

Computed tomography colonography for the practicing radiologist: A review of current recommendations on methodology and clinical indications

Paola Scalise, Annalisa Mantarro, Francesca Pancrazi, Emanuele Neri

Paola Scalise, Annalisa Mantarro, Francesca Pancrazi, Emanuele Neri, Department of Translational Research and New Technologies in Medicine and Surgery, Diagnostic and Interventional Radiology, 56124 Pisa, Italy

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Correspondence to: Emanuele Neri, MD, Professor, Associate Professor of Radiology at the University of Pisa, Department of Translational Research and New Technologies in Medicine and Surgery, Diagnostic and Interventional Radiology, Via Paradisa 2, 56124 Pisa, Italy. emanuele.neri@med.unipi.it
Telephone: +39-050-995551
Fax: +39-050-997316

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Abstract

Colorectal cancer (CRC) represents one of the most

relevant causes of morbidity and mortality in Western societies. CRC screening is actually based on faecal occult blood testing, and optical colonoscopy still remains the gold standard screening test for cancer detection. However, computed tomography colonography (CT colonography) constitutes a reliable, minimally-invasive method to rapidly and effectively evaluate the entire colon for clinically relevant lesions. Furthermore, even if the benefits of its employment in CRC mass screening have not fully established yet, CT colonography may represent a reasonable alternative screening test in patients who cannot undergo or refuse colonoscopy. Therefore, the purpose of our review is to illustrate the most updated recommendations on methodology and the current clinical indications of CT colonography, according to the data of the existing relevant literature.

Key words: Colorectal cancer; Computed tomography colonography; Colorectal polyps; Virtual colonoscopy; Screening

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Core tip: Computed tomography colonography (CT colonography) was first introduced in 1994 and since then it rapidly evolved with considerable improvements achieved in the technique. CT colonography allows a minimally-invasive evaluation of the entire colon with elevated level of patient acceptance, actually representing the radiological examination of choice in colorectal cancer diagnosis. Furthermore, beyond diagnostic purposes, great interest is rising in CT colonography application as a screening tool for colonic cancer on individual basis in asymptomatic patients at average-risk. Our objective is to illustrate the current literature concerning CT colonography to better delineate its major clinical indications and the most updated recommendations on the technique methodology.

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INTRODUCTION

Colorectal cancer (CRC) actually represents one of the most relevant causes of morbidity and mortality in Western societies^[1]. According to the widely accepted adenoma-to-carcinoma sequence, colorectal adenocarcinoma development is a multi-step process. Firstly, sequential accumulation of genetic and epigenetic mutations in specific genes causes the transition from normal epithelium to hyperproliferative mucosa, then it gives rise to a benign adenoma which could degenerate into carcinoma in about 10 years^[2]. Given this carcinogenic pathway, population-screening programmes play a key role in bowel cancer prevention by detecting and removing pre-symptomatic lesions in early stage.

CRC screening is actually based on faecal occult blood testing (FOBT), which is currently employed in several European countries with significant reduction in number of deaths from CRC^[3,4].

Optical colonoscopy (OC) still remains the gold standard screening test for CRC detection: It is indicated in FOBT-positive or symptomatic patients and as preventive strategy in patients at increased risk of CRC^[5,6]. However, it is burdened by scarce patients' compliance, so alternative solutions are needed to improve patient adherence to screening programmes. Computed tomographic colonography (CT colonography) constitutes a reliable, minimally-invasive method to rapidly and effectively evaluate the entire colon for clinically relevant lesions; it shows high sensitivity in polyps and CRC detection and might selectively and non-invasively filter out those patients who would benefit most from therapeutic OC^[7-10].

CT colonography may represent a reasonable alternative screening method in patients who cannot undergo or refuse colonoscopy and would otherwise remain unscreened; in fact, the benefits of CT colonography employment in CRC mass screening are actually under evaluation and its potential role as first-line screening modality is emerging. In the setting of CRC screening in asymptomatic adults at average-risk, the diagnostic performances of CT colonography were approximately equal to OC in terms of the detection of clinically relevant lesions^[11]. In 2011, some authors reported that, even if CT OC showed higher pooled sensibility than colonoscopy only in a specific subgroup of patients with polyps between 8 and 10 mm, CT colonography was efficient in terms of cost per QALY in comparison to no screening; furthermore the evidence for CT colonography if compared to no screen was favourable for CT colo-

graphy screening^[12].

The purpose of our review is to illustrate the most updated recommendations on methodology and the current clinical indications of CT colonography, according to the data of the existing relevant literature.

