imaging of patients with MRI-compatible prostheses or implants is permissible, artefacts from these objects may obscure portions of the FOV. Table 20.1 is an example of a checklist for screening patients prior to MRI. Although 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 the detection of polyps greater than 6 mm in size between 1.5 and 3 T machines [2, 6]. 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 prostheses produced over the last 10–15 years are now considered MRI safe, this compatibility may be dependent upon the field strength of the MRI scanner [7]. Objects, which are deemed to be MRI safe for imaging with a 1.5 T scanner, but may have questionable MRI safety at 3 T imaging, include dental braces, cardiac metallic stents, sternal wires, aneurysm clips, etc. [7]. Compatibility of these prostheses and implants must be established with the manufacturer prior to imaging. Table 20.2 presents the indications for magnetic resonance colonography (MRC).

As in CTC, optimal bowel preparation [6] is essential for MRC, particularly for the detection of polyps and screening for early neoplasms. The protocols currently being used are similar to those of CTC. The suitability of stool tagging in MRC is still under investigation but appears promising. As for 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 hyoscine butylbromide (Buscopan) or glucagon, may be administered to alleviate discomfort and reduce motion artefact from bowel peristalsis. It should be noted however that Buscopan is not available in certain countries such as the United States. In addition the use of glucagon may induce reflux through the ileocaecal valve which will affect colonic distension [6].

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).

Table 20.1 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, etc.)?		
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?		

Table 20.2 Indications for MRC

MRC: *indications*	Incomplete colonoscopy
	Colorectal cancer screening
	Inflammatory bowel disease
	Diverticulitis

Adapted from [6]

- Bright lumen MRC (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 [6].
  For diagnostic imaging, a 3D T1-weighted spoiled GRE sequence is used with imaging in both prone and supine positions [6].
  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 (i.v.) 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 [6].
- Dark lumen MRC (DLMRC)
  Rather than a gadolinium chelate-spiked enema, DLMRC most frequently requires administration of a negative agent such as water, air or carbon dioxide via a rectal insufflation device. Air or CO2 is 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 [6]. DLMRC requires the administration of an i.v. 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 i.v. 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 [6]. However, it is important to remember that due to the use of i.v. contrast material in DLMRC, an additional problem is posed due to the risk of nephrogenic systemic fibrosis (NSF), a potentially fatal complication in the setting of significant renal impairment.

MRI rectum involves limited imaging of the pelvis utilising multiplanar fine-slice imaging to depict the pelvic structures. In the field of CRC, it is performed for staging of rectal and recto-anal cancer and for detection of local recurrence following therapeutic intervention. In the work-up of patients with rectal carcinoma, there are five prognostic factors that must be identified [8].

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 [8, 9]. Furthermore, tumour involvement of the mesorectal fascia (MRF) is also an important prognostic factor in determining the correct course of therapy and for evaluating the risk of tumour recurrence [5, 8, 10]. Therefore, it is essential to ensure that the images produced are acquired in the appropriate plane to ensure the most accurate measurements possible [11]. In particular the axial images must be obtained perpendicular to the long axis of the rectum to depict tumour extension into the mesorectal adipose tissue and MRF involvement. In addition to the T-staging, MRI can provide valuable information on the presence of infiltration of the neurovascular bundles by the tumour, as well as possible nodal spread.

There is no current agreement on the optimal imaging technique for rectal cancer staging, with differing opinions on the use of surface phased array and endoluminal coils and endoluminal contrast agents. Endorectal coils provide greater spatial resolution and detail of the rectal wall. However, the limited FOV, the need for a patent rectal lumen and patient discomfort mean 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 i.v. gadolinium-based contrast does not add significantly to the accuracy of tumour staging and therefore does not justify the added cost and risk of NSF and contrast allergy [5, 10].

Diffusion-weighted imaging has also shown promise in identification of the primary tumour as well as possible nodal involvement [5, 11]. Further research is however required to refine the technique and improve reliability. The advantage of MRI of the pelvis, particularly in view of the lack on 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 20.1a (i–iv) is multiplanar MR images of the pelvis in a patient with rectal carcinoma. Figure 20.1b (i–ii) is MR images of the liver in a patient with metastatic rectal carcinoma.

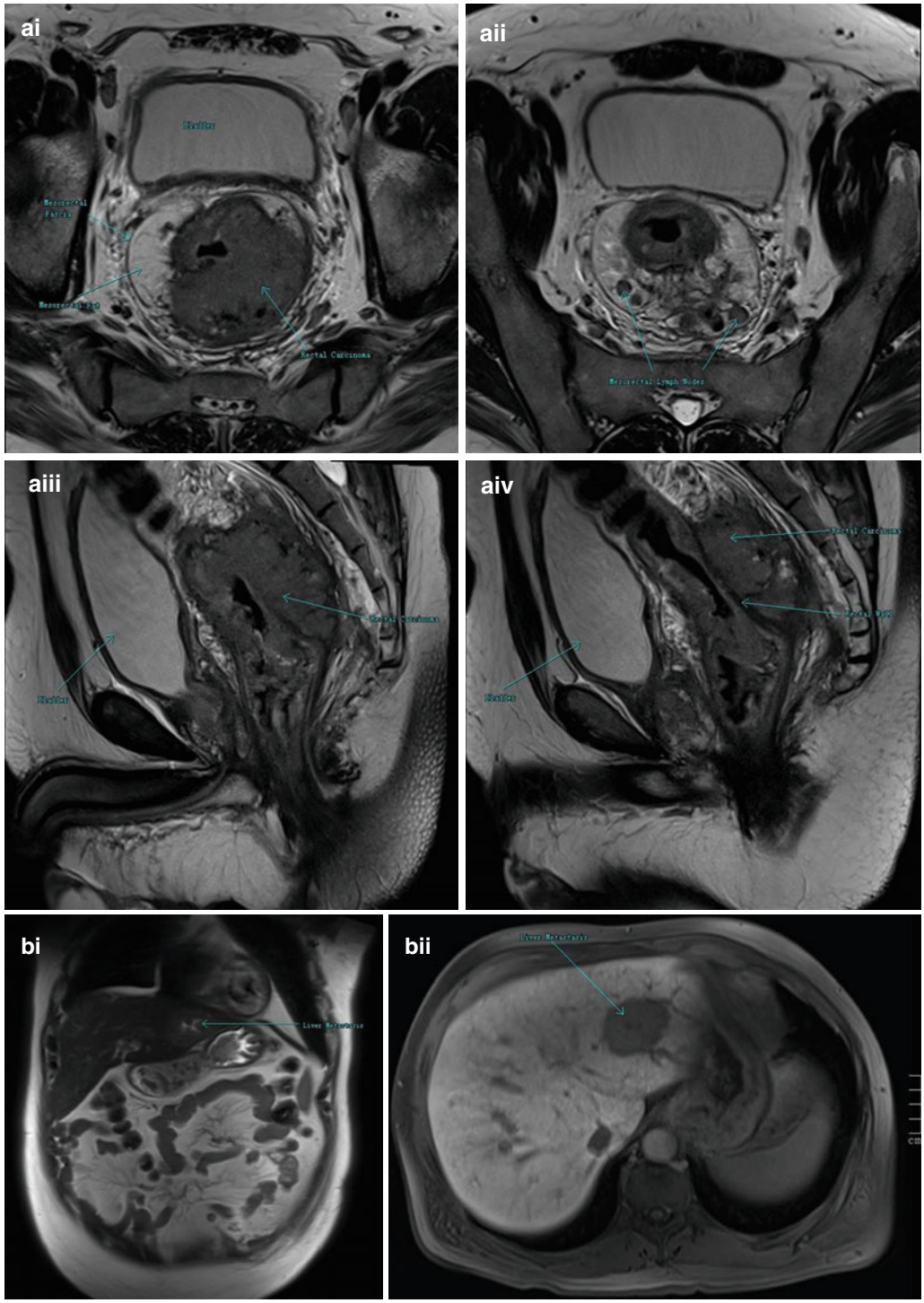

Fig. 20.1 (**a**) (**i**) Axial T2-weighted image demonstrating tumour extension to the mesorectal fascia. (**a**) (**ii**) Axial T2-weighted image depicting mesorectal adenopathy. (**a**) (**iii**) Sagittal T2-weighted image demonstrating tumour extension into the mesorectal tissue posteriorly. (**a**) (**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. (**b**) (**ii**) Axial T1 VIBE image obtained 20 min following administration of Primovist i.v. contrast. The metastatic deposit in the left lobe of the liver is further delineated

20.3.1 Comparison of Accuracy of Imaging Modalities in TNM Staging of Colon Cancer

Table 20.3 shows the comparative percentages of TRUS, MRI, CT and CTC in TNM staging.

Table 20.3 Comparative accuracy of TRUS, CT, CTC and MRI

Modality	T-stage (%)	N-stage (%)
TRUS [3]	80–95	70–75
CT, MRI [3]	75–85	55–65
CTC [10]	73–83	59–71

Adapted from [3, 10]

20.4 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 [12].

Radioisotopes decay with the emission of electromagnetic radiation, that is, gamma or 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 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 [13]. 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 fluorine-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 [14].

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 [14]. Many colon carcinomas arise from adenomas, but not all adenomas result in carcinomas [14]. Chap. 15 deals with colon cancer and the adenoma-carcinoma sequence. The diagnosis and management of many cancers is being influenced by advanced imaging techniques.

