Refining CT colonography methods
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Colon distension and scan protocol for CT colonography:

An overview

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Abstract

This article reviews two important aspects of CT colonography, namely colonic distension and scan parameters. Adequate distension should be obtained to visualise the complete colonic lumen and optimal scan parameters should be used to prevent unnecessary radiation burden. For optimal distension, automatic carbon dioxide insufflation should be performed, preferably via a thin, flexible catheter. Hyoscine butylbromide is – when available – the preferred spasmolytic agent because of the positive effect on insufflation and pain/burden and its low costs. Scans in two positions are required for adequate distension and high polyp sensitivity and decubitus position may be used as an alternative for patients unable to lie in prone position.

The great intrinsic contrast between air or tagging and polyps allows the use of low radiation dose. Low-dose protocol without intravenous contrast should be used when extracolonic findings are deemed unimportant. In patients suspected for colorectal cancer, normal abdominal CT scan protocols and intravenous contrast should be used in supine position for the evaluation of extracolonic findings.

Dose reduction can be obtained by lowering the tube current and/or voltage. Tube current modulation reduces the radiation dose (except in obese patients), and should be used when available. Iterative reconstructions is a promising dose reducing tool and dual-energy CT is currently evaluated for its applications in CT colonography.

This review also provides our institution’s insufflation procedure and scan parameters.
Introduction

Adequate distension is a prerequisite for computed tomography (CT) colonography and efforts should be made to obtain good distension [1]. In CT colonography distension is obtained by the insufflation of gas. Drawback of insufflation is that it may lead to cramping pain, windiness, burping, nausea, vasovagal reactions and very rarely to perforation [2–5]. Practitioners should therefore acquire enough knowledge and experience to find the right balance between patient comfort and adequate distension. To reach optimal distension several choices have to be made concerning the distension methods used, such as: which type of catheter, type of insufflation (automatic vs. manual), room air or carbon dioxide, use of a spasmolytic agent and the positions to use during insufflation.

When optimal distension has been obtained, it is important to use an adequate CT scan protocol. Here a compromise has to be made between the benefits and risks involved with ionising radiation. The first protocols for CT colonography were based on clinical abdominal CT protocols. Some of these protocols had a relative high radiation dose [6]. During the last decade the dose has been reduced and the CT colonography protocol has been differentiated based on the clinical suspicion for colorectal cancer [7]. In patients with a low chance on colorectal cancer (e.g. screening), CT colonography without intravenous contrast medium can be performed, while in other patients (e.g. obstructive cancer at colonoscopy) intravenous contrast medium will be administered as CT colonography is also used for staging. In the latter situation higher-dose protocols are needed as contrast for extracolonic organs is much smaller than for intracolonic lesions. When the CT primarily concerns colonography, less radiation can be used due to the large contrast between air and polyps.

Initial studies on CT colonography were performed using single- or 4-detector-row CT scanners. Here there was a trade-off between thin slices for detecting all relevant polyps and the length of a single breath hold. Nowadays, many centres are equipped with scanners having at least 16 detector-rows or more, making the difficult considerations of the past unnecessary as good image quality can be obtained with acceptable breath hold times.

In this review, we will point out which insufflation methods are available and we will discuss the development of high-dose scan protocols into low-dose protocols in the last 15 years.
Insufflation methods

Type of catheters
The first catheters used for CT colonography were rigid large diameter barium enema tubes with a 100 mL balloon. This type of balloon-tipped catheters was primarily used to prevent spill of barium contrast (and air) during the examination. However, in CT colonography there is no rectal administration of barium contrast and therefore no risk of rectal spill of this material. At the most incontinence for air (or carbon dioxide) may occur. Importantly, the introduction of a rigid large diameter catheter is uncomfortable, as is the inflation of the large rectal balloon. Further, some of the rare perforations in CT colonography are associated with the use of large balloon catheters [8]. This also included caecal perforations, which are most likely caused by the combination of uncontrolled insufflation in a colon with a competent ileocaecal valve and occlusion of the rectum by a large balloon. Because of the aforementioned reasons, the authors as well as guidelines [9, 10] advise against the use of rigid catheters and the use or large balloons. Currently, the standard catheter used for CT colonography is a thin flexible rectal catheter of approximately 20 French with a small (20–30 mL) balloon which is much smaller than the ones used for barium enema (Figure 1). The discomfort is substantially lower while the risk of perforation with this type of balloon is expected to be much smaller. In addition, no significant difference in number of adequately distended segments during CT colonography could be detected [11]. Although currently used balloons are small, it still might obscure a rectal lesion, therefore it is important to make sure that the balloon is deflated in at least one of the positions in which CT colonography is made. For that reasons, some centres use a catheter without balloon (or the balloon is not inflated) to have the view not obscured in neither position.