To collect the evidence contributing to this work, two independent reviewers carried out a systematic literature review in MEDLINE, Cochrane Library, Scopus and Google Scholar. The research was limited to English language papers from 1997 to 2015. Studies were considered eligible for inclusion if focused on CT colonography technical aspects, methodology and current clinical practice. The majority of relevant articles were searched by using the following Medical Subject Headings, or MeSH, terms as keywords: Computed tomography colonography, virtual colonoscopy, computed tomography colonoscopy, colography, or virtual endoscopy. Additional potentially relevant papers were identified by browsing bibliographies and references listed in primary sources and in relevant guidelines and systematic reviews. A final selection of 115 relevant studies was included in the review.

DISCUSSION

Indications to CT colonography

The recent European Society of Gastrointestinal Endoscopy (ESGE)/European Society of Gastrointestinal and Abdominal Radiology (ESGAR) consensus for CT colonography indications produced by the ESGE and ESGAR, integrated by an updated literature review are listed as follows^[13].

CT colonography and diagnosis of colorectal neoplasia:

CT colonography is recommended as the radiological examination of choice in CRC diagnosis, enabling the assessment of local tumor invasion, lymph nodes, and distant metastases. In case of obstructing cancers, it allows bowel evaluation proximally to the lesion to exclude synchronous lesions^[14,15]. In the specific context of laparoscopic surgery, CT colonography may help in better tumor localization/segmental mapping even in obstructive lesions, and permits a precise measurement of the distance from the anal canal^[16].

Patients with abdominal symptoms suggestive of CRC:

Patients with CRC might present highly non-specific symptoms, such as abdominal pain or discomfort, rectal bleeding, iron-deficiency anaemia, and unintended weight loss^[17]. CT colonography is considered as an acceptable alternative investigation to better investigate these patients, especially when OC cannot be performed or is contraindicated.

CT colonography following incomplete colonoscopy:

CT colonography is promoted as the imaging modality of choice after incomplete OC. Incomplete OC, defined as a failure to intubate the caecum, may occur due to several reasons, such as patient discomfort or

intolerance to the procedure, looping of the scope, poor bowel preparation, redundant colon, colonic spasm or looping, acute angle flexures and tortuosity and colonic obstruction caused by neoplastic or non-neoplastic stenosis (*i.e.*, adherences from previous surgery)^[18]. CT colonography might overcome these technical limitations and enlighten the causes of OC failure. If OC is incomplete, CT colonography should be performed preferably the same or next day to reduce patient discomfort avoiding additional bowel preparation; however, CT colonography should be delayed if an endoscopic resection has been performed during OC^[19]. In case of obstructing CRC, preoperative contrast-enhanced CT colonography might be useful in detecting and localizing synchronous colonic lesions and in malignant lesions staging^[20,21].

CT colonography and screening for CRC in patients with family history of CRC: ESGAR and ESGE do not recommend CT colonography as primary test in screening or individuals at average or high-grade risk to develop CRC and/or with positive first-degree family history of CRC. However, CT colonography may have a role as CRC screening test on an individual basis, after adequate patient information about its characteristics, benefits and risks.

CT colonography within a screening program, following positive faecal testing with incomplete/unfeasible colonoscopy: In 2008, the American Cancer Society, the US Multi-Society Task Force on CRC and the American College of Radiology released the consensus guidelines on CRC screening, which for the first time included CT colonography among the screening tests to be offered to asymptomatic individuals at average-risk^[3,22]. Individuals are considered to be at average-risk in absence of the following conditions: Clinical symptoms, personal history of CRC, adenomatous polyps or inflammatory bowel diseases, family history of advanced neoplasia^[23]. In particular, CT colonography is strongly endorsed in case of a positive FOBT or faecal immunochemical test coupled with incomplete or unfeasible OC, in particular in patients unable or unwilling to undergo OC^[24].

CT colonography following curative-intent resection of CRC: After curative-intent resection of CRC, the current surveillance guidelines include a combination of clinical assessment, serum carcinoembryonic antigen testing, OC, and contrast-enhanced CT^[25]. CT colonography with intra-venous (IV) contrast medium injection is able to detect local recurrence, metachronous disease, and extracolonic distant metastases, but it may represent an alternative investigation in surveillance only in patients in whom OC is unfeasible, due to the lack of robust and evidence-based data^[15,17]. CT colonography is also useful to demonstrate post-surgical colonic anatomy and offers information about wall morphology of the anastomosis^[18,26].

