

**John F. Bruzzi**  
**Alan C. Moss**  
**Helen M. Fenlon**

## Clinical results by CT colonoscopy

Received: 13 December 2000  
Accepted: 19 December 2000  
Published online: 19 April 2001  
© Springer-Verlag 2001

J. F. Bruzzi (✉) · A. C. Moss · H. M. Fenlon  
Departments of Radiology  
and Gastroenterology,  
Mater Misericordiae Hospital,  
Eccles Street, Dublin 7, Ireland  
E-mail: bruzzij@gofree.indigo.ie  
Phone: +353-1-803 2274  
Fax: +353-1-838 1019

**Abstract** With increasing emphasis among the medical community on the early diagnosis and staging of colorectal cancer, interest has grown in CT colonography as a developing technique to challenge existing methods such as the barium enema and conventional colonoscopy. First introduced in 1994, CT colonography has experienced dramatic improvements in both hardware and software capabilities, resulting in shorter scanning times, greater user-friendliness and promising performance statistics. The recent development in multi-slice CT scanners has meant the ability to scan patients in a single breath hold, while innovations in image reconstruction and manipulation have optimised

and yet greatly simplified study interpretation. Recent imaging protocols that use IV contrast to stage known or suspected colorectal cancer have been described. Current interest has focused on improving patient acceptance of the technique through the development of faecal tagging agents to avoid full bowel catharsis. This review summarises the development of CT colonography to date, evaluates its applications and performance in the detection and screening of colorectal polyps and looks at future directions of this exciting technique.

**Keywords** CT · Colonography · Virtual colonoscopy

### Introduction

Colorectal carcinoma is the second leading cause of cancer death both in Europe and in the United States. The lifetime incidence of colorectal cancer is 5%, with 90% of cases occurring after 50 years of age. One-third of patients who develop colorectal cancer die of the disease. Clinical trials have demonstrated that the incidence and mortality of colorectal cancer can be decreased by early diagnosis, particularly through detection and removal of colonic polyps [1, 2]. More recently, the issue of screening for colorectal carcinoma in the general population has been discussed and recommendations made [2]. The impetus behind screening is the acknowledgement of the malignant potential of colorectal polyps, the recognition of populations at varying risk of developing colorectal carcinoma, and the im-

proved survival of patients who have cancers detected and removed at an earlier stage. As 45% of cancers arise proximal to the splenic flexure the importance of evaluating the entire colon has been emphasised over the past decade.

Virtual colonoscopy is the term used to describe thin-section CT of the prepared colon with the volumetric data set reviewed both as two-dimensional and three-dimensional endoluminal images of the colonic mucosa. It is an exciting new innovation, first introduced by Vining and Gelfand in 1994, when they displayed three-dimensional endoluminal images of the colon in a cine loop, stimulating intense interest in investigators in the field of gastrointestinal imaging [3]. Since that time it has rapidly evolved with substantial improvements both in scanner hardware and computer reconstruction software. The advantages of virtual colonoscopy over con-

ventional endoscopy include safety, its ability to demonstrate the entire colon from rectum to caecum in almost all patients even following incomplete colonoscopy, to examine the bowel in both antegrade and retrograde directions in order to visualize both sides of haustral folds, to accurately localize lesions with reference to extra-colonic landmarks seen on axial images, to examine the proximal bowel with minimal risk in patients with obstructing lesions and in frail, debilitated patients, and to provide staging information in the pre-operative evaluation of patients with carcinoma.

### Technique

Investigators have described a variety of techniques for performing virtual colonoscopy, but the basic principle of thin-section helical data acquisition following colon cleansing remains the same. Bowel preparation consists either of a magnesium citrate laxative commonly employed for barium enema examinations such as Picolax (Ferring Pharmaceuticals, Berkshire, UK), or an osmotic laxative such as Klean-Prep (Helsinn Birex, Dublin, Ireland), as used prior to conventional colonoscopy. The advantage of the barium enema preparation is that it avoids the excessive residual intraluminal fluid seen with the colonoscopic preparations, which hinders visualisation of the colon on virtual colonoscopy. Adequate bowel preparation is one of the most crucial requisites of virtual colonoscopy. It is, however, the most uncomfortable for the patient, leading to intense interest in the development of fecal tagging agents that might reduce the need for full bowel catharsis. In a recent study of 40 consecutive patients who were randomised to undergo either standard colonic cleansing or reduced cleansing with tagging of fecal residues, the investigators found a significant improvement in their confidence to differentiate stool from polyps with the use of fecal tagging agents with the added benefit of reducing patient discomfort [4].

Also important for maximum soft tissue–air contrast is optimal colonic distension: the patient is placed in a decubitus position on the CT table and room air is insufflated into the colon by means of a soft rectal enema tip. Carbon dioxide has been advocated by some as an alternative agent for colonic distension, on the grounds that it is better tolerated by the patient and produces better bowel distention as a result [5, 6], but for convenience, room air is still widely used. Adequacy of colonic distension is assessed on the scout film and further insufflation is performed, if necessary.