Insertion of the catheter
A careful history including recent colonoscopy, previous colonic surgery and active colitis is mandatory before inserting a catheter (especially when using a larger diameter rigid catheter – which we discourage). If the patient recently underwent a colonoscopy, an occult perforation may be present. Therefore it may be useful to obtain a low-dose CT scan before starting the CT colonography procedure, to detect extraluminal air. One should consider performing digital rectal examination prior to insertion. Firstly, to diagnose possible reasons for not inserting the catheter (e.g.
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Figure 1 Two examples of thin flexible balloon-tipped rectal catheters. The uppermost catheter is 20 French gauge with a 30 cm³ balloon (for Protoco2l, Bracco). The undermost catheter is 18 French gauge with a 20 cm³ balloon (for MedicCO2LON, Medicsight).

low rectal obstruction) and secondly to diagnose very low rectal lesions close to the catheter that otherwise may not be detected at CT colonography. In many patients digital rectal examinations (or colonoscopy) has been performed by the referring physician, and in these patients digital rectal examination is not mandatory. The easiest way to insert the catheter is when the patient is lying on its left or right side, with his back towards the insufflation machine. Before insertion the anus should be inspected for haemorrhoids or other lesions that might need cautious insertion. Some lubricant is administrated to the tip of the catheter. Avoid force during the flexible catheter insertion, but gently introduce the catheter. The balloon is preferably filled with air instead of fluid to secure its position during position changes of the patient, as with air an indentation of the catheter by a polyp can be appreciated while it will be obscured when using water for balloon insufflation. When no balloon is used, the catheter is taped near the anus to secure its position.

Manual vs. automatic insufflation

Initially CT colonography was performed using manual insufflation of room air. Here a number of puffs of air were given until either a preset volume was administrated or the patient indicated discomfort. Subsequently the distension was checked at a scout view. Since then, both type of insufflation and gas used have changed, as nowadays it is routine to use an automatic insufflator with carbon dioxide. Although both room air and carbon dioxide lead to adequate distension, the advantage of carbon dioxide is that it is rapidly absorbed through the bowel wall, followed by elimination via the lungs. Therefore desufflation of the colon is much faster using carbon dioxide with therefore reduced discomfort of colonic distension after the examination [12].
In previous studies, carbon dioxide has proven to reduce discomfort in colonoscopy and double-contrast barium enema studies [13–15]. One study showed a reduction of discomfort using automatic carbon dioxide insufflation compared with manual room air insufflation for CT colonography. In this study little post-procedural pain was observed, the least in the carbon dioxide group [16]. However, the use of carbon dioxide might be contraindicated in patients with severe chronic pulmonary obstructive disease.

Colon insufflation can be performed manually or automatically. The advantage of manual insufflation is that it is a simple, cheap method requiring minimal use of material. Disadvantage is the uncontrolled administration of the gas with therefore the chance of either over distension or suboptimal distension. The use of an automatic insufflator has been introduced in 2002 [17]. Studies showed an improved distension using automatic insufflation as compared to manual insufflation, while patient acceptance was not superior [16] and [18]. The beneficial distension is greatest in the left colon, particularly when the patient is in supine position. Very few perforations have been recorded since the introduction of automatic insufflation and the use of flexible catheters with small volume balloons [2], which seems to confirm the advantage of using this technique.

Automatic insufflation has several other important advantages over manual insufflation. Automatic insufflation produces a controlled intracolonic pressure. Pressure sensors measure the pressure continuously and gas is insufflated when the pressure drops below the target pressure. This means that gas loss is also replaced during scan acquisition. When the pressure exceeds the preset threshold an alarm sound is produced and an air valve releases excessive pressure. This last safety feature may reduce the risk of perforation. Automatic insufflation creates a more constant flow, is less operator dependant compared with manual insufflation (less experience is needed to obtain good distension results) and information on pressure and volume are available and it gives a better estimate on the amount of distension [16]. Automatic insufflation also allows the practitioner to work alone and monitor the patient carefully [19]. Further, the security measures of the automated insufflator facilitate performing the examination by a radiographer. Most important disadvantage of automatic insufflation is the increased equipment costs compared to manual insufflation. In the experience of Burling et al. manual insufflation is more time consuming as compared to automatic insufflation, although there is no literature available about the insufflation times of both techniques [18].
As far as we know, no studies evaluated the best target pressure or volume. In our experience a target pressure of 25 mmHg usually works well for adequate insufflation and is generally accepted. When 3 litres of gas are insufflated or estimated adequate distension (based on posture and maximum tolerance) is reached, target pressure is reduced to 20 mmHg, which is almost always sufficient and reduces the discomfort level of the patient. Pain and discomfort are not infrequently seen especially during the last litre of insufflation. It is therefore very important to explain this possibility to the patient before one starts the examination. Adequate knowledge prevents the patient from becoming distressed when he actually experiences some substantial cramps at the end of the insufflation phase, as he knows it is a normal reaction of his bowel. If the insufflation is not yet sufficient when substantial pain sets in, encourage the patient to tolerate the pain for just one or two more minutes. Explain that the pain will lessen, when the bowel is insufflated enough, as the pressure of the air will be lowered and the bowel will not be stretched any further. If this is not enough, it might help to lower the target pressure for about 10–20 seconds, to help the patient calm down.

**Automatic insufflation systems**

At this moment, there are several insufflation systems commercially available (like Bracco, Medicsight, Clamed and Vimap). The authors advise to use an automatic insufflator equipped with pressure sensor and that will insufflate when the intracolonic pressure drops below the target pressure and releases gas through an evacuation valve when the intracolonic pressure is too high. In our institution we have experience with two automatic insufflation systems: Bracco Protoco2l (Bracco Diagnostics, Princeton, New York, USA) and Medicsight MedicCO2LON (Medicsight, London, UK) (Figure 2). Largest experience and (almost) all studies on automated

![Figure 2](image-url)

*Figure 2*

Two examples of automatic carbon dioxide colon insufflators for CT colonography: (a) Protoco2l, Bracco (b) MedicCO2LON, Medicsight.
insufflation until now concerns the Protoco2l device which was introduced in 2003, while the MedicCO2LON has been introduced in 2010 [16, 19–21]. Both systems are available with different catheters, including (balloon-tipped) thin rectal catheters. Both use carbon dioxide, have a maximum target pressure (MedicCO2LON 30 mmHg and Protoco2l 25 mmHg) and are equipped with safety valves when pressure is above a certain threshold. Both systems use a controlled flow rate increasing from 1.0 L/min for the first 0.5 L to 2.0 L/min from 0.5 to 1.0 L and 3.0 L/min for the remaining insufflation.