20.4.1 Radiopharmaceutical

PET-CT imaging using F-18-fluoro-deoxyglucose (F-18-FDG) is being increasingly used for evaluating colon cancers especially CRC [14]. 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 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 [15]. As a result FDG-PET can be used for diagnosis, staging and monitoring treatment of cancers.

20.4.2 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 the 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) and the patient can wait, recheck and inject once level is below 10 mmol/L or rebook the 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.

20.4.3 How to Perform a PET Study

1. Establish intravenous access.
2. If necessary, where a patient is anxious or restless and will 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 anti-emetic drug may be administered intravenously.
4. Ensure 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 postinjection syringe and note time. Subtract from pre-injection dose to get total injected dose.
8. The patient to drink one cup (250 mL) of 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 his/her 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 [15]. The time for each bed position and the number of bed positions depend 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 [15]. It is preferable to cover this entire area during imaging as colon cancers are known to metastasise widely, mainly to the liver and lungs.

20.4.4 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 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 drugs and ongoing therapy (see Fig. 20.2a, 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 [16].

It has been reported [17] 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

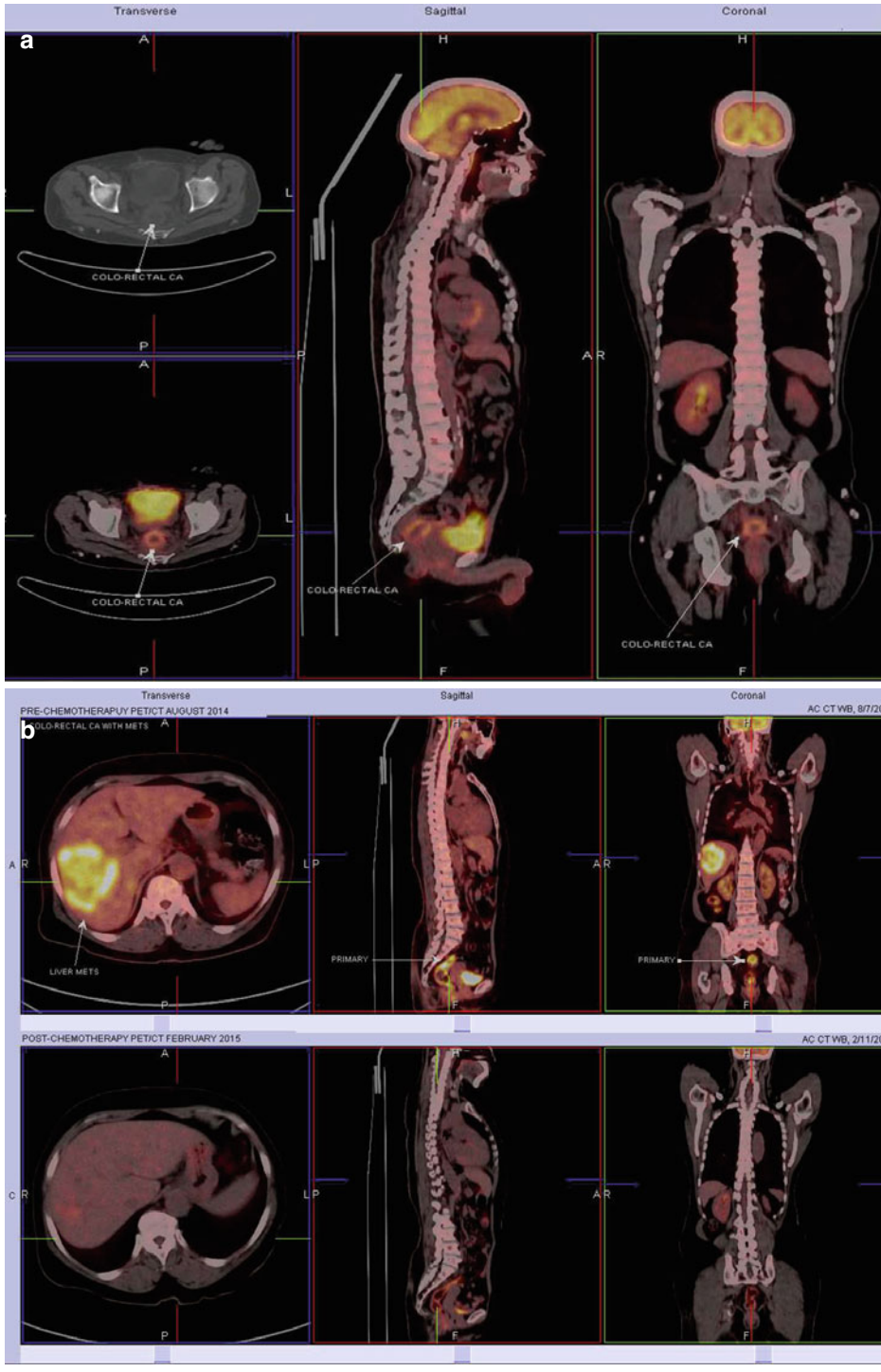

Fig. 20.2 (**a**) PET-CT scan of a patient following surgery and chemotherapy for rectosigmoid cancer. The scan shows significant rectal cancer recurrence with sigmoid involvement and mesenteric and left external nodal spread. Fat stranding noted in the mesorectal fascia on the CT component (non-FDG 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

colorectal surgery although PET-CT and ceCT provide similar information regarding hepatic metastases of CRC. Hence, PET-CT is routinely performed on all patients with metastatic CRC who are being evaluated for liver resection [17].

In a study by Even-Sapir et al. [18] on 62 patients, it was concluded that after surgical removal of rectal cancer, PET-CT is an accurate technique in the detection of pelvic recurrence [18]. Since metabolic changes under treatment are likely to precede anatomic alterations [19], 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.

20.4.5 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 [5]; 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 [16].
- PET imaging is most effective in the detection of cancer recurrence.
- PET-CT imaging is not only helpful for nearly all aspects 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) [16].

20.5 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 MR colonography, 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 (T-staging).
- 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.
- Based on changes in cellular activity observed on PET-CT images, treatment regimens may be changed.

20.6 Summary

The advantages and disadvantages of ultrasound, MRI and PET-CT are discussed in terms of CRC management. Nuclear medicine imaging shows physiological function and is helpful to assess for metastatic disease. Patients for MRI studies have to undergo extensive screening for metallic objects before entering the imaging suite. Each modality plays a complementary role in imaging patients with CRC.

References

1. Lincender-Cvijetic L, Banjin-Cardzic M, Vegar-Zubovic S, Vrcic D. Radiological imaging of rectal cancer. Acta Med Acad. [Review]. 2012;41(2): 199–209.
2. Liang TY, Anil G, Ang BW. Imaging paradigms in assessment of rectal carcinoma: loco-regional and distant staging. Cancer Imaging [Review]. 2012;12: 290–303.
3. Laghi A, Bellini D, Petrozza V, Piccazzo R, Santoro GA, Fabbri C, et al. Imaging of colorectal polyps and early rectal cancer. Colorectal Dis. [Research Support, Non-U.S. Gov't]. 2015;17(Suppl 1):36–43.
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. [Comparative Study]. 2012;23(5):530–4.
5. Tapan U, Ozbayrak M, Tatli S. MRI in local staging of rectal cancer: an update. Diagn Interventl Radiol. 2014;20(5):390–8.
6. Thornton E, Morrin MM, Yee J. Current status of MR colonography. Radiographics: a review publication of the Radiological Society of North America, Inc. [Research Support, Non-U.S. Gov't]. 2010;30(1): 201–18.
7. 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: a review publication of the Radiological Society of North America, Inc. [Review]. 2009;29(5):1451–66.
8. Dieguez A. Rectal cancer staging: focus on the prognostic significance of the findings described by high-resolution magnetic resonance imaging. Cancer Imaging. [Review]. 2013;13(2):277–97.
9. Rafaelsen SR, Vagn-Hansen C, Sorensen T, Ploen 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.
10. 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. [Review]. 2014;20(45): 16964–75.
11. Kaur H, Choi H, You YN, Rauch GM, Jensen CT, Hou P, et al. MR imaging for preoperative evaluation of primary rectal cancer: practical considerations. Radiographics: a review publication of the Radiological Society of North America, Inc. [Review]. 2012;32(2):389–409.
12. https://www.iaea.org/About/Policy/GC/GC51/GC51InfDocuments/English/gc51inf-3-att2_en.pdf. Accessed 26 July 2015.
13. http://nucleus.iaea.org/HHW/Radiopharmacy/VirRad/Introduction/Radiopharmaceuticals/. Accessed 26/7/2015.
14. Utility of PET scanning in the management of colorectal cancer. http://www.medscape.org/viewarticle/461315. Accessed 22 June 2015.
15. Basics of FDG. http://www.med.harvard.eduJPNMchetanbasicsbasics.html.mht. Accessed 2 July 2015.
16. Fact sheet: molecular imaging and colorectal cancer. http://www.snmmi.org/AboutSNMMI/Content.aspx?ItemNumber=5658. Accessed 22 June 2015.
17. 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. 240(6):1027–34; discussion 1035–6. [Medline].
18. Even-Sapir E, Parag Y, Lerman H, Gutman M, Levine C, Rabau M. Detection of recurrence in patients with rectal cancer: PET/CT after abdominoperineal or anterior resection. Radiology. 2004; 232(3):815–22. [Medline].
19. Vera P, Dubray B, Palie O, et al. Monitoring tumour response during chemo-radiotherapy: a parametric method using FDG-PET/CT images in patients with oesophageal cancer. EJNMMI Res. 2014;4:12.