CT colonography following polypectomy: After polypectomy, patients should undergo endoscopic surveillance since they are likely to develop metachronous lesions and CT colonography should be performed in patients at high-risk polyps only if OC is unfeasible. However, patients' adherence to follow-up is extremely variable and generally poor in clinical practice, hence follow-up with CT colonography might be suggested as an alternative option for those patients unwilling to undergo OC^[27]. The frequency intervals for follow-up remain controversial and are based on the findings of the first colonoscopy (size, number, and histology of the removed polyps). CT colonography should not be employed as a surveillance test after polypectomy in patients with long-standing history of ulcerative colitis or Crohn's disease and/or hereditary cancer predisposing diseases (*i.e.*, hereditary non-polypoid CRC, Lynch syndrome and APC-associated polyposis conditions) due to the highly increased risk of developing CRC^[28,29].

Endoscopic polypectomy following CT colonography: If at least one polyp greater than 6 mm in diameter is detected at CT colonography, endoscopic polypectomy is required. Same-day polypectomy has to be considered as a possible option after CT colonography performed with full bowel preparation, thus it is necessary to consider related technical and logistical factors, including patient consent.

Whether a lesion detected at CT colonography is not confirmed by a high quality OC, CT colonography findings should be carefully reviewed. However, if radiological confidence for the presence of a lesion greater than 10 mm remains high, early repetition of colonoscopy should be considered^[13].

CT colonography in patients with contraindications to OC: CT colonography might be performed in the evaluation of patients with contraindications to OC or refusing other screening options^[30]. In particular, this group of patients includes frail or immobile patients, often with advanced age, who cannot be sedated due to severe medical comorbidities or under anticoagulation therapy, with a previous history of difficult or incomplete OC. It is important to underline that OC is burdened by an increased risk of perforation and bleeding especially in elderly patients and in those undergoing anti-coagulant therapy^[31,32].

Future emerging indications: New emerging indications of CT colonography include the evaluation of patients with sigmoid colonic stoma and those affected by deep pelvic endometriosis^[33-35]. Furthermore, it could be useful in chronic diverticular disease, where it could improve the differential diagnosis between inflammatory vs neoplastic stenosis^[36-38]. In this setting, the role of CT colonography is controversial in estimating the parietal involvement caused by inflammatory bowel diseases and there are only few studies reporting the performances of CT colonography in such setting^[39].

However, it might have a potential application in the evaluation of endoluminal, intramural and extra-colonic findings and, to some degree, allows differential diagnosis between ulcerative colitis, Crohn's disease and other inflammatory conditions^[40].

The potential role of CT colonography as a first-line CRC population screening modality is currently under debated. Several studies have shown that CT colonography has a wider public acceptance if compared to OC^[41-43]. The Dutch trial showed an increased participation rate at the screening program with CT colonography than OC (34% vs 22%; $P < 0.0001$)^[44]. Even if these results are extremely promising, more data on patient adherence to CT colonography-based screening programs and cost-effectiveness must be obtained and confirmed by on-going trials^[45,46].

Contraindications: CT colonography is contraindicated in patients complaining active colonic inflammation (*i.e.*, acute diverticulitis, acute active stage of ulcerative colitis or Crohn's disease, toxic megacolon) due to the high risk of bowel perforation^[47-49]. Other main contraindications to CT colonography include: Acute abdominal pain; abdominal wall hernia with entrapment of colonic loops; recent colorectal, abdominal or pelvic surgery; recent endoscopic resection. In the latter case, a two-week delay is suggested between polypectomy and CT colonography^[13], despite lack of clear scientific evidence.

Methodology

Bowel preparation: As for OC, bowel preparation represents the first and crucial step to obtain an optimal CT colonography quality, removing any luminal faecal or fluid residues which might obscure or mimic colonic lesions^[50]. In this regard, many bowel preparation regimes had been proposed; however, in all protocols an adequate colonic cleansing can be accomplished by means of a low-residue diet and cathartic cleansing, with oral administration of polyethylene glycol (PEG), magnesium citrate or sodium phosphate^[51]. The choice of laxative scheme depends mainly on patient health status and compliance, indeed colonic cleansing represents the most unpleasant step of CT colonography^[52]. To overcome these drawbacks, research is aimed at developing less invasive preparations by means of non-cathartic or reduced-cathartic approaches (called "prep-less" or "minimal prep" CT colonography)^[53,54]. Actually, according to the ESGAR guidelines, cathartic preparation should be reduced to 24 h or less before CT colonography examination and non-cathartic approach (without laxative but with faecal tagging) may be considered in frail and elderly patients when CRC is the target lesion^[55].

The laxatives employed for CT colonography bowel preparation can be classified into two categories: "Dry preparation", including saline cathartics as magnesium citrate and sodium phosphate; and "wet preparation" encompassing PEG-based regimes (PEG solution alone or in combination with magnesium citrate or bisacodyl)^[56].