Advantages of the MedicCO2LON system are that it has a remote control and displays and records all information (litres, flow rate, intracolonic pressure) on an electronic display, while the Protoco2l shows only the amount of litres insufflated and intracolonic pressure on display. In addition, the amount of litres before shutdown can be adjusted at the MedicCO2LON system, while the Protoco2l system stops the insufflation at 4.0 Litres. At that point, the reset button needs to be pressed and the insufflation needs to be started again (both manually). After the first limit of 4.0 litres the new limit is every following 2.0 litres.

**Spasmolytics**

After intravenous administration of 10–20 mg hyoscine butylbromide (Buscopan®, Buscapina®, Boehringer, Ingelheim, Germany), a maximal pharmacological effect (among others the effect on pulse rate, saliva secretion and visual accommodation) was reached at 2–8 minutes and waned off completely by 30–40 minutes [22]. A study of Froehlich et al. showed that the aperistaltic effect of 40 mg intravenous hyoscine butylbromide on the small bowel begins on average at 22 seconds and has normalised at 23 minutes. The aperistaltic effect of 1 mg intravenous glucagon hydrochloride (Glucagen®, Novo Nordisk A’S, Bagsvaerd, Denmark) starts on average at 13.4 seconds and is normalised after 33 minutes [23]. For both hyoscine butylbromide and glucagon the standard deviation is large and the effect on the colon may differ. In our experience the beneficial effect during CT colonography warns off more quickly than the 23 and 33 minutes mentioned above. Since the rapid onset of the effect both hyoscine butylbromide and glucagon can best be administered just before insufflation, after introduction of the catheter.

Although often used in clinical practice, the use of spasmolytic agents is still somewhat controversial. Intravenously hyoscine butylbromide or glucagon hydrochloride have been investigated for this purpose (Figure 3). The general idea is that these drugs reduce colonic spasms, with subsequent better distension,
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Figure 3 The two commonly used spasmolytics: left: glucagon hydrochloride; right: hyoscine butylbromide.

less motion artefacts and less discomfort for the patient (i.e. less pain). The ACR guideline considers antispasmodics not necessary, but we need to take into account that hyoscine butylbromide – considered to be the most potent colonic relaxant – is not licensed for that purpose in the USA [24]. CT colonography standards advise to consider hyoscine butylbromide unless contraindicated and some advise to use glucagon hydrochloride as an alternative [9, 10]. Doubling the regularly used dose of 20 mg hyoscine butylbromide has no additional value [11].

Both hyoscine butylbromide and glucagon have been investigated first in DCBE studies and reduced discomfort in some studies [25–27], while hyoscine butylbromide also improved bowel distension in some DCBE studies [27, 28]. In addition, several studies evaluated the effect of hyoscine butylbromide, glucagon or both in CT colonography [11, 29–34]. Hyoscine butylbromide has shown to improve bowel distension in some studies [11, 31, 32], although one study could not confirm this result [33]. Glucagon has shown a non-significant improve in distension compared with no premedication [31]. Beneficial effects on polyp detection of both spasmolytics, have not been detected for hyoscine butylbromide and not studied for glucagon hydrochloride [30]. However, both hyoscine butylbromide and glucagon have shown to reduce discomfort in CT colonography [33].

A disadvantage of hyoscine butylbromide is that it cannot be used in all patients. Contraindications are prostatism, tachycardia, cardiac failure, mechanical obstruction in the gastrointestinal tract, megacolon, myasthenia gravis, and untreated narrow angle glaucoma [22]. Some advocate to abandon the history of
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glaucoma and substitute this for advice to seek urgent medical advice should eye pain and visual loss develop [35]. Whether this is an acceptable approach depends on medicolegal aspects that differ between countries. Further, it may have possible side effects like accommodation disturbances (mostly less than 30 minutes), tachycardia, dry mouth, nausea and hypotension. Glucagon hydrochloride on the other hand has only pheochromocytoma as true contraindications, but should also be used with caution in patients with poorly controlled diabetes mellitus, glucogenoma or insulinoma and in elderly with a cardiac condition. Most important side effects of glucagon are nausea, vomiting and tachycardia [36].

Another consideration is that glucagon hydrochloride is far more expensive than hyoscine butylbromide (in our hospital €24 vs. €1). Cost-effectiveness is one of the main topics in CT colonography and will have an effect on the decision about which tool is preferred for CRC screening [37, 38].

The authors favour using a spasmolytic in all to optimise distension and decrease discomfort in all patients. Some use a spasmolytic only when there is insufficient distension on a scout view or CT colonography in the initial position or when there is substantial patient discomfort. As several studies showed that hyoscine butylbromide improves bowel distension and reduced discomfort in CT colonography, it is advised to use hyoscine butylbromide as primary spasmolytic. However, as stated before, hyoscine butylbromide is not licensed for this purpose in the USA. As several studies with glucagon hydrochloride has not showed improved bowel distension but did show a reduced amount of discomfort among CT colonography participants, glucagon hydrochloride might be a valuable alternative in case of license problems or when hyoscine butylbromide is contraindicated.