Motion artifact must be minimised. Peristalsis can be reduced by spasmolytic agents: glucagon hydrochloride (Glucagon, Eli Lilly, Indianapolis, Ind.) at a dose of 1 mg IV is popular in the United States, whereas hyoscine-n-butyl bromide (Buscopan, Boehringer Ingel-

heim, Berkshire, UK) is more widely used in Europe. Buscopan has the advantage of eliminating small bowel peristalsis more effectively and of being cheaper than glucagon, but its anticholinergic properties may produce troublesome side effects and its use is contraindicated in patients with closed angle glaucoma or cardiovascular disease. In one study of 152 patients undergoing CT colonography with or without glucagon, the use of IV glucagon did not improve colonic distension or enhance diagnostic accuracy for detecting colorectal polyps and cancers [7]. Scanning the entire abdomen and pelvis with conventional helical CT requires approximately 50 s. Respiratory artifact can be reduced by increasing the pitch to 1.5 [8], by asking the patient to exhale slowly following a longest breath hold [9], or by scanning in stages with several breath holds [10]. Faster multi-slice CT acquisitions will overcome problems with motion artifact in the future.

The abdomen and pelvis are scanned in both the supine and prone positions. The following parameters have been described for single-slice helical CT: collimation of 5 mm; table speed of 6.25 mm/s (pitch of 1.25); 2-mm reformatting index; 4-mm filming index; smallest field of view to fit; 120 mA; 110 kVp; and a 512 × 512 matrix [8]. The patient radiation dose per acquisition is approximately 0.44 rem, which is lower than that of conventional axial CT of the abdomen and pelvis and is equivalent to that of a barium enema study [11]. The high inherent soft tissue–air contrast allows reduction of the milliamperes to as low as 70 mA without sacrificing image quality [8, 12]. Further dose reductions can be brought about by higher pitch values: Springer et al. have shown how dose is mainly dependent on collimation, and that thinner collimation with higher pitch values can dramatically reduce patient dose without significantly affecting image quality [13]. The authors advise beam collimation of 3 mm and a higher pitch of 1.5–2 as a reasonable compromise between radiation dose and acceptable image quality. A reformatted slice overlap of 50% minimizes partial-volume averaging effects and stairstep artifacts. A smooth or standard algorithm is chosen, and axial 2D images are reviewed at lung window settings (window level, –750 HU, window width, 1500 HU). Scanning in both the supine and prone positions enables discrimination between mobile fecal material and polyps. It also allows a second evaluation of sections of the colon that may have contained excessive intraluminal fluid or may not have been adequately distended with air on the supine scan, particularly the rectosigmoid as well as ascending and descending colons.

Studies using multi-detector array CT scanners utilise slightly different parameters. The fast rotation time (500 ms) and simultaneous acquisition of four slices mean that an abdomen and pelvis can be imaged in under 20 s, allowing rapid single breath-hold studies. Laghi

et al. described excellent results with a pitch of 1:6,  $4 \times 1$ -mm collimation and 150 mAs [14]. Patient dose from multi-slice virtual colonoscopy has not yet been fully evaluated, but satisfactory image quality can be achieved with a reduced radiation dose of 100 mAs and a collimation of  $4 \times 2.5$  mm.

### Virtual colonoscopy and polyp detection

The accuracy of virtual colonoscopy for polyp detection in patients at high risk for colorectal neoplasia has been reported in many studies. Virtual colonoscopy was first described by Vining et al. in 1994 [15], but the first clinical trial was not reported until 1996, when Hara et al. described a proprietary method of CT colonography to evaluate 30 endoscopically-proven polyps in ten patients [12]. They found that this technique detected 100% of all polyps  $> 1$  cm in diameter, 71% of polyps between 0.5 and 0.9 cm, and up to 28% of polyps  $< 0.5$  cm in diameter. They followed this initial study with a larger trial of 70 consecutive patients who underwent both CT colonography and conventional colonoscopy. In this series of high-risk patients, the technique had a sensitivity and specificity of 75 and 90%, respectively, for identifying patients with adenomas larger than 10 mm; of 66 and 63%, respectively, for identifying patients with adenomas between 0.5 and 0.9 mm in diameter; and of 45 and 80%, respectively, for identifying patients with adenomas  $< 0.5$  mm in diameter. The technique had equivalent performance figures for detecting individual lesions, but the authors stressed that an acceptable goal of a colorectal screening examination was the correct identification of patients with lesions who needed to proceed to colonoscopy, for which they found that virtual colonoscopy had a high predictive value. Missed adenomas were attributable to perceptive errors in 55% of cases, highlighting the importance of operator experience for optimization of the technique. Suboptimal patient preparation accounted for nearly all of the other missed adenomas. To avoid costly and unnecessary colonoscopy, a high specificity is desirable. False positives in this study arose because of correctable factors, such as misidentification of stool, respiration artifact and perceptive errors. The authors concluded that, with greater operator experience and improved scanning techniques, the incidence both of false positives and of false negatives could be substantially reduced.