PEG is a water-soluble and osmotically active polymer

able to retain about 30% water administered. It is an isosmolar solution that determines an intense watery diarrhoea without affecting electrolyte balance. PEG-based solutions can be administered at a high (3-4 L) or reduced volume (2 L) based on their composition with different substances or electrolytes, such as sodium sulfate, sodium chloride, potassium chloride, bisacodyl, and ascorbic acid. High volume PEG solutions are poorly tolerated by patients for its salty and disagreeable symptoms, like abdominal discomfort, bloating, nausea, and vomiting^[57]. Moreover, these solutions could leave fluid residuals in the colonic lumen, covering the endoluminal surface and thus reducing sensitivity in colonic lesion detection. For the above-mentioned reasons, low volume solutions are preferred for bowel cleansing in CT colonography examination. Furthermore, the addition of simethicone promotes coalescence and discharge of colonic bubbles, improving mucosal surface visualization^[58]. Actually, PEG solutions are the preferred agents to obtain CT colonography bowel preparation, thanks to their quick and safe laxative action, especially in elderly patients or in those with poor general condition^[59]. The main contraindications comprehend paralytic ileus, gastric retention, gastrointestinal obstruction, bowel perforation, toxic colitis and megacolon.

Sodium phosphate is a non-absorbable, osmotically active inorganic salt causing more fluid to enter in the colonic lumen than can be absorbed by the mucosa. Usually, it is administered in a single dose combined with bisacodyl. These hyperosmotic solutions at low volume lead to inversion of the normal water flow through the bowel wall, stimulating colonic peristalsis and emptying^[60]. As compared with PEG, sodium phosphate promotes a reduction of the amount of residual fluid in the colonic lumen and is more tolerated by patients, due to the lower volume and better taste of solution^[51]. Nevertheless, sodium phosphate is contraindicated in patients with serum electrolyte imbalances, advanced hepatic dysfunction, acute and chronic renal failure, recent myocardial infarction, unstable angina, congestive heart failure, ileus, malabsorption, and ascites^[61].

Magnesium citrate is another saline laxative with osmotic action, which increases the intraluminal fluid volume and promotes the colonic peristalsis. Dry colonic preparation obtained with magnesium citrate is very similar to that achieved with sodium phosphate; however, magnesium citrate has a better safety profile with negligible risk of severe hydro-electrolytical disturbances^[56,62].

Faecal tagging: The presence of faecal and fluid residuals in the large bowel may affect colonic finding interpretation, resulting in lower diagnostic accuracy especially in 3D analysis^[63]. Despite efforts to achieve a thorough cleansing by means of a low-residue diet and cathartic cleansing, some faecal or fluid residuals may be retained^[24,54]. In this context, the addition of oral tagging with positive contrast media (either iodine, barium, or both) is mandatory in order to distinguish polyps from

faecal material and to detect lesions submerged by fluids^[64,65]. In this way, contrast medium increases the density of faecal/fluid residues, while the colonic walls and lesions maintain the typical soft tissue density. Several tagging regimens have been proposed; however, no definite consensus still exists about the most effective tagging scheme. Therefore, the choice of the agents to obtain faecal tagging is optional and depends mostly on site experience.

Oral tagging achieved with barium may produce heterogeneous tagging of faecal/fluid residues due to its relatively low water solubility. Barium is an inert contrast medium free from risk of allergic reactions or laxative effects, but with increased risk of colonic constipation. Furthermore, barium may impair same-day colonoscopy in case of CT colonography positive findings^[66].

By contrast, oral tagging with iodinated agents allows greater homogeneity of intraluminal CT density than barium-based protocols^[67]. Sodium amidotrizoate and meglumine amidotrizoate (Gastrografin[®], Bracco) is the most frequently used contrast medium for oral tagging. It has a variable compliance because of its unpleasant taste and hyperosmolar effects. Usually, its oral administration is safe because a small amount (approximately 3%) of Gastrografin is absorbed through the enteric mucosa and discharged through the urinary tract. Nevertheless, rare anaphylactoid reactions have been reported after its oral administration and caution is required in case of patients with previous reaction to iodinated contrast agents^[68,69]. Moreover, colonic enhancement depends on contrast medium transit time and the presence of enhanced small bowel may disturb colonic assessment, mostly in 3D analysis.

Tagging with oral administration of barium and iodinated contrast medium represents a more complex preparation scheme that may reduce patient compliance^[55].