**How much gas should be insufflated?**

As far as we now, no studies have been published studying the optimum amount of gas that should be insufflated to achieve optimal distension. In our experience, good results are obtained with the following protocol: insufflate automatically 3 litres of carbon dioxide (1.3 right decubitus, 0.9 supine and 0.8 left decubitus) or at least two-and-a-half litres within a maximum insufflation time of 5 minutes (Figure 4) [39]. Another order of insufflation positions is used by other experts [19, 40]. To our knowledge, no research has been performed studying the optimal positions for insufflation. Perform a scout view to scrutinise colonic distension after you reached 3 litres, but at least within 5–6 minutes after starting insufflation. The amount of air that can be insufflated, depends on the patients’ posture. For example, a small
person might have a good colonic distension after 2.5 litre, while a large person might need at least 3 litres. Be sure that you are not too rigid in reaching this volume, as there might be important pathology (like an obstructing colonic tumour) preventing insufflation of air. In addition, in case of an incompetent ileocaecal valve or gas incontinence, the insufflated volume might be considerable more and the actual volume in the colon is not known. In patients with prior colonic surgery the optimal volume will be reduced.

Figure 4 Insufflation positions as used in our institution: we start with 1.3 L in right decubitus position (a), followed by 0.9 L in supine position (b) and 0.8 L in left decubitus position (c).
When the intracolonic pressure is rising towards 25 mmHg, this might indicate that enough air is insufflated, but it might be caused also by a colonic fluid layer obstructing the way. Further, it is important to assess the fullness and comfort of the patient. This of course is strongly related to the pain threshold of each individual, but it can help to estimate. When reaching the sufficient insufflation patients often experience a moderate level of discomfort. It must be noted that some patients will not feel any pain at all.

A colostomy is not an absolute contraindication for CT colonography. In colostomy patients the use of a balloon-tip catheter is needed to prevent air leakage and hold the catheter in place. The narrower lumen as compared to the rectum increases the chance of damaging the bowel. Extra careful introduction of the catheter and balloon careful (sometimes partial) insufflation is therefore needed. A digital exam of the colostomy can be useful to obtain more information regarding the size and direction of the colon (Figure 5).

**After insufflation**

**Scanning**

When you expect that sufficient distension has been reached given the volume insufflated, the intracolonic pressure or because the patient indicates discomfort, a scout view is the next step. This gives you a good overview of the degree of bowel distension, although this is more difficult to evaluate when bowel loops overlap.

![Figure 5](image.png) An example of a CT colonography performed in a colostomy patient, in this case with a parastomal herniation. Notice that the space for the catheter and balloon is much more limited than in the rectum.
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(eespecially sigmoid). In case of optimal distension the bowel is clearly visible at the scout view and in the CT images the haustral folds will be pencil line thin and without collapsed segments. In case of collapse, additional air can be insufflated although one should be aware that dependent bowel only (optimal) distends with the patient in the opposite position. The scout view will give the technician the opportunity to plan the scan dimension in craniocaudal direction. Some additional slices will be obtained at the superior border of the volume to account for differences in inspiration depth. This number of slices should be limited to prevent unnecessary additional radiation exposure.

The colonic segments have a different position in the body in the anteroposterior plane and therefore distension will differ per segment, depending on the position of scanning, for this reason all patients should be scanned in both the prone and supine position (Figure 6). This significantly reduces the number of insufficiently distended segments [41,42]. The sensitivity for polyp detection also increased with dual positioning [1, 42]. Some studies show on that average more adequately distended

Figure 6 Scanning position: (a) supine position with hands above the head and (b) prone position with hands forward and the pillow under the chest.
Figure 7 Typical examples of collapsed and distended colonic segments plus an example to illustrate the value of a scout view: (a) shows a collapsed rectum in supine position and (b) a good distension in the same patient. (c) Shows a collapsed transverse colon (arrow) and (d) a good distended transverse colon in the same patient. (e) Shows the scout view that was obtained before acquisition of (c) and (f) shows the scout view that was obtained before acquisition of (d). Here the distended transverse colon is clearly seen on the scout view.
segments in prone than supine position [34,41,43]. In supine position the rectum is often collapsed and in prone position the transverse colon (Figure 7 and 8) [11]. Optimal distension of ascending and transverse colon is more common in supine position and for descending and sigmoid colon during prone position [42]. The sigmoid is the segment that is most often collapsed [11] and [34] and special care should be taken to scrutinise its distension prior to finalising the examination. In our institution we start with the supine scan if no intravenous contrast is used. This position is more comfortable for the patient and it is easier to communicate during this first scan procedure. When intravenous contrast medium is administrated, we start with the prone scan and then perform the supine scan. This as the first scan is a plain scan and the second contrast-enhanced scan will be in the position a radiologist is familiar to read a contrast-enhanced CT (i.e. supine scan). Also, contrast medium administration is more practical in supine position. During the acquisition of the prone scan, a pillow is placed under the thorax to minimise the pressure on the abdomen and thereby reducing compression of the transverse colon. Be sure, that – when used – the balloon is deflated after the second scout view, to ensure that the rectum is completely visualised. In patients who are not able to lay prone, a lateral decubitus position is a good alternative to the prone position [43].