Several studies have compared the sensitivity and specificity of interpreting axial images alone compared with a combination of axial images and 3D virtual reconstructions. Hara et al. found that the interpretation of axial images alone had a lower sensitivity and specificity compared with virtual colonoscopy (58 and 74%, vs 75 and 90%, respectively, for adenomas  $> 10$  mm in diameter) [10]. Other workers have also found the two

techniques to be complementary [16, 17]. Dachman et al. examined 44 high-risk patients by reviewing only axial images initially, and reserving reconstructed 3D endoluminal views for problem solving. Their technique of primarily evaluating axial images and reserving limited endoluminal views for problem solving had a sensitivity and specificity of 83 and 100%, respectively, for polyps larger than 8 mm in diameter. The average interpretation time was 28 min 30 s (range 14–65 min), and the use of additional endoluminal views had a minimal impact on interpretation time [9].

Larger, more recent studies on the accuracy of virtual colonoscopy in the detection of colonic polyps are consistent with reported sensitivities of 73–100% for lesions  $> 1$  cm in diameter, and of 22–94% for lesions between 5 and 9 mm in diameter [18, 19, 20, 21]. Fenlon et al. evaluated the diagnostic accuracy of virtual colonoscopy in 100 patients at high risk for colorectal neoplasia [21]. All patients underwent bowel preparation and a scanning protocol as previously described, and colonoscopy was performed immediately after image acquisition. Virtual colonoscopy was complete in 87% of patients; conventional colonoscopy was complete in 89%. There was one complication at conventional colonoscopy, a perforation of the sigmoid colon. The interpreting radiologists were blinded to the results of conventional colonoscopy. All three cancers found at colonoscopy were also detected at virtual colonoscopy, as were 91% of polyps greater than 10 mm in size, and 82% of polyps between 6 and 9 mm in size. The sensitivity of virtual colonoscopy for polyps  $< 6$  mm in size was 55%. When these results were analysed on a per-patient basis, virtual colonoscopy was found to have positive and negative predictive values, respectively, of 82 and 84% for polyps of all sizes, of 92 and 94% for polyps between 6 and 9 mm in diameter, and of 96% each for polyps  $> 9$  mm in diameter, indicating the projected accuracy of patient referrals from virtual colonoscopy to conventional colonoscopy. In a larger study of 300 symptomatic and asymptomatic patients referred for virtual colonoscopy from an outpatient department, Yee et al. [18] found that the technique had an overall sensitivity and specificity for colorectal polyp detection per patient of 90.1 and 72%, respectively. The sensitivity for polyps of all sizes was 69.7%, whereas it was 90.2% for polyps equal to or larger than 10 mm, 80.1% for polyps between 5–9.9 mm and 59.1% for polyps smaller than 5 mm [18].

The sensitivity and specificity of virtual colonoscopy have consistently been shown to be dependent on polyp size, with a low reported accuracy for polyps  $< 6$  mm in diameter; however, the importance of removing polyps smaller than 6 mm in diameter may be neither clinically justified nor cost effective. The risk of malignancy in such polyps is  $< 0.1$ % [22], and the likelihood of these being invasive in 10 years is less than 5%

[23]. An argument has been made for removing only polyps > 5 mm in diameter, as opposed to universal polypectomy, which would result in a similar reduction in mortality but with lower risk and lower cost [22, 24]. The sensitivity of virtual colonoscopy for polyps > 5 mm in diameter reported in recent studies approaches that of conventional colonoscopy. If the colon can be reliably cleared of lesions larger than this, it may be reasonable to defer further colon testing for 5–10 years without undue concern [25].

### Virtual colonoscopy and colorectal carcinoma

Between 1.5 and 9% of patients with colorectal carcinomas have a second synchronous cancer [26]. Pre-operative evaluation by colonoscopy or barium enema may be hampered by the occlusive nature of the disease, and failure to recognise the presence of a synchronous cancer will be associated with the added morbidity and mortality of a second surgical procedure. Virtual colonoscopy is an immediately appealing tool for the diagnosis and staging of colorectal cancer through its ability to evaluate all segments of the colon in addition to imaging the peri-colic tissues and liver. Conventional colonoscopy fails to reach the caecum in up to 15% of cases. Virtual colonoscopy has been shown to successfully evaluate segments of the colon not examined either at colonoscopy or by barium enema [27, 28]. In one such study, Fenlon et al. performed virtual colonoscopy on 29 patients with occlusive colorectal carcinomas [28]. Conventional colonoscopy and barium examination of the proximal bowel failed in all cases. Virtual colonoscopy successfully demonstrated the proximal colon in 26 of the 29 patients (90%). All 29 occlusive carcinomas were identified, as well as two additional unsuspected carcinomas and 24 polyps in the proximal bowel. Both additional carcinomas were confirmed at surgery and led to a revision of the original surgical plan.