21 Legal and Professional Requirements: A Framework for Practice

Richard Price

Abstract

Role development is a natural process and radiographers have had to adapt their practice as new and innovative technologies, and techniques have been and continue to be introduced. Radiology services are faced with the need to provide optimum, appropriate and timely care to our patients and service users. The requirement is that care has to be delivered at the expected standard. This chapter explores responsibility and accountability within a practice framework and the possible consequences of failing to provide a duty of care and practice at the required standard.

21.1 Introduction

The past 45 years have witnessed dramatic changes. For example, the introduction of computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound has increased the capacity and capability of imaging. Roles have not only developed but have been extended as radiographers adopt tasks traditionally undertaken by other disciplines. Image interpretation is the prime example of role extension in the modern era with the scope of radiographic practice extending beyond image acquisition for many to embrace image interpretation. Initially most of the reporting undertaken by radiographers, with the exception of ultrasound, was of the appendicular system, but over a period of just a decade, the scope of reporting practice advanced to include the full musculoskeletal system largely in trauma, mammograms, gastrointestinal studies, chest X-rays, MRI, CT and nuclear medicine studies.

The basic premise for all practice is that it is safe and effective and, where a role is extended, it has to be in the best interests of patients. In considering a practice framework, there has to be recognition that radiographers owe a duty of care to their patients and to those who are affected by their actions. The starting point is the relationship with an employer.

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21.2 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 the employee and the employer.

Employees are accountable to follow the reasonable instructions of the employer; this normally will be through their line manager. On the employer's side, the obligation is to take all reasonable care for the employee's safety. This would include ensuring a safe system of work, 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 a given situation. Both a manager and employee by virtue of their education, training and experience should have the background and skills to take the right decisions at the right time. For a manager to ask someone to perform a task for which he or she has not been trained would be unreasonable as it 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 an extended role task such as reporting?

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 to the case of reporting by radiographers, they 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 has to be assured of the competencies of the individual radiographer concerned.

The conditions place clear obligations on both the employee and the employer. In regard to training, it must be specific to the field of reporting and adequate means to the level and standard of education required. The threshold standard is normally specified by an approved course. If an employer has sent an employee on a course or provides a suitable alternative, then the training is recognised de facto.

Radiographer reporting is certainly recognised by the Society of Radiographers (SoR) as a legitimate activity for radiographers, and employers are unlikely to support training if they had no intention of recognising the task as suitable for their employees [2]. To consolidate the position, the employer will very likely have a scheme of work or guidelines that cover the reporting task. On that basis, the task can be seen to be delegated to radiographers by the employing authority probably via the clinical director.

The conditions listed above, although set out some time ago, provide important safeguards for any practitioner wishing to adopt an extended role task. Meeting the conditions to adopt an extended role is an important step, but continuing to practise has to be executed competently and safely.

21.3 Professional Regulation

Radiographers are practitioners with special skills and are placed in a position of trust by an employer and by society. Accountability to the public in the UK is through the regulatory body, the Health and Care Professions Council (HCPC) [3]. The title 'Radiographer' is protected in the law, and the use of the title by someone not on the HCPC register is a criminal offence.

We have seen that on an individual level, a radiographer is responsible for providing a duty of care for patients to the appropriate standard. The requirement here is for radiographers to practise within their scope of practice and not attempt tasks for which they are not competent. The Standards of Proficiency marks a threshold level for entry onto register [3]. Registrants not only have to maintain their competence but also continue to develop their practice throughout

their career. A radiographer who is unable to meet the Standards of Proficiency and Standards of Conduct, Performance and Ethics [4] can be investigated and as a consequence could be subject to the ultimate sanction of being removed from the register, thus prevented from practising and employment.

As practice changes over time, a professional body such as the SoR has a critical role in supporting and developing that practice. The SoR publishes guidelines such as its Code of Professional Conduct which includes the Scope of Professional Practice [2]. As a member of the organisation, a radiographer is agreeing to abide by its 'rules' and standards.

21.4 Duty and Standard of Care

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, although there would 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 as a result of a practitioner doing something that ought not to have been done or omitting to do something that should have done. A civil wrong is referred to as a 'tort' and is an unintentional violation of another person's rights, usually due to negligence; in other words 'carelessness'. A claim for compensation is subject to the common or case law which has been developed by judicial decisions over time through civil courts and tribunals. The common law is pertinent for practice as it determines the rights and duties individuals have towards each other [5]. Professional codes of conduct 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. Before negligence is 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 wrong doings 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 practitioner. However, it does not mean that an individual employee is unaffected by any action as he or she could be subjected to a disciplinary procedure by the employer plus a referral to their regulatory body who would be bound to investigate whether there is a case to answer and to take necessary action which could include removal, of the person's name from the register.

In most cases, it would be relatively straightforward to prove that a radiographer and the employer owed a duty of care to a patient but more difficult to prove (b) and (c) above. The Bolam test is used to determine whether the reasonable standard of care has been given and hence whether a practice has been negligent [6]. In the Bolam case, the patient was receiving electroconvulsive therapy. The doctor did not give any relaxant drugs, and 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 he 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. The Bolam case provides the 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. The specialism is key as it is reasonable to assume that the practitioner in that field has the skill and competence to undertake the duties required of him or her.

The direct implication for a reporting radiographer is that he or she must perform to the standard of the ordinary competent practitioner in the field, i.e., radiologists or where radiographer reporting is established by other radiographers. However a question often asked is: 'Does someone who is new to reporting 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 a course of training. One such approach is for a new practitioner to be directly supervised for an agreed number of reports and to have a mentor for a given period of time. To assure continuing competence, the reporter would be subject to audit and further training as appropriate.

21.5 A Practice Framework

So far we have considered essential information, much of it background, that a practitioner needs to be aware of when not only adopting a new task but throughout his or her continuing practice. Now let us consider some specifics about clinical reporting.

For many radiographers who have qualified in recent years, they have already developed a number of key skills on graduation which provide the basis for further progression. Requirements are clearly set out in the HCPC Standards of Proficiency [3] for radiographers. While all of the standards are complementary to providing the standard of care, two in particular are worth considering further:

> 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 every clinical radiographer will possess these skills upon graduation and may be appropriate for initial commenting, they are insufficient for formal clinical reporting. In addition, the SoR [2] sets out clear policy statements. Newly qualified radiographers, in relation to standard radiographic images, must:

- Have demonstrated competence in the assessment of image appearances to identify abnormalities and describe them in written form.
- Be competent in identifying normal image appearances, including normal anomalies.
- Be able to advise on further radiographic projections based on their clinical findings.

Experienced radiographers must demonstrate competence in undertaking and producing written preliminary clinical evaluations.

These statements consolidate the position of the radiographer in regard to clinical evaluation of images and do instil a different mind-set from when image acquisition and technical evaluation were prime considerations. However, there are further steps required before someone is recognised to undertake formal clinical reporting. Some of these we have considered such as further education and training which is adequate and specific to the reporting field and in this case CTC reporting. In the view of the SoR, this should be a College of Radiographers approved postgraduate qualification. Such a qualification is good practice, but legally, training that is approved and underwritten by an employer within its scheme of clinical governance would be adequate and specific; this could include in-house training. From a practitioner's perspective having achieved a qualification from an accredited course point of view would seem to be the preferred option for career development [7].

When a radiographer is at the stage to commence clinical reporting, he or she will do so within 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:

- 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 that should avoid a practitioner exceeding their scope of practice:

1. There is responsibility with accountability.
2. Radiographers have a duty of care to their patients.
3. 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.
4. You must follow the reasonable instructions of your employer.
5. An extension of role demands training.
6. Do not exceed the scope of your practice.
7. An understanding of what constitutes negligence.
8. Recognise the need for effective self-management of workload and be able to practise accordingly.
9. Understand the obligation to maintain a fitness to practise and the need for career-long self-directed learning.

21.6 Key Messages

- In considering a practice framework, 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 certainly recognised by the Society of Radiographers (SoR) as a legitimate activity for radiographers, and 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 the 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.
- Experienced radiographers must demonstrate competence in undertaking and producing written preliminary clinical evaluations.
- 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.

21.7 Summary

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 extending their role.

References

1. Department of Health and Social Security (1977) Department of Health and Social Security Health Circular (1977)22. The extended role of the clinical nurse. Legal implications and training requirements. Department of Health and Social Security: London.
2. Society of Radiographers. Code of professional conduct. 2013. From http://www.sor.org/learning/document-library/code-professional-conduct/statements-professional-conduct. Accessed 28 Dec 2015.
3. Health and Care Professions Council. Standards of proficiency for radiographers. 2013. From http://www.hpc-uk.org/assets/documents/10000DBDStandards_of_Proficiency_Radiographers.pdf. Accessed 28 Dec 2015.
4. Health and Care Professions Council. Standards of conduct, performance and ethics. 2012. From http://www.hcpc-uk.org/publications/standards/index.asp?id=38. Accessed 28 Dec 2015.
5. The Health Professions Order 2001. Statutory Instruments. Health Care and Associated Professions. 2002; 254. From http://www.legislation.gov.uk/uksi/2002/254/made. Accessed 28 Dec 2015.
6. Bolam v Friern Hospital Management Committee. 1 WLR 583. 1957. From http://www.e-lawresources.co.uk/Bolam-v--Friern-Hospital-Management-Committee.php. Accessed 28 Dec 2015.
7. Society of Radiographers. Preliminary clinical evaluation and clinical reporting by radiographers: policy and practice guidance. 2013. From https://www.sor.org. Accessed 28 Dec 2015.