Figure 8 Illustrates the importance of scan acquisition in two positions: (a) a piece of stool that could be misinterpreted as a polyp on a fold in a layer of tagged fluid. (b) Shows the stool has changed position by gravity. With the absence of a stalk the polyp like structure can be confidently identified as a stool.
Intravenous contrast medium

Intravenous contrast medium is administered for extracolonic lesion detection in patients in which the CT colonography is also performed for staging. As this is aimed at evaluating the extracolonic organs, the scan is performed in the portal phase. For the detection of intracolonic findings, intravenous contrast medium has only shown to improve lesion detection (enhanced polyps) in suboptimal prepared colons without tagging [44]. However, nowadays, stool/fluid tagging is routine and intravenous contrast medium may even be detrimental for detection of intracolonic lesions. This as polyps may even become less conspicuous as the contrast between polyp and tagged bowel content is reduced. No sizable study using intravenous contrast medium shows polyp sensitivity that compares favourably with the good accuracy results of the most recent large screening trials [45, 46]. No studies have shown to improve colonic lesion characterisation using an intravenous contrast medium [47–49]. Although not helpful in routine CT colonography, the increased attenuation of polyps and cancers in contrast-enhanced series might be informative in dual-energy CT colonography [50, 51]. Further studies should investigate whether this has added value.

When CT colonography is used for surveillance, contrast-enhanced CT colonography has shown to accurately evaluate local recurrence as well as metastatic disease [52–55].

The use of intravenous contrast medium has shown to increase the number of extracolonic findings and possibly leads to more diagnostic work-up and operations (Figure 9) [56]. In this study findings in symptomatic patients who received an unenhanced CT colonography because of a contraindication for iodinated contrast medium, were compared with symptomatic patients who did receive intravenous iodinated contrast. As expected, the group receiving intravenous contrast medium had a significantly greater portion of extracolonic findings (94% vs. 77%). Although not significant, the group with intravenous contrast received further work-up more frequently (31% vs. 13%). Many institutions will not perform plain CT for staging colorectal cancer as a plain CT has additional value in only a limited number of situations (e.g. helpful for characterising adrenal lesions). When CT colonography is also performed for staging, a plain CT will be obtained as intrinsic part of the procedure which can be helpful.

In patients with a low chance of relevant extracolonic lesions (e.g. screening), no intravenous contrast medium is administrated. Advantages are that low-dose protocols can be used, there are no risks of adverse reactions (i.e. contrast-induced
nephropathy and hypersensitivity reaction) and costs are lower which is important for the cost-effectiveness of CT colonography.

**CT colonography scan parameters**

When CT colonography was introduced in 1994, multi-detector-row (MDCT) scanners did not yet exist, with exception of a two-detector-row scanner (CT-Twin, Elscint). For the first CT colonography studies single-detector-row scanners were used with as a consequence longer scan times. For example in the study of Amin et al. [57] 90–150 seconds scan time was used, divided over two to three breath holds. The slice thickness was 5 mm, and the time per rotation was 1 second [57].
At present CT colonography is performed virtually always with multi-detector-row scanning. In the dose evaluation study of Liedenbaum et al. [7], in which 34 institutions that performed CT colonography participated, more than 60% of the institutions used 64-detector-row CT scanners (the maximum number of detector rows available at that time), and only two institutions used single-row CT scanners [7]. In the meantime, 128- and even 320-detector-row scanners are used in clinical practice. It is reasonable to assume that nowadays virtually all centres use CT scanners with at least 4 detector rows. In recent consensus statements this is considered to be a minimal requirement [9, 10, 24].

Because of the far greater possibilities of the state-of-the-art CT scanners, there are nowadays hardly any technical limitations in the choice of the parameters to obtain a CT scan of the abdomen in a few seconds time. A broad consensus on the scan parameters exists [9, 10, 24]. In the following sections we discuss all parameters in more detail: the number of detector rows, detector row thickness, and slice thickness, rotation time and pitch, tube voltage (kV), tube current (mA), tube current modulation, dose and dual-energy CT colonography.

The choice of these scan parameters has of course a direct effect on the image quality and the radiation exposure. Best image quality is generally obtained with the highest dose. In the consideration which parameters to use, one has to take into account for which purpose the CT colonography scan is made. For example, when CT colonography is also performed for staging after failed colonoscopy caused by an obstructing tumour, radiation dose is less important than for CT colonography scans made for screening.