Recently, Neri *et al.*^[70] proposed an alternative technique, called "rectal iodine tagging", consisting of the introduction of iodinated contrast material through the same insufflation probe, immediately before CT image acquisition. This very simple and immediate tagging scheme provides a significant reduction of overall examination time with comparable accuracy in polyp detection, tagging quality and better patient's acceptance^[70].

Moreover, several clinical trials clearly support the use of CT colonography after an incomplete colonoscopy (same-day iodine tagging), performed on the same day avoiding an additional cathartic preparation^[71]. In this setting, CT colonography allows the detection of colonic lesions in non-visualized segments, determining also the cause of incomplete colonoscopy (*i.e.*, tortuous colon or severe diverticular disease). Furthermore, CT colonography permits the identification of synchronous lesions in cases of obstructing carcinomas, adding information about tumor localization and surgical planning^[72].

Rectal tube: At the beginning of the procedure, a thin flexible probe provided with a small inflatable balloon is inserted into the rectum by a physician or a specifically

trained assistant^[18,73]. Employment of rigid, large-caliber catheters is not recommended^[52]. A preliminary digital rectal examination is not mandatory, but it is recommended if inflatable rectal balloons are used^[55]. Some authors suggest maintaining rectal catheters *in situ* until the end of the examination^[74]; however, it is advisable to deflate it in one scan acquisition to improve visualization of more distal lesions^[55]. Bowel distension may cause colonic perforation, with sudden onset of acute pain during probe insertion and/or air inflation^[75]. Even if CT colonography cannot be considered completely free from serious adverse events, the risk of bowel perforation remains an extremely rare complication, especially in asymptomatic subjects at average-risk. A recent review reported a CT colonography-related colorectal perforation rate of 0.04%, more than four times lower than OC^[74,76,77].

Spasmolytics: Even if some authors reported limited benefits in their employment, in selected cases spasmolytics may reduce insufflation-related discomfort and facilitate bowel evaluation, especially in patients with colonic strictures, stenosing cancers or diverticular disease^[78-82]. Hyoscine-N-buthylbromide (Buscopan[®], Boehringer Ingelheim) is the antispasmodic of choice; however, it is not licensed in several countries, including the United States. If contraindicated or not available, it could be replaced by Glucagon (1 mg)^[55]. Whatever spasmolytic is chosen, it should be administered prior to start insufflation. Specific contraindications to antispasmodic administration must be preliminarily assessed^[55].

Bowel distension: Bowel distension is required to permit a better visualization of the colonic surface. To achieve pneumocolon, administration of room air and/or carbon dioxide (CO₂) through the rectal probe could be performed either manually, through a balloon pump patient-controlled or physician-controlled, or using automatic insufflators^[52,74,83]. Automated dynamic CO₂ delivery is the most preferred distension technique^[52,55]. In fact, if compared to manual insufflation, automated insufflation with CO₂ allows a better colonic distension, particularly in left colon and supine position^[74]. Moreover, controlled values of flow rate and pressure minimize the potential risk of perforation and procedure-related discomfort, since CO₂ is rapidly reabsorbed and continuous low-pressure CO₂ delivery reduces colonic spasm^[52,83]. Alternatively, manual distension with room air and/or CO₂ can be performed if automated insufflation systems are not available^[55,73]. In both cases, pneumocolon should be performed by specifically trained practitioners^[55].

A proper colonic distension of the colon is essential to accomplish technical success. The goal is to obtain an adequate colonic distension, rather than maximal lumen dilation^[52]. The overall amount of gas administered may vary widely among patients (from 3 to more than 10 L) and, if considered alone, it does not correspond to

adequate distension^[52,55]. In fact, also other factors, such as patient tolerance to insufflation, colonic appearance at scout scan and colonic pressures should be also taken into account^[55]. Bowel distension should be considered as adequate if the luminal surface of each colonic segment could be entirely visualized ideally in both decubitus, but at least in one patient position^[55,75]. Appropriateness and degree of bowel distension should be assessed on both scout views prior to perform images acquisition; if necessary, additional insufflation may be performed^[55,62,75]. Beyond quality of distension, overall diagnostic quality of the examination should be assessed before the patient leaves the facility; in particular, presence of bowel perforation should be ruled out.

Image acquisition: As widely reported in literature, CT scanning should be performed on multidetector row CT scanners (> 4 rows), which permit a complete evaluation of the whole abdomen with reduced time of acquisition and high spatial resolution^[18,55].