Self-Assessment of CT Colonography Images

22

Joel H. Bortz, Aarthi Ramlaul, and Leonie Munro

Abstract

A range of 2D and 3D images are included in twenty self-assessment questions. The answers for each of the images are based on images and discussions in the chapters on CTC. In addition, we include comment on some questions, as well as CTC images with legends to expand on possible findings.

22.1 Introduction

Interpretation of both colonic and extracolonic images is essential in all CTC studies. Thirty-five 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. Some questions require knowledge of the E classification presented in Table 18.1. It is important to refer to C classification in Table 10.2 when interpreting CTC images. A C3 classification requires recommending colonoscopy follow-up, for example. Where applicable, reference is made to the reporting template in Chap. 19. Some answers include comments with additional information. Copies of some images with arrows are included in the comment to show pathology.

22.2 Self-Assessment Questions

Question 1

Lipoma is the most common of the non-epithelial tumours of the gastrointestinal tract. Describe the CT features of a colon lipoma image.

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Question 2
Describe the image appearances seen on Fig. 22.1a. State the likely findings.

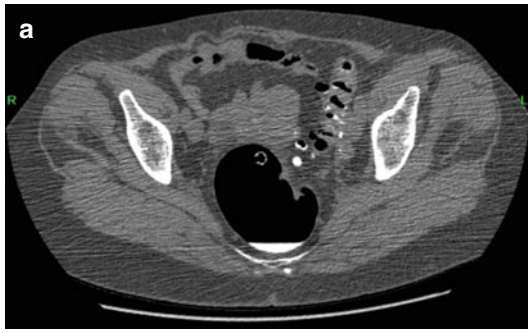


Fig. 22.1 (**a**) 2D axial view

Question 3
Describe the supine axial chest image appearances seen on Fig. 22.1b. Would you request an additional view prior to making an informed interpretation, and if so what additional view would you request and why?

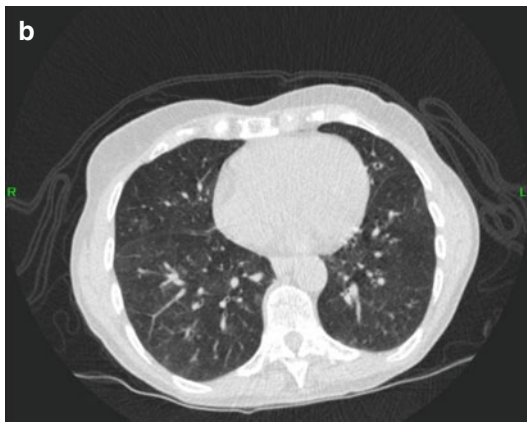


Fig. 22.1 (**b**) 2D supine axial view

Question 4
Describe the image appearances of the structure illustrated on Fig. 22.1c(i), (ii). State the likely findings.

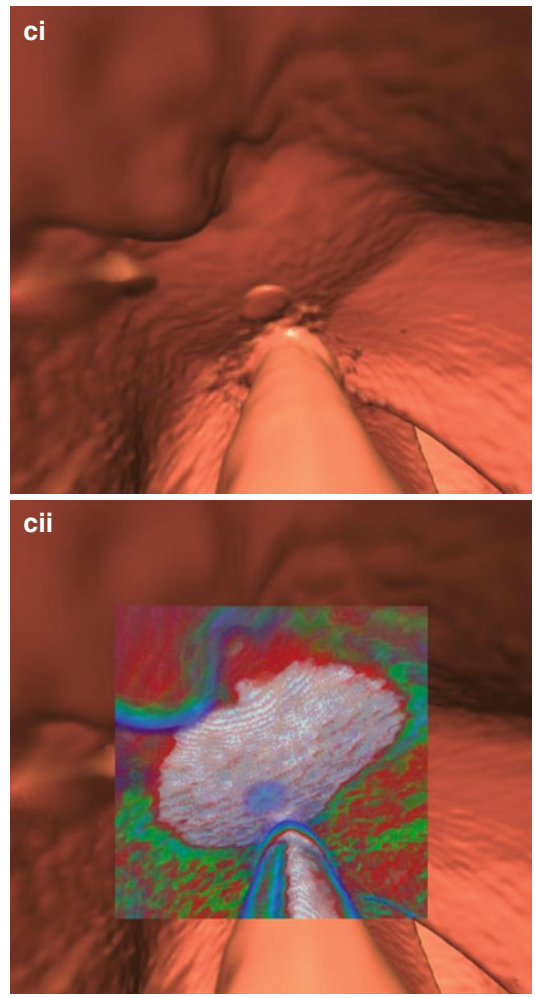


Fig. 22.1 (**c**)(**i**) 3D endoluminal view. (**ii**) TD view

Question 5

A 55-year-old female presented for a screening CTC examination. Describe the image appearances seen on Fig. 22.1d. State the likely findings. Under which E classification would you list your findings?

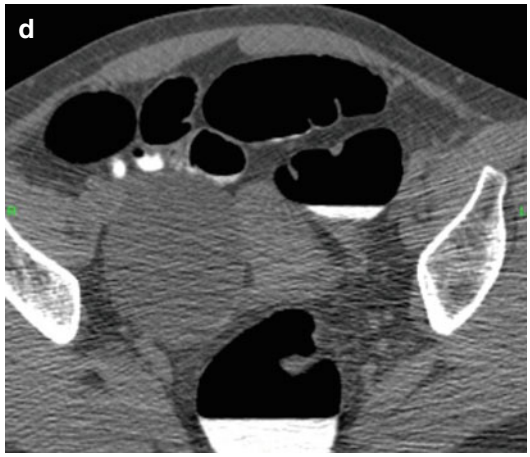


Fig. 22.1 (**d**) 2D axial view

Question 6

An asymptomatic patient presented for a screening CTC examination. Describe the image appearances on Fig. 22.1e. What pathology are the appearances consistent with? Under which E classification would you list your findings?

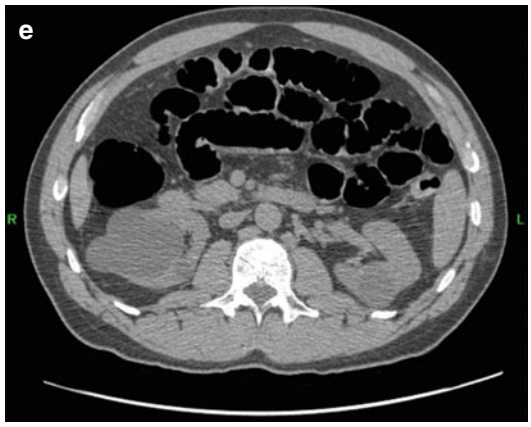


Fig. 22.1 (**e**) 2D supine axial view

Question 7

An asymptomatic 65-year-old patient presented for CTC. Describe the image appearances seen on Fig. 22.1f(i), (ii). What is the likely diagnosis?

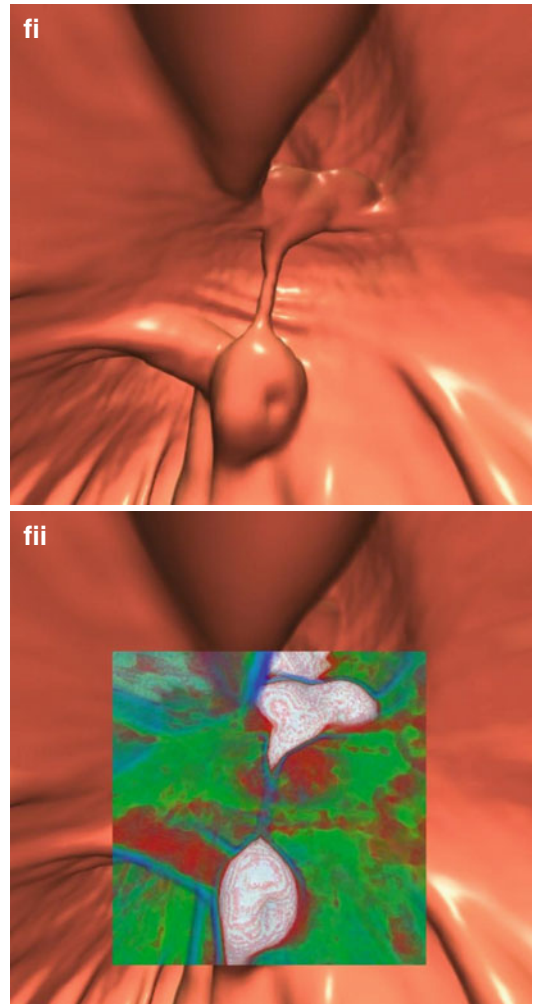


Fig. 22.1 (**f**)(**i**) 3D endoluminal view. (**ii**) TD of the same patient

Question 8

An asymptomatic 60-year-old patient presented for a CTC examination. Describe the image appearances on Fig. 22.1g(i)–(iv). State the likely findings. Under which C classification would you list your findings?