**Number of detector rows, detector-row thickness and slice thickness**

In the CT scanners used in the dose evaluation study of Liedenbaum et al. [7] the maximum number of detector rows was 64, with detector-row thickness between 0.5 and 0.625 mm [7]. CT scanners are now offered with 128 or 320 detector rows, although this last number of detector rows cannot be used in the spiral mode. Detector-row thickness (also, but incorrectly, termed ‘collimation’, a phrase originating from the time of the single-detector-row scanners, when this thickness was indeed established by collimation) is an important parameter, as it sets a lower limit to the minimal usable slice thickness. This slice thickness determines the minimal detectable lesion. Of course the in-plane resolution of an axial reconstruction is also important in this respect, but with present-day CT scanners this resolution is 1 mm or less [58], and therefore the slice thickness is of prime importance.
In consensus statements on CT colonography [9, 10, 24] a minimal slice thickness of less than 3 mm is indicated, and this should probably be sufficient in case the target is a polyp 5 mm or larger [59]. In a patient study in which the images were reconstructed both with 2.5 and 1.25 mm slice thickness, no difference was found in sensitivity and specificity for the detection of polyps 6 mm and larger [60]. However, in a study in which a colectomy specimen containing a large number of polyps was used the sensitivity for the detection of smaller (< 5 mm) polyps increased substantially when the detector-row thickness was reduced from 2.5 to 1.25 mm [61]. An increased sensitivity was also found for polyps of all sizes in a pig colon phantom for a slice thickness of 1 mm as compared to 3 mm, in a computer-aided diagnosis (CAD) study of Kim et al. [62]. The increased sensitivity was at the expense of an increased number of false positive findings, however. It also has been suggested that thin collimation is beneficial for specificity, because of an improved detection of air bubbles in stool [59].

Given the sub millimetre detector-row thickness of state-of-the-art CT scanners, a sensible strategy seems to be to use a thin slice thickness (in the order of 1 mm), in order to obtain a data set of isotropic resolution, with the advantage on modern workstations of the possibility to make additional reformat in oblique planes with the same resolution, and/or reconstructions with larger slice thickness, whenever required [58, 63]. Of course also for 3D viewing isotropic resolution is advantageous. It is generally indicated that the reconstructed slices should be somewhat overlapping in order to obtain optimal image quality, and the use of a slice increment of roughly 50% of the slice thickness is often advocated, although for slices with a thickness in the order of 1 mm a somewhat greater increment (0.7 mm) also produces satisfactory results and limits the number of images per data set [63].

Rotation time and pitch

In state-of-the-art CT scanners rotation times in the order of 0.3–0.5 seconds can be used. Pitch values in the order of 1 are therefore adequate. When a MDCT scanner with a coverage of 40 mm in the z-direction is used, for example, and a rotation time of 0.5 seconds is used, a scan of the complete abdomen, for example 50 cm, can be made in the order of 6 seconds. For older CT scanners a slightly higher pitch (up to 1.5) may be required in order to obtain scans within a breath hold [59].
**Tube voltage (kV)**

Traditionally, the vast majority of CT scans are made with a tube voltage of 120 kV. However, lower and higher tube voltages can be chosen, in the range between 80 and 140 kV. The choice of tube voltage influences the output of the X-ray tube (the X-ray intensity is roughly proportional to the square of the tube voltage) and the penetrating power of the photons: the higher the tube voltage, the higher the penetrating power. This also means that the contrasts in CT images made with a higher tube voltage are lower, especially with regard to structures with a higher atomic number (for example iodine and bone) in tissue.

As a consequence CT scans made with a low kV are relative noisy, have relative high contrast, and are made with a lower dose, as compared to scans made with a higher kV, when all other parameters remain fixed. As the image quality is determined by the contrast-to-noise ratio (CNR), it is no trivial task to determine the optimal tube voltage for a CT scan at a given dose.

Recently this issue was addressed in a study of Kalender et al. [64]. For soft-tissue imaging, thus for the imaging of polyps in air, settings of 120–140 kV were found as adequate choices with optimal values increasing for larger cross sections, e.g. for large diameter abdomens voltages even higher than 140 kV were found. Differences in CNR between 120 kV and higher voltages were only a few percent, however. For iodine and bone imaging the optimum values were generally found at significantly lower kV.

**Figure 10** Simulated CT images (level 0, window 1600) of a mathematical phantom mimicking an abdominal cross-section (diameter 34 cm) containing five cross-sections of the colon, each one containing a 6-mm polyp and a stylised vertebra in the lower part of the image. The colon is filled with iodine-tagged water. The simulation on the left (a) was made with 120 kV, 25 mAs; in the middle (b) with 80 kV, 25 mAs; on the right (c) with 80 kV, 75 mAs. The slice thickness for all images is 2.5 mm. The simulation shows the effect of reducing of tube voltage from 120 to 80 kV on the contrast and the noise level. The dose of the simulated CT scan on the right (c) is slightly lower than that of the simulated CT scan on the left (a), yet the signal-to-noise ratio (and the visibility of the polyps) is better.

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lower voltages of typically below 80 kV. For CT colonography imaging a voltage of 120 kV appears to be a reasonable compromise, as both the imaging of soft tissue contrast and iodine contrast is relevant. A lower tube voltage could be appropriate to improve the visibility of polyps covered by material tagged with iodine or barium (Figure 10) [58].

**Tube current (mA)**

The tube current of a CT colonography examination determines – together with tube voltage, rotation time and pitch – the noise in the CT images of the abdomen of a patient. For a fixed abdominal cross-section and fixed kV, the noise is determined by the effective tube charge: The cross-sectional dimensions of the abdomen are a very important factor as well, and the noise level may become extremely high in scans of very obese persons.

Because of the high intrinsic contrast of the structures of interest in CT colonography (soft tissue with a density of 30–50 HU vs. air in the colon with a density of 0.1 HU), a low tube current is often used to reduce radiation exposure. However, this can also lead to reduced image quality. Figure 11 shows images of a 15-mm polyp in a 60-year-old male patient at colonoscopy and at CT colonography with five doses. The images at the four lower doses were obtained by simulation. Top row: left: Colonoscopic image shows 15-mm polyp in ascending colon (arrow). Middle: CT colonographic image obtained at 100 mAs. Right: CT colonographic image obtained at 25 mAs. Bottom row: left: CT colonographic image obtained at 6.3 mAs. Middle: CT colonographic image obtained at 1.6 mAs. Right: CT colonographic image obtained at 0.4 mAs. Although the image quality decreases, polyp visibility is unimpaired.