While most polyp detection studies are performed at lung window settings with a low milliamperage setting, performing the examination at a higher milliamperage setting and viewing the images on soft tissue windows after IV contrast has been administered allows tumours to be staged and may be a more appropriate technique where a colorectal cancer has been shown to be present or is highly suspected. Morrin et al. [29] prospectively examined 34 patients at high risk for colonic tumours using such a method. They correctly staged 81% of colorectal cancers and detected 93% of synchronous polyps. A total of 97% of all colonic segments were adequately visualized, compared with 60% at barium enema [29]. Miao et al. [30] recently reported on 201 patients who underwent both conventional colonoscopy and CT pneumocolon following IV contrast. The latter technique had a sensitivity of 100% and specificity of

99% for invasive cancer, identified invasive cancer not seen at colonoscopy because of incomplete examination in 3 patients, and detected metastases in 6 colorectal carcinoma patients and extra-colonic cancers in an additional 7 patients [30].

### Virtual colonoscopy and population screening

Current recommended screening strategies for low to average-risk people include annual fecal occult blood testing, 5 yearly flexible sigmoidoscopy, 5–10 yearly double contrast barium enema or 10 yearly colonoscopy [2]. Compared with sigmoidoscopy, fecal occult blood testing has poor sensitivity for detecting rectosigmoid cancers and polyps [31]. Flexible sigmoidoscopy is highly sensitive and specific but visualises only the distal colon, where only 50–60% of polyps and cancers reside, and entails some discomfort, risk and inconvenience for the patient [2]. Although both colonoscopy and double contrast barium enema have high-performance values for polyp detection, neither technique has been directly studied as a screening test in prospective randomized trials [32]. Both methods also entail some discomfort and risk for the patient and both are operator dependent. In high-risk patients, the reported sensitivity of barium enema for polyps greater than 5–7 mm is approximately 70%, whereas its specificity is approximately 90% [24]. The National Polyp Study Work Group found that barium enema had a sensitivity for polyps > 1 cm as low as 44% and that colonoscopic examination was to be preferred for post-polypectomy surveillance [33, 34]. Colonoscopy fails to examine the proximal colon in 10–15% of cases, and when performed by experienced gastroenterologists on average to high-risk patients, may miss up to 24% of polyps [35]. In high-risk patients the reported sensitivity of virtual colonoscopy for polyps > 10 mm in diameter ranges from 75 to 91%, and falls to 82–66% for polyps > 5 mm in diameter; respective specificities are 90 and 63% [10, 21]. No large studies have directly compared virtual colonoscopy with double contrast barium enema, but indirect evidence suggests that the predictive value of virtual colonoscopy in high-risk patients exceeds that of barium enema and approaches that of conventional colonoscopy.

For virtual colonoscopy to be considered as a population screening tool, it must be shown to be competitive with existing techniques, to be safe, to be acceptable by patients, to be available and to be cost-effective [2]. While there has been much research of virtual colonoscopy in highly selected high-risk populations, the reported performance of virtual colonoscopy to date may be an overestimate of its value in patients at average risk of colorectal neoplasia. In one trial of virtual colonoscopy in average-risk patients, virtual colonoscopy was found to produce findings that might lead to conven-

tional colonoscopy in 75% of patients with an adenoma 2 cm or larger, in 83% of patients with an adenoma between 1 and 1.9 cm, in 43% of patients with an adenoma between 6 and 9 mm and in 25% of patients with an adenoma < 6 mm; however, the sensitivity of virtual colonoscopy for individual adenomas was poorer, with only 25% of adenomas > 2 cm being detected, 60% of adenomas 1–1.9 cm in diameter and 43% of adenomas between 6 and 9 mm in diameter. The authors found that meticulous bowel preparation and adequate distension were critical to accurate interpretation [36]. Clearly further large-scale multicentre studies are required to more fully evaluate the performance of virtual colonoscopy in average-risk patients before the technique can be promoted for population screening. Such trials are currently underway and results are awaited with interest.

Patient acceptance is another important factor to be considered when evaluating virtual colonoscopy as a screening tool, and is crucial in relation to compliance with screening. Few studies have directly evaluated patient discomfort from virtual colonoscopy. Patients generally describe discomfort as mild bloating or cramping, resulting from rectal air insufflation. Fenlon et al. found that none of the patients in their series requested that the procedure be stopped