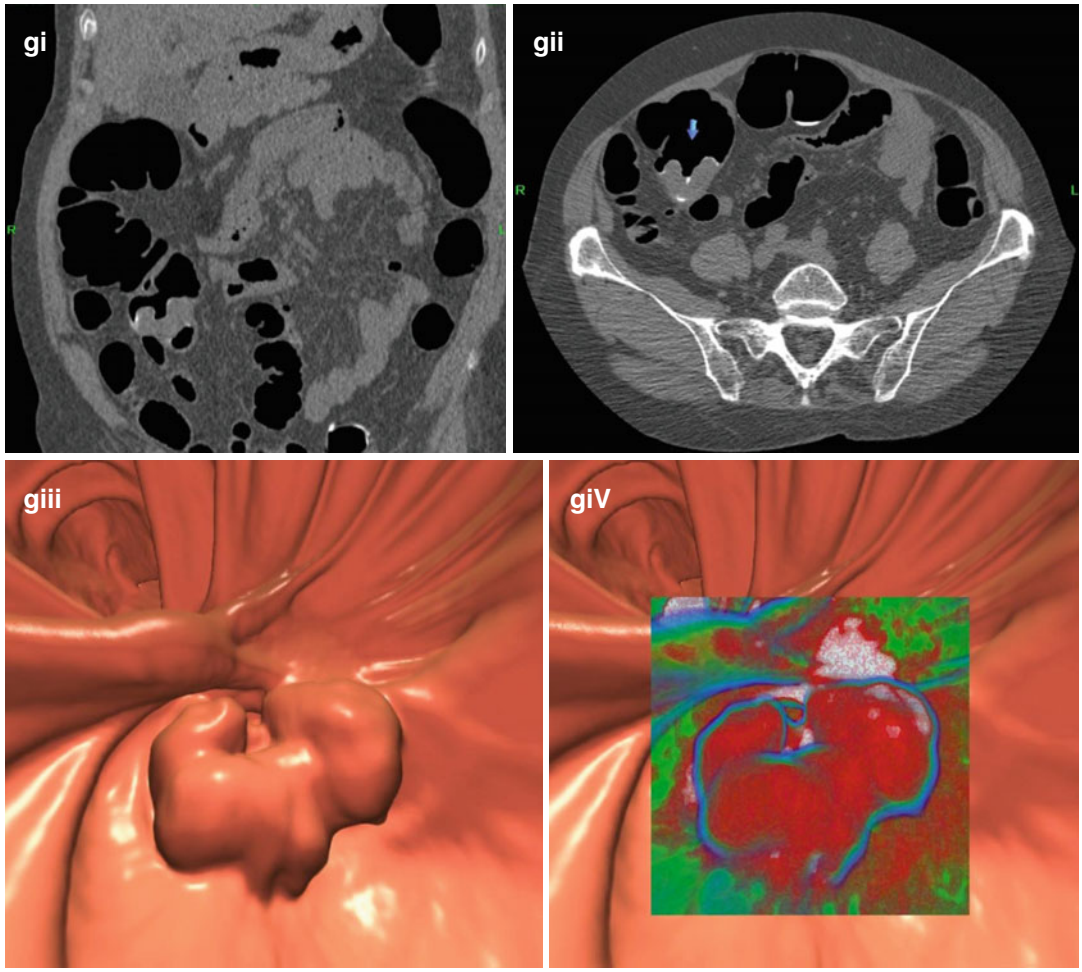


Fig. 22.1 (**g**)(**i**) 2D coronal image. (**ii**) 2D axial image. (**iii**) 3D image. (**iv**) TD image

Question 9

Describe the image appearances seen in Fig. 22.1h(i), (ii). State the likely findings.

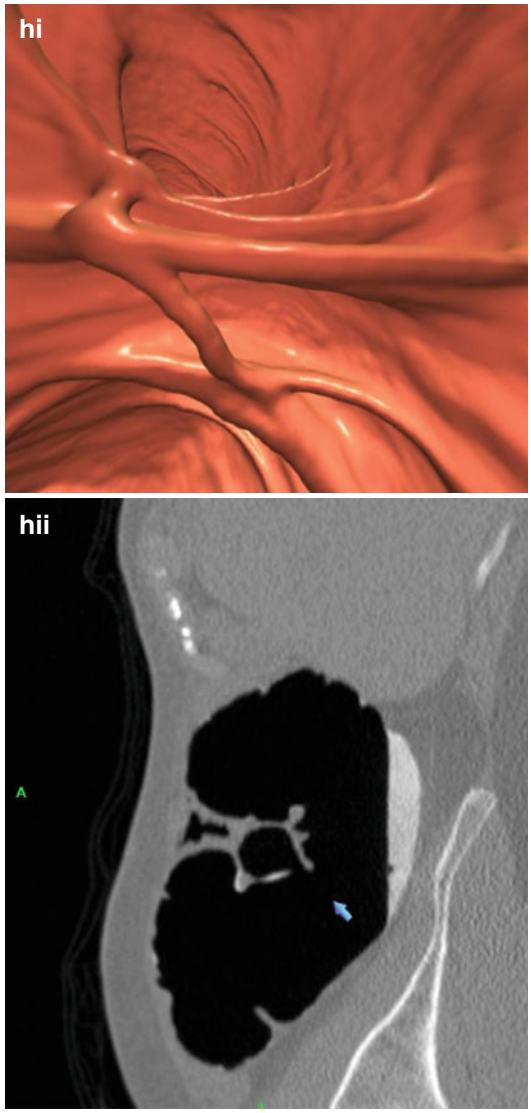


Fig. 22.1 (**h**)(**i**) 3D image. (**ii**) Sagittal view

Question 10

Figure 22.1i is an image of a colon-map. Describe the technique for evaluating a colon-map. Evaluate this image and state whether this represents a normal colon-map. If not, what is the likely diagnosis?

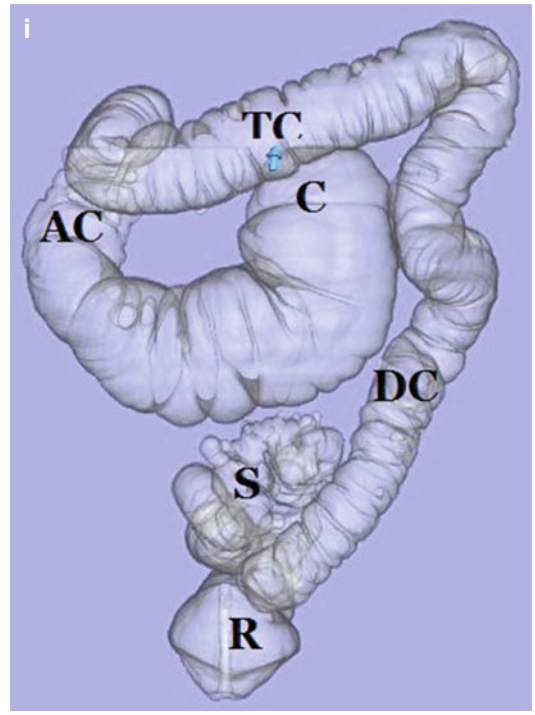
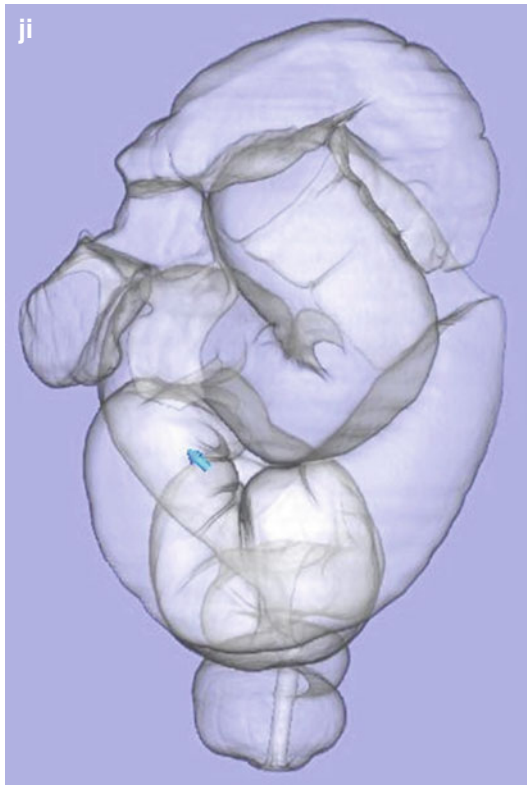


Fig. 22.1 (**i**) Colon-map

Question 11
A 64-year-old patient with history of lumbar sympathectomy presents for a CTC examination. Describe the image appearances seen on Fig. 22.1j(i), (ii). State possible reason for these findings.



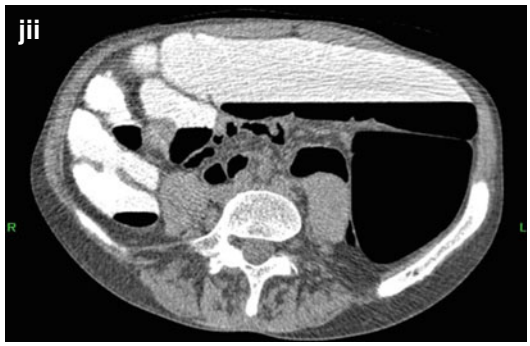
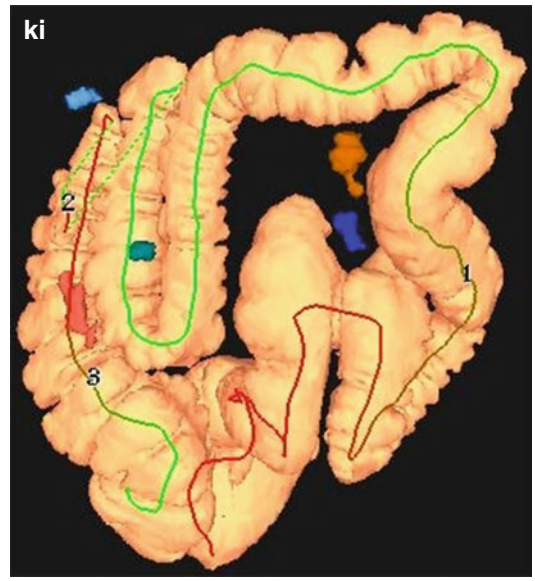


Fig. 22.1 (**j**)(**i**) Colon-map (**ii**) 2D axial view

Question 12
A 60-year-old asymptomatic patient with a history of previous surgery presented for a screening CTC examination. Describe the image appearances seen on Fig. 22.1k(i), (ii).