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![Figure 11](image-url)
the detectability of the relevant structures is relatively insensitive to the noise level of the images. Thus, studies on this topic indicate that the sensitivity for the detection of polyps of 6 mm or larger is hardly influenced by the effective tube charge, and patient studies show that the lowest mAs available should be adequate (Figure 11 and 12) [65–69]. The same results are found in phantom studies [61, 62]; unfortunately in these studies the size of the phantom was not specified, while this size is an important factor for the noise in the images.

For the detectability of polyps covered with tagging the situation is somewhat different, however. de Vries et al. [70] studied the detectability of 6 mm sessile polyps in an anthropomorphic phantom with the size of a fairly obese patient, at effective tube charge levels between 40 and 10 mAs. Sensitivity for polyps in air was 100% down to 10 mAs, as expected. Sensitivity of detection of polyps covered by tagging, however, depended strongly on the density of the tagging material. While

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**Figure 12** Images of a 5-mm polyp in a 57-year-old male patient at colonoscopy and at CT colonography with five doses. The images at the four lower doses were obtained by simulation. Top row: (a) colonoscopic image shows 5-mm polyp (arrow) in transverse colon. (b) CT colonographic image obtained at 100 mAs. (c) CT colonographic image obtained at 25 mAs. Bottom row: (d) CT colonographic image obtained at 6.3 mAs. (e) CT colonographic image obtained at 1.6 mAs. (f) CT colonographic image obtained at 0.4 mAs. The image quality decreases and polyp visibility is affected at lowest doses as a result of increased image noise and smoothing.

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for high-density tagging (density of the tagging in the order of 1100 HU) sensitivity was still 100% at 10 mAs, it was considerably lower for lower densities, and higher tube charge levels (up to 40 mAs for a tagging density in the order of 500 HU) had to be used to obtain a sensitivity of at least 90%. While in practice only part of the polyps will be covered by tagging material, especially when supine and prone images are acquired, it is clear that a sufficiently high density of the tagging is important when low mAs values are used.

The above study indicates that very low mAs levels are not adequate for the depiction of details of lower contrast. Thus, when the detection of extracolonic findings is deemed important, higher mAs-levels have to be used (Figure 13 and 14). The same holds when CT colonography is accompanied by the administration of intravenous

Figure 13 CT colonography in the supine position after extensive bowel preparation and tagging with an iodine contrast medium in a 57-year old woman. (a) CT colonographic image obtained at 70 mAs; (b) CT colonographic image simulated at 25 mAs; (c) CT colonographic image simulated 6.3 mAs; (d) CT colonographic image simulated at 1.6 mAs. The examination was performed for surveillance for colorectal cancer. As an incidental finding an enlarged right adrenal is visible (arrow) with CT features (size, density) suggestive for metastasis. This finding was not known prior to the CT colonography and prompted further work-up. The patient proved to have lung cancer with a metastasis in the right adrenal gland. The enlarged right adrenal is identifiable at 25 mAs and 6.3 mAs, but hardly identifiable at the lowest simulated dose of 1.6 mAs.

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contrast, in which case the higher-mAs protocols used for clinical abdominal scans are appropriate.

We finally mention a fairly recent development that could facilitate the use of low-mAs CT colonography scans, which is the introduction of iterative reconstruction techniques instead of the traditional filtered back-projection. It is claimed that when these new techniques are used the tube current of the CT colonography scan can be lowered, while the diagnostic accuracy remains unimpaired. Although first results are promising, more work needs to be done to establish the performance of iterative reconstruction relative to the established reconstruction techniques [71, 72].

**Tube current modulation**

In the preceding section the choice of the tube current was discussed to obtain images of optimal quality for the different imaging tasks. This choice depends to a
large extent, however, on the dimensions of the cross-section that is imaged. Thus, for thin persons the optimal tube current will be considerably lower than for obese patients. And, once the tube current is chosen for a given patient, the image quality may be good in for instance the upper abdomen, while in the pelvic region with much larger cross-sectional dimensions the image quality may be poor.

These considerations have led to the introduction of tube-current modulation, with the purpose of adapting the intensity of the X-ray beam to the attenuation in the patient [73, 74]. The combination of both angular modulation, i.e. while the X-ray tube rotates around the patient, and longitudinal modulation, while the patient moves through the X-ray beam and the different anatomical regions are scanned, is optimal [75]. When tube current modulation is used the image quality becomes more constant in different regions of the patient, but the modulation is not performed to such an extent that the image noise is constant over all patient sizes. This is because an extreme variation in tube current would be required to obtain constant noise. When a tube voltage of 120 kV is used, 4 cm of tissue attenuates the X-ray beam by approximately a factor of 2, and therefore 8 cm of tissue a factor of 4, 12 cm of tissue a factor of 8, and so on [75]. Extreme variations in tube current are technically not feasible, and in any case not desirable, as they would lead to extreme exposure to radiation for obese patients.