Colonic lesions detection is highly influenced by maximum collimation; for this reason, narrow collimations not exceeding 3 mm, are currently recommended^[24,55,84]. Moreover, nearly isotropic voxels and acquisition of multiple thin sections reconstructed with a 20%-30% overlap are highly suggested^[18,55,75]. Barish *et al.*^[24] reported datasets reconstructed as 1 mm sections overlapped every 0.7 mm as adequate to perform high-quality multiplanar reformations (MPR) and 3D reconstructions. Furthermore, acquisitions in cranio-caudal direction are advisable to minimize breathing artifacts, which prevail in the upper abdomen^[85].

A preliminar scout should be performed before each full scan acquisition in order to assess adequacy of bowel distension^[52,73]. Moreover, in patients at high-risk of bowel perforation, a low-dose basal scan should be considered^[55].

The standard image acquisition protocol consists in a combination of supine and prone positions, which helps to differentiate mobile stool from polyps and cancers. In fact, variations in decubitus facilitate gas redistribution, prevent inadequate distension and show colonic surfaces previously hidden by intraluminal fluid, improving sensitivity and specificity in colorectal polyps detection^[86,87]. A complete anatomic coverage of colon and rectum should be obtained in at least two decubitus^[75,87]. The ESGAR consensus reported little evidence about the influence of the order of patient positioning (*i.e.*, supine or prone position first) and quality of distension^[55].

In patients unable to maintain the prone position, an alternative approach with a lateral scan decubitus is advised. Additional scans after re-insufflation or repositioning in alternative lateral (left or right) decubitus should be performed in case of suboptimal and/or inadequate distension (*i.e.*, focal collapsing occurring in the same segment on both supine and prone scans), which may affect segments proper visualization^[55,73,75,88,89].

About radiation exposure, the employment of low

radiation-dose protocols is strongly advised. In general, 120 kV are suggested for both supine and prone position, but in selected cases lower kV might be used^[55,73]. Milliampere values should be adjusted according to contrast medium administration: When contrast medium is not used, ≤ 50 mAs are suggested for both supine and prone position^[55]. However, if IV contrast medium is injected, acquisition parameters should be adjusted to maintain diagnostic image quality^[75]. In fact, such mAs values may impair extracolonic structures evaluation and may not be appropriate in overweight patients due to the raise in image noise, so they should be appropriately increased^[18,75].

The employment of automated dose modulation techniques and iterative reconstruction may lead to a significant reduction of radiation exposure to patient, so they should always be applied, whenever they are available^[55,90,91]. In CT colonography performed for screening purposes, IV contrast medium administration is not mandatory and low-dose protocols should be adopted^[92,93]. Macari *et al.*^[94] reported excellent results for the detection of polyps > 10 mm using thin beam collimation and an effective tube current of 50 mAs; however, detection of intermediate size polyps (6-9 mm) was compromised. Better results were obtained by Iannaccone *et al.*^[95], who evaluated ultra-low-dose protocols (10 mAs) for the detection of colorectal lesions, reporting good sensitivity for both large and intermediate polyps, with a 40%-70% reduction of the radiation dose delivered to patients.

Contrast medium administration: In examination conducted for screening purposes, routinely IV administration of contrast medium is not required for colonic evaluation since it improves visualization of extra-colonic organs but it is not mandatory for colonic evaluation^[18,55]. It is important to underline that oral tagging does not preclude IV administration of contrast medium^[55].

On the contrary, contrast medium should be always administered to better characterize both intracolonic and/or extracolonic structures in case of diagnostic examination conducted for the following indications: Staging of known CRC; patients with symptoms suggestive of CRC; suspect of local recurrence, metachronous disease, or distant metastasis in case of prior history of CRC^[96-98].

If IV contrast is administered, patient should be placed in supine decubitus and images should be acquired in the portal venous phase using standard radiation dose protocols^[18,55,96,99]. Lee *et al.*^[100] reported polyp attenuation values on portal phase ranging from 50 to 173 HU. Reduction dose settings should be applied when acquiring non-enhanced scans^[55].

Data interpretation and reading strategies: Both 2D and 3D readings should be integrated to accurately evaluate presence or absence of significant colonic lesions, in order to avoid errors in detection and better characterize colonic findings^[55,75].

A standard 2D analysis consists in a "lumen tracking" bowel evaluation: The reader tracks all the air-distended colonic lumen from one end to the other^[18,97]. Supine and prone views are projected together on the monitor and scrolled up and down simultaneously.

A wide CT window width (bone window) and window centre close to that of the lung window setting are advised to enhance intraluminal polyps and allow discernment of the colon wall from mesenteric fat; recommended display settings are, respectively, 1500 HU and -200 HU^[101]. Soft tissue window is useful to assess lesion attenuation (density values, homogeneous or heterogeneous attenuation, faecal tagging and IV contrast media characteristics)^[18,75]. However, in 2D reading, convoluted folds and diverticula may impair colonic evaluation, and small lesions may be unrecognized^[97].