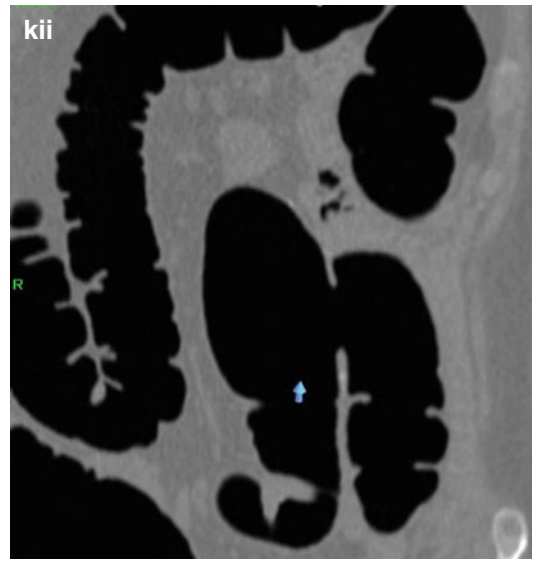


Fig. 22.1 (**k**)(**i**) Colon-map. (**ii**) 2D sagittal view

Question 13

Describe the image appearances seen on Fig. 22.1l(i), (ii). State the likely findings.

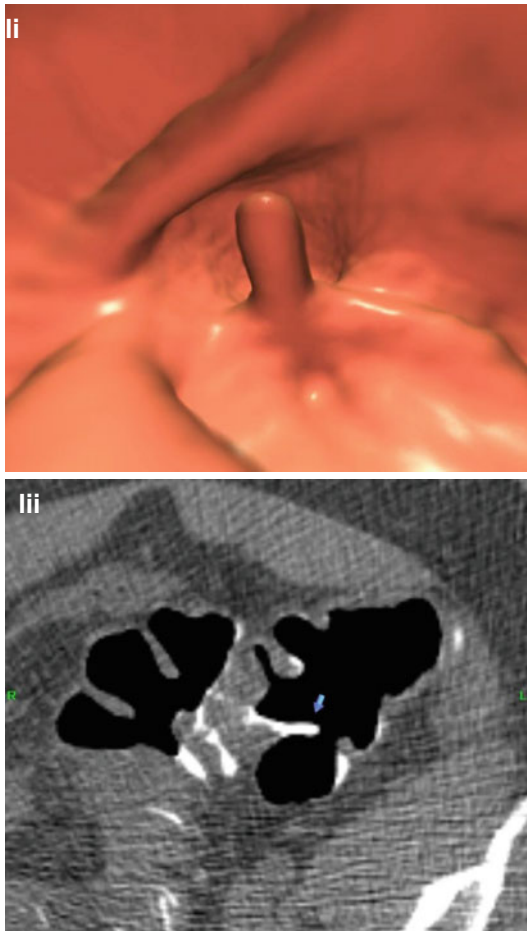


Fig. 22.1 (**l**)(**i**) 3D view. (**ii**) 2D view

Question 14

Figure 22.1m(i)–(iii)is of the same patient. Describe the image appearance seen on Fig. 22.1m(i). State the likely cause of your finding? What additional check/s would you carry out to determine whether this is a lesion? Explain your answer. State the likely findings on the remaining figures.

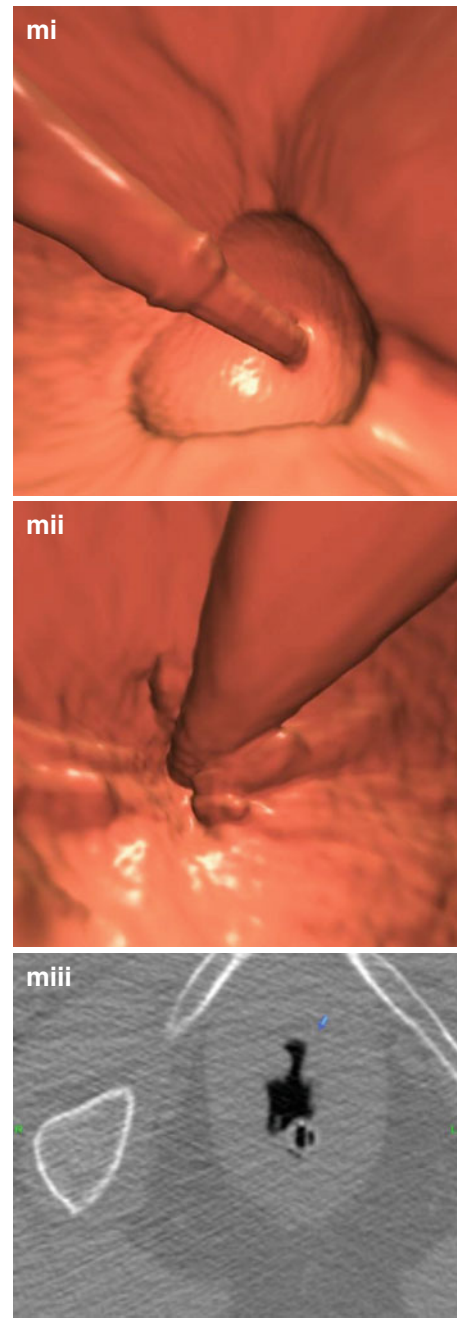


Fig. 22.1 (**m**)(**i**) 3D supine endoluminal view. (**ii**) 3D view. (**iii**) 2D axial

Question 15
Describe the image appearances seen on Fig. 22.1n(i), (ii). State the likely findings.

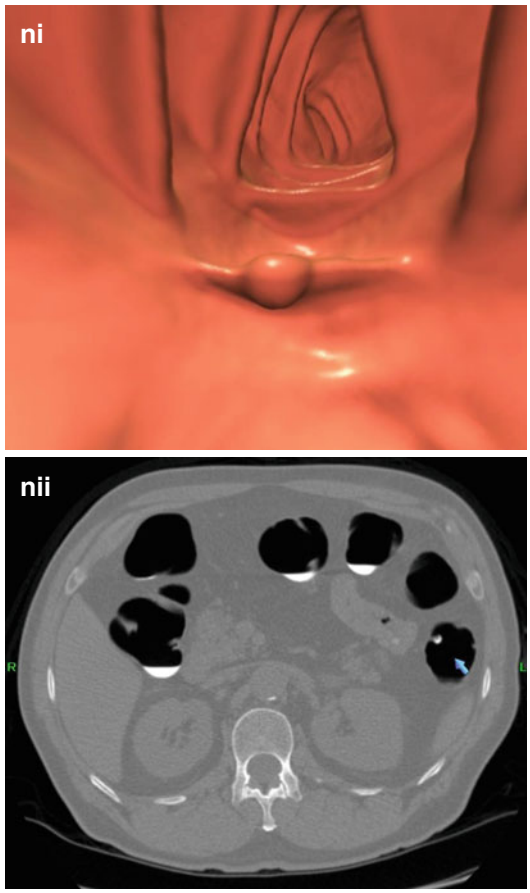


Fig. 22.1 (**n**)(**i**) 3D image. (**ii**) Axial image

Question 16
A 50-year-old patient with a family history of colorectal cancer presented for a CTC examination. Describe the image appearances seen on Fig. 22.1o(i), (ii). State the likely findings.

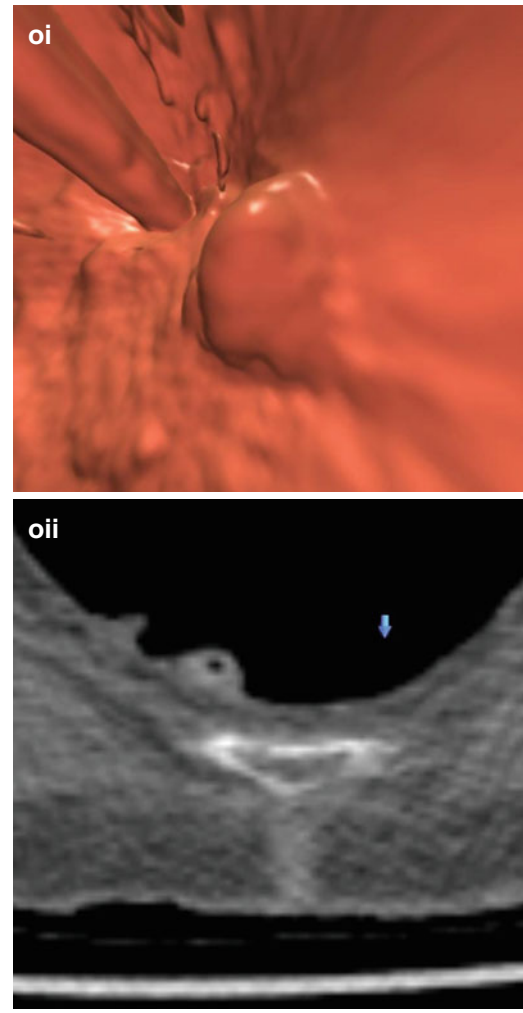


Fig. 22.1 (**o**)(**i**) 3D image. (**ii**) 2D image

Question 17

A 60-year-old patient is undergoing a surveillance CTC examination. Describe the image appearances seen on Fig. 22.1p(i)–(iii). State the likely findings.