**Dose**

As mentioned above, the dose of a CT colonography examination is determined primarily by the choice of the tube voltage (kV) and current (mA). The chosen tube voltage has a considerable influence on the effective dose: compared with 120 kV, effective dose is reduced by a factor 3–4 when the tube voltage is lowered to 80 kV, and increased by a factor in the order of 1.5 when 140 kV is chosen. Dose depends linearly on the chosen tube current. The use of tube current modulation reduces the dose for the thin and average patients [74, 75]. Although, as mentioned above, the increase in tube current with increasing attenuation is kept within certain limits, for obese patients, dose will increase, but image quality in these patients will increase as well.

Typical effective dose values for CT colonography examinations are 9 mSv for daily practice protocols, and 6 mSv for screening protocols [7]. The risk of induction of cancer for a 50-year-old person for a protocol with an effective dose of 8 mSv was estimated to be 0.14% [76]. A screening CT colonography using an optimised low-dose protocol (effective dose 2 mSv) thus has a risk of induction of fatal cancer
in the order of 1 in 5000 for a fifty-year old, the risk for cancer mortality being considerably less than the risk for cancer itself. Risks of this kind are difficult to assess with certainty, however [58].

**Dual-energy**
During the last years, dual-energy CT scanners haven been introduced, with exploit the possibility to simultaneously make two scans at low and high tube voltages (80 or 100 kV, and 140 kV). The combination of the information in these two scans makes it possible to differentiate tissues according to their effective atomic number. It is for instance possible to calculate the concentration of iodine or barium in the scanned volume.

First applications of dual-energy CT colonography are attempts to improve the performance of electronic cleansing algorithms to remove tagged stool form the CT images, and attempts to characterise lesions by their uptake of (iodine) contrast material [77, 78].

Differentiation of tissues according to their effective atomic numbers makes the images relatively noisy [79, 80]. Therefore dual-energy techniques are not feasible with low-dose CT colonography scans.

**How we do it in our hospital**

**In the dressing room, before the examination**
Check for:
- Ask for history (including recent colonoscopy and surgery, such as a rectal stump or anastomosis)
- Ask for contraindications spasmolytics:
  - Hyoscine butylbromide: narrow angle glaucoma, prostatism or tachycardia
  - Glucagon hydrochloride: pheochromocytoma (and diabetes because caution is needed)
- Ask to empty the rectum if possible

**In the examination room, before the examination**
Explain the examination.
1. At first we will bring a small catheter with a little balloon, which will be insufflated (show them the tip of the catheter).
2. Secondly we will give you some medication intravenously, which will help the bowel to relax.

3. Thirdly, we will start to insufflate your bowel with some carbon dioxide for about 5 minutes. The advantage of this gas is that you will exhale it within a few minutes. At first it will feel like you will have to go to the toilet, but at the end you might experience some bowel cramps. You should not worry about it, as almost everyone experiences this. These cramps will disappear immediately after we stop insufflating.

4. After that we will make to scans, one in the supine and one in the prone position.

5. This is probably a lot of information, but during the examination we will tell you what to do at which moment.

6. In about 10–15 minutes you will be back in the dressing room.

**Preparation of the patient**

1. Let the patient turn into the left or right decubitus position, depending on where the insufflation system is situated.

2. Lubricate catheter (flexible thin rectal catheter with a small (30 mL) balloon on the tip).

3. Inspect the anus (haemorrhoids, etc.) and insert the catheter.

4. Insufflate the balloon with air, check if the catheter stays in by pulling at the catheter and if there is faecal material coming into the tube. Try to empty the tube, as this might give some insufflation problems.

5. Turn the patient back to the supine position. If needed, this is the point at which you should give a spasmolytic agent intravenously in the cubital vein (20 mg of hyoscine butylbromide or 1 mg of glucagon hydrochloride). In case of hyoscine butylbromide, check the pulse for tachycardia. If both spasmolytics are contraindicated, use none.

6. After injection of the medicine, start the automatic insufflation of carbon dioxide. Ask the patient to turn on the right side, let him turn on the back after approximately 1.0–1.3 litre and turn the patient on the left side after approximately 2.0–2.3 litre until 3.0 litres or 5 minutes of insufflation time are reached. Turn the target pressure to 20 mmHg, instead of 25 mmHg (which it probably will be at this point). Note: In case there is no flow, check is the tube is not clinched. If not most likely there is bowel content in front of the tube. Try to squeeze in the bag, while you clinch the tube between the insufflator and the
bag, to make sure the air will go in the direction of the catheter. Another cause can be the automatic shutdown after a certain amount of litres is insufflated.

**Scanning**

1. Make the first scout view and check for evidence of collapsed segments. If there are no signs of collapsed segments, perform the first scan. Check if the distension and preparation (in terms of tagging) are sufficient.
2. Let the patient change position (supine to prone and vice versa).
3. Make the second scout view. Deflate the rectal balloon and perform (in case of no evidence for collapsed segments) the second scan.

Note: If the sigmoid or one of the other colon parts was collapsed during the first scan, it might be useful to squeeze some extra air into the colon.

Note: During the supine scan, a pillow should be under the patients’ chest.

**After the examination**

Deflate the balloon and remove the catheter (after switching of the automatic insufflator). Ask the patient if he feels well (i.e. not light headed). Make sure the dressing room has a toilet, towel and washcloth.

**Acquisition**

These are our hospital protocols for different indications, performed with our 64-slice Philips brilliance scanner (Brilliance, Philips Medical Systems, Best, the Netherlands).
Colon distension and scan protocol for CT colonography: An overview

References


Colon distension and scan protocol for CT colonography: An overview