MPR reconstructions allow reconstructing any scan orientation desired by the reader and should be used whenever necessary for problem solving^[97,102,103]. 3D volume-rendered views allow endoluminal evaluation of the colon similarly to an endoscopic examination. Since polyps' conspicuity and duration of visualization are increased, lesions identification is facilitated, but anterograde and retrograde "fly through" are needed to visualize both sides of haustral folds^[104,105]. Moreover, in 3D images residual fluids may hide lesions and residual faecal material cannot be distinguished from true polyps, making 2D evaluation mandatory to confirm and characterise any suspected lesion seen on 3D views^[97].

Other advanced 3D methods of visualization (*e.g.*, virtual dissection, panoramic view, filet view, unfolded cube projection, and tissue transition projection) may overcome some of 2D and endoluminal 3D views limitations increasing colonic surface visibility, but they should be dedicated to readers with high-experience in 2D and 3D visualization^[55,97,104].

There is still some considerable controversy about which approach (2D/3D) should be employed for primary search of colorectal polyp and cancer.

Actually, the most common method of interpretation is primary 2D approach with additional 3D endoluminal views for problem solving^[24,97]. However, some authors favour a preferential primary 3D evaluation, turning to 2D images to confirm and characterize colorectal findings^[97,102,106]. Pickhardt *et al.*^[107] compared primary 2D vs 3D colonic evaluation in low-prevalence screening population, reporting better effectiveness and greater polyp detection in primary 3D approach.

On the other hand, some studies suggested that a combined evaluation of 2D and 3D images provides the highest sensitivity in colorectal lesions detection and avoid potential pitfalls, but it is clearly more time-consuming^[102,105,108].

According to the ESGAR consensus statement, both 2D and 3D reading strategies are acceptable for initial interpretation even if primary 2D interpretation is generally faster^[55]. Therefore, the choice of the primary reading method is subjective and based on the reader's own personal preference and experience^[97].

Recently, computer aided detection (CAD) algorithms have been developed to assist the radiologist in polyps and cancer detection. In a recent multicenter prospective trial, Regge *et al.*^[109] demonstrated that the employment of CAD by experienced readers improves CT colonography sensitivity in the detection of polyps measuring 6-9-mm, with only a little increasing in the reading time (about 2 min).

However, even if second read CAD may increase sensitivity for polyp detection, radiologist must be aware that there is the possibility of misdiagnosing a true positive, with misleading test results. Moreover, CAD tools are less useful in situations at high-likelihood of false positive results (*i.e.*, poor bowel preparation) and should be employed only after specific training in adjunction of unassisted interpretation^[55,110,111].

CT colonography reporting: CT colonography should be reported by radiologists with high experience in abdominal imaging and specific training in the technique^[55].

As suggested by the ESGAR consensus statement and ACR practice guideline for communication, the following data should be included in the report^[55,75]: (1) Anamnestic data (patient medical history, family history, symptoms and signs, previous rectoscopy/colonoscopy or biopsies); (2) technical data (low or normal dose protocol, effective dose in mSv); (3) IV contrast medium administration; (4) patient preparation and tagging (laxative agent, tagging regimen); (5) patient positioning; (6) room air and/or CO₂ insufflation; (7) use of spasmolytics; and (8) overall quality and limitations of the examination (*i.e.*, incomplete or impaired colonic visualisation due to inadequate bowel preparation, retained stool, untagged fluid, suboptimal distension, metal or movement artifacts; any colonic segments that cannot be adequately evaluated should be indicated).

If colonic abnormalities are found, the following information should be reported: (1) Colonic anatomy (normal or abnormal) and features (wall thickening, diverticula, strictures, extrinsic compression, post-surgical variations); and (2) polyps and/or cancer characteristics (size, maximum diameter and two or three-dimensional measurements, density, morphology, mobility, location, infiltration of extracolonic fat)^[18,55].

In 2005, the Working Group on Virtual Colonoscopy elaborated a consensus statement, the CT colonography Reporting and Data System, aimed to ensure clarity and consistency and standardize reporting of colonic and extracolonic findings in CT colonography^[101]. This standardized structure firstly distinguishes polyp lesions from colonic masses.

A "polyp" is defined as a structure with homogeneous soft-tissue attenuation that arises from the colonic mucosa, characterized by fixed point of attachment to the bowel wall and projecting into the colonic lumen.