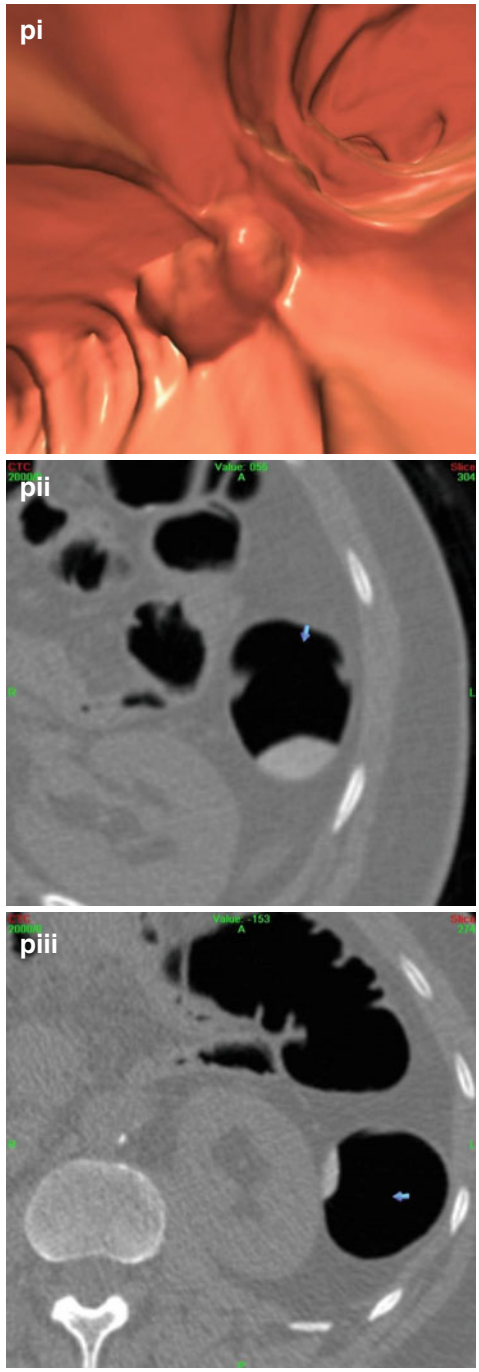


Fig. 22.1 (**p**)(**i**) 3D view. (**ii**) 2D supine axial view. (**iii**) 2D RLD view

Question 18

A 50-year-old patient presents for a screening CTC examination. He mentioned that there was a painful and swollen bulge near his umbilicus. Describe the image appearances seen on Fig. 22.1q. State the likely findings. Under which E classification would you list your findings?

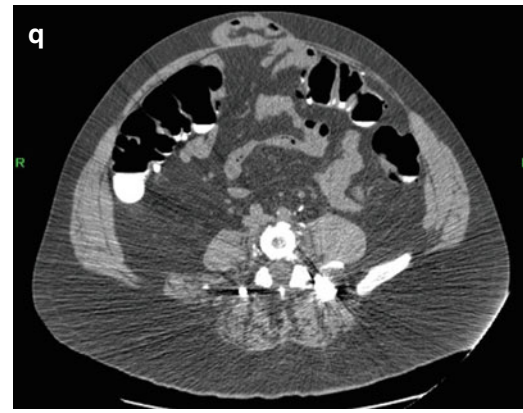


Fig. 22.1 (**q**) 2D axial view

Question 19

Describe the image appearances seen on Fig. 22.1r. What are the two likely causes of this appearance? Can this image be improved? Explain your answer.

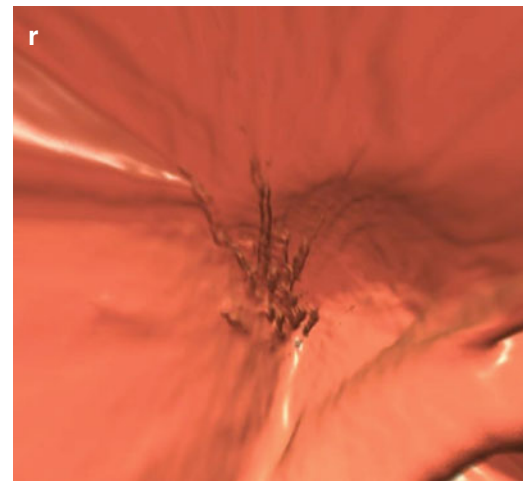


Fig. 22.1 (**r**) 3D image

Question 20
A 50-year-old female presented for screening CTC. Describe the image appearances seen on Fig. 22.1s(i), (ii). State the likely findings.

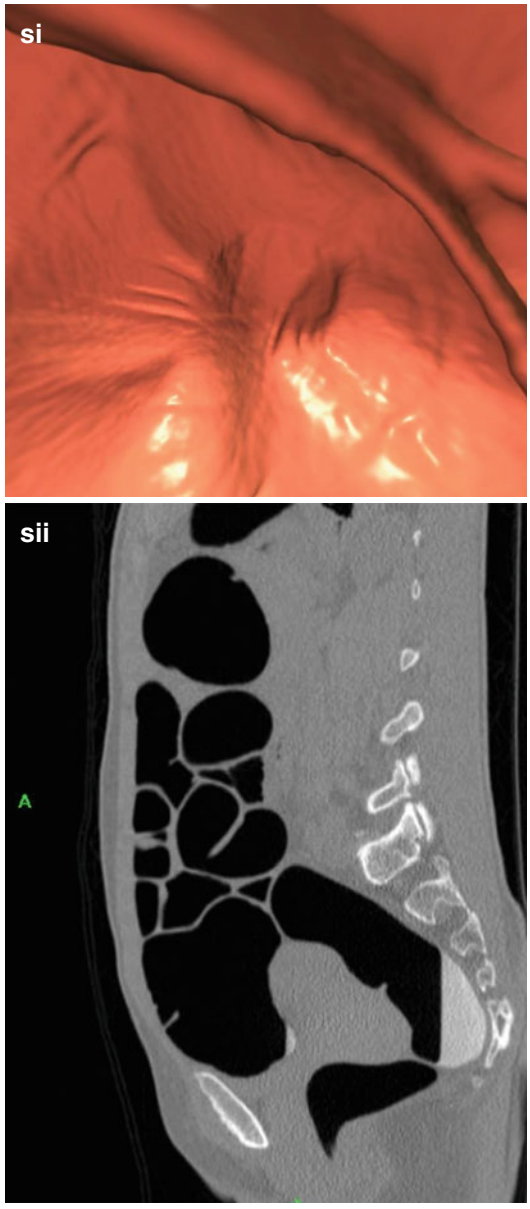


Fig. 22.1 (**s**)(**i**) 3D image. (**ii**) Sagittal image

22.3 Answers

Question 1
On CT images the appearance of a lipoma is uniform, with a fat equivalent density range between −80 and −120 Hounsfield units (HU). On TD a lipoma is pure green in colour.

Question 2
There is an appearance of an atrophic rectus abdominis muscle. There is evidence of diverticula in the sigmoid colon. Findings: diverticular disease.

Comment
Possible causes of an atrophic rectus abdominis muscle:

- Inactivity
- Extra-peritoneal surgical approach for infrarenal aortic repair

Question 3
No pathology evident on 2D supine view. Yes an additional view is required. Essential to check prone series of the chest as there is often more coverage and certain lesions, such as those from lung cancer, may only be detected on prone imaging.

Comment
The value of a prone chest series is highlighted in Fig. 18.4g(ii) which shows a non-calcified lesion in the left lung.

Question 4
A round mass is noted in close proximity to the rectal catheter. The TD view shows the mass as blue indicating negative values, such as air. The likely cause is an air bubble.

Question 5
Ovarian cyst on the right with moderate clinical importance thus E3. There is no other pathology evident. No other work-up required.

Comment
As per the reporting template Table 19.2:

- Always comment on any further work up needed.
- Include a disclaimer: Note that extracolonic evaluation is limited by the low-dose CT technique and lack of i.v. contrast.

Question 6
Bilateral renal cysts noted. These are of low clinical importance thus E2 classification. No other extracolonic and colonic pathology noted.

Question 7
3D view shows a lesion resembling a pedunculated polyp. The TD shows the lesion to be barium. Finding is that the lesion is stool simulating a pedunculated polyp.

Comment
Tagging is important as stool is a potential pitfall thus important to determine that the lesion seen is real or merely an artefact.

Question 8
Lobulated caecal mass indicating tumour seen on the coronal and axial images. A circumferential lobulated caecal mass is seen on the 3D image. This mass on the TD is of high intensity tissue consistent with a mass. Likely finding would be an adenocarcinoma. This is a C4 classification thus surgical referral essential.

Question 9
Abnormal haustral fold noted on both the 3D and sagittal views. Bowel size large on sagittal view indicating caecum and ascending colon.

Comment
Figure 22.2 shows the abnormal fold and the usefulness of barium tagging.

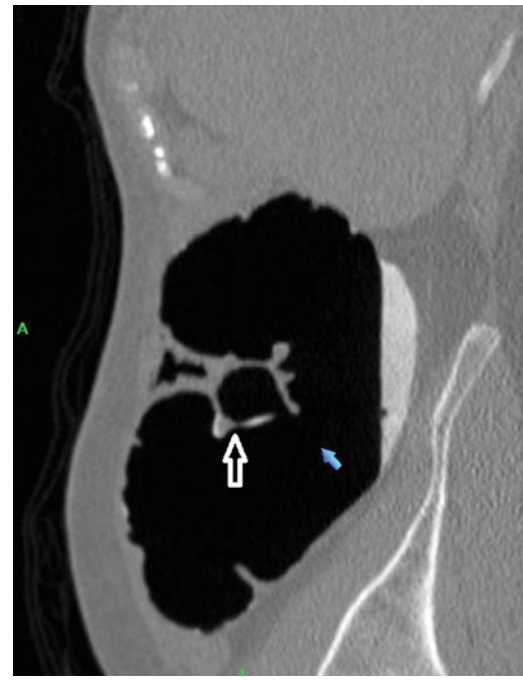


Fig. 22.2 Note barium on abnormal fold inferiorly (*open white arrow*)

Question 10
When assessing a colon-map, it is important to check all colon segments. The caecum is not in the right iliac fossa but facing upwards under the transverse colon. This indicates a malrotated caecum. There is a pedunculated polyp in the transverse colon (TC) near the hepatic flexure. Diverticulosis in the sigmoid colon.

Comment
A reader should carefully check all colon segments for pathology. Figure 22.3. shows the pedunculated polyp.

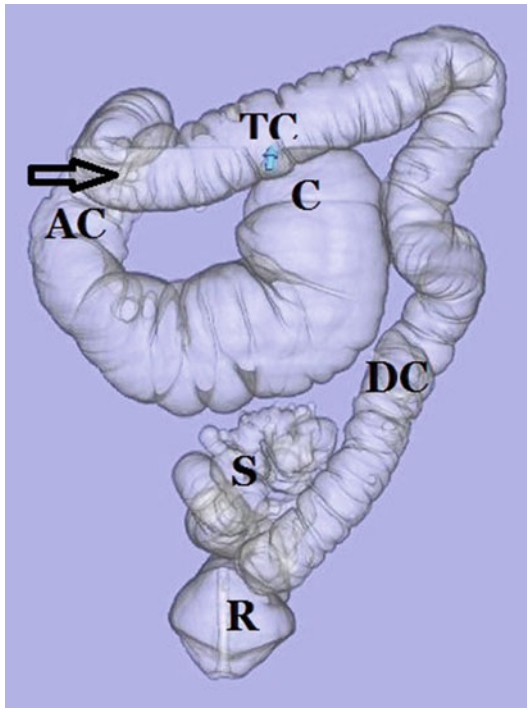


Fig. 22.3 *Arrow* indicates the pedunculated polyp

Question 11
Colon-map shows a well-distended colon. Redundancy of sigmoid and transverse colon noted. Excessive fluid noted in the transverse colon in the prone view. Possible cause could be due to previous lumbar sympathectomy.

Question 12
Anastomosis-sigmoid to descending colon on colon-map. Side-to-side anastomosis-sigmoid – descending colon on the sagittal view.

Comment
Previous surgical resection of part of descending colon for underlying diverticular disease. Figure 22.4(i), (ii) shows site of anastomosis.

Question 13
A vertical projection is seen on the 3D. The 2D axial view shows barium outlining stool and simulating a polyp.

Comment
Value of tagging evident in the 2D view.

Question 14
3D supine endoluminal view shows rectal catheter with meniscal filling defect. Normal appearance. However, to exclude pathology, it is important to turn patient prone and deflate balloon because an inflated balloon may obscure lesions. On the prone 3D (Fig. 22.1m(ii)), large haemorrhoids are visible. These are confirmed on the 2D axial prone view (Fig. 22.1m(iii)).

Question 15
Polypoidal mass noted on the 3D image. On the 2D view, the mass is covered in barium indicating stool.

Comment
The complementary role of 3D and 2D is evident. Importance of tagging is well shown to distinguish stool from a polyp.

Question 16
3D view shows a polypoidal mass. 2D axial shows air in structure indicating stool and not a polyp.

Comment
Stool may be covered by barium and frequently contains small bubbles of air giving it a heterogeneous appearance. Air within stool is not identified on 3D viewing.

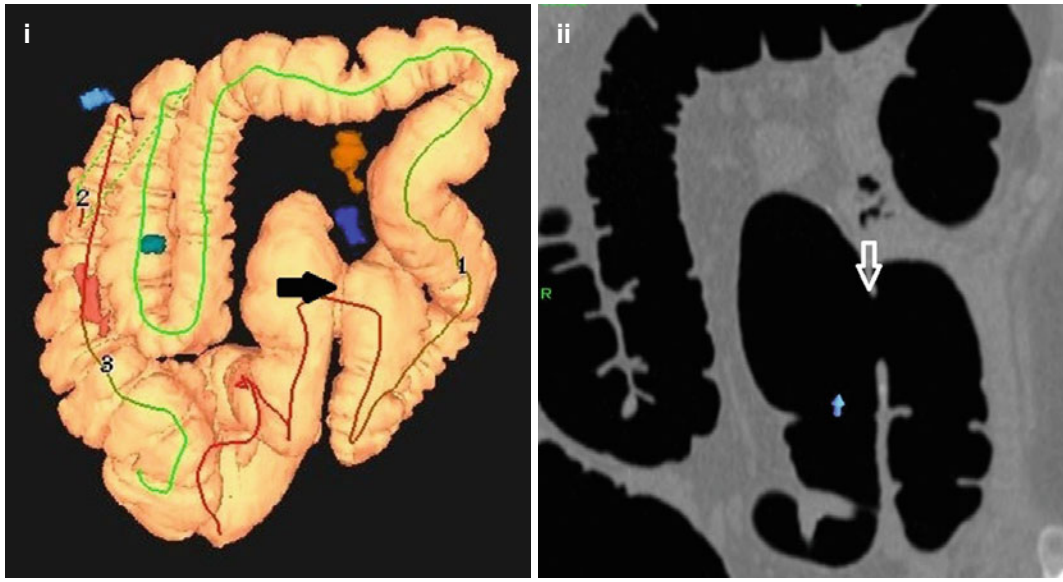


Fig. 22.4 (**i**) *Black arrow* indicates side to side anastomosis. (**ii**) Site of anastomosis (*open white arrow*)

Question 17

3D view shows a polypoidal mass. Multiple diverticula are visualised. 2D view supine view shows the barium coated mass on the posterior wall of colon. The barium coated mass moved to adjacent wall of colon in the RLD view indicating stool and not polyp.

Comment

Important to scan a patient in different positions to check whether a mass moves as illustrated in these 2D images. Most typically stool will move to the opposing wall when a patient is turned from the supine to the prone position. A sessile polyp does not move with postural change. However, beware of the pedunculated polyp on a long stalk which may move with postural change.

Question 18

There is an umbilical hernia containing bowel. Previous lumbar spine surgery noted. This extracolonic finding is an E3 with moderate clinical importance which may require surgical intervention.

Comment

- This finding is of moderate clinical importance.
- Further work-up may be indicated.
- In nearly all cases of asymptomatic patients, these lesions prove to be benign.

Question 19
Beam hardening – probably due to hip prosthesis or surgical clip. If available there is software that could be applied to improve the 2D image of this artefact (e.g. Smart Metal Artefact Reduction – GE ®); O-MAR (Metal Artefact Reduction for Orthopedic Implants – Philips ®).

Comment
The use of such software is discussed in Chap. 7.

Question 20
An extrinsic impression is seen below the haustral fold on the 3D view. Sagittal 2D view shows uterus indenting posterior wall of caecum. Large uterus pushing on colon.

Comment
A 2D view will show cause of the 3D appearance of an extrinsic impression that may simulate a mass. Figure 22.5 shows the cause of the 3D appearance.

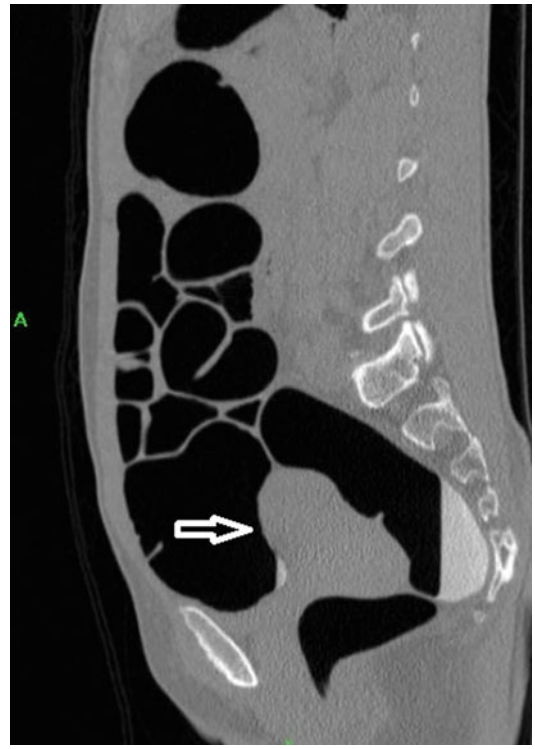


Fig. 22.5 *Open white arrow* shows enlarged uterus pushing on posterior wall of caecum. No follow-up required

Glossary

Air insufflation 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

Hypertonic Refers to a solution that has a higher salt concentration than normal body cells resulting in an increase in osmotic pressure

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

Prejudicial Relates to bias and prejudice with the intent to cause harm

Polyp (colon) Is an abnormal growth of tissue from a mucous membrane and is found on the inner lining of the colon

Pneumomediastinum The presence of air within the mediastinum

Pneumopericardium The presence of air or other gas within the pericardial cavity surrounding the heart

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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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