A "mass" is defined as any colonic lesion with soft-tissue attenuation, greater than 3 cm in its largest dimension.

However, when the presence of cancer is highly suspected, the ESGAR Consensus Group has suggested that the suspected cancer lesions should be designated as such, avoiding the term mass.

Colonic lesion should be characterized in morphology (sessile, pedunculated, flat), size and segmental location^[75,85,101]. Sessile lesions are characterised by a broad implant base, with width greater than vertical height. Pedunculated lesions peculiar feature is the presence of a separate stalk. Flat lesions demonstrate a plaque-like morphology, with vertical protrusion < 3 mm above the colonic mucosa^[101]; their clinical relevance has been widely debated and lower CT colonography sensitivity rates are reported for flat lesions than for other polyp morphologies^[112].

About location, the large bowel should be divided into 6 segments: Rectum, sigmoid colon, descending colon, transverse colon, ascending colon, and caecum. The use of the term "flexure" is discouraged^[97,101].

Size still represents the most important criterion to stratify colonic lesions according to the risk of malignancy^[18,75,101]. Therefore, polyps are classified as diminutive lesions (< 6 mm), small (6-9 mm), and large polyps (10-30 mm), which are likely to represent advanced adenomas^[97,101]. Lesion maximal diameters could be evaluated on both supine and prone views, as well as both 2D and 3D images, but it is advisable to perform measurements on the plane which best demonstrates its dimension^[55,70,101]. In case of pedunculated polyps, the largest diameter of the polyp head is measured avoiding the stalk, while the base is measured in case of flat or sessile lesions polyps^[75,113].

The main target of CRC screening is detecting the advanced adenoma, defined as a lesion measuring ≥ 10 mm with significant villous features (> 25%), high-grade dysplasia, or early invasive cancer^[8,101,114]. However, for screening purposes, polyps measuring ≥ 6 mm should be identified and reported in all patients, symptomatic or not^[55,101]. About diminutive polyps (≤ 5 mm), CT colonography has limited diagnostic performance, especially considering that the acquisition techniques (*i.e.*, low dose protocols) are mainly targeted to identify lesion sized 6 mm or more, and do not always allow smaller lesions detection. Furthermore, polyps ≤ 5 mm have slow growth rate, reduced risk for development of colon carcinoma and they are frequently missed even at OC^[75,101]. Therefore, ACR currently does not deem necessary reporting diminutive lesions^[75,101].

On the other side, ESGAR current recommendation is to report diminutive lesions only if they can be detected with high confidence, especially if measuring ≥ 3 mm^[55]. Macari *et al.*^[115] recommend a CT colonography follow-up within 3-5 years if lesions smaller than 6 mm are detected.

It must be considered that CT and endoscopic measurements are frequently discordant, influencing patient's management; in fact, neither 2D nor 3D measurement are entirely accurate nor perfectly reflect lesion dimension, since they are both affected by the way the

measurement is made^[55]. In particular, MPR views may underestimate the size of irregularly shaped lesions, while a potential overestimation by 3D methods should be taken into account^[55,101].

For what concerns lesion attenuation, adenomatous polyps often show homogeneous soft-tissue attenuation. Fat attenuation is suggestive of either a lipoma or an inverted diverticulum, and it is commonly found at the ileocecal valve. Presence of regional infiltration of the pericolonic fat, pathologic lymphadenopathy, extracolonic extension of a mass and distant metastases should also be assessed and reported^[101].

Retained stool have variable features: Foci of air within a lesion and angular morphology are typical findings; moreover, residual stools move according to supine/prone decubitus, whilst polyps tend to maintain their position respect to bowel surface^[18,101].

According to CT colonography findings and relative follow-up recommendations, patients are sub-classified into categories depending on examination quality, absence of and/or benign colonic findings, number of colonic lesions and their clinical relevance, recommended work-up (routine screening interval, surveillance and/or colonoscopy recommended, need for surgical consultation)^[101].

Finally, incidental findings detected in extracolonic structures with potential clinical significance should be included in the report, taking into account potential limitations in accuracy due to unenhanced scan or low dose technique^[55,75,97]. Similarly to colonic findings, even extracolonic ones can be classified through a categorization system according to their clinical relevance and necessity for further diagnostic work-up^[101].

CONCLUSION

CT colonography is a continuously evolving technique; its sensitivity and specificity in colorectal polyps detection and the advances in bowel preparation, faecal tagging, colonic distention and image interpretation made CT colonography the preferred radiological examination to diagnose colorectal neoplasia. In addition, the minimal invasiveness of CT colonography together with better patient compliance configures its potential role in CRC screening on individual basis.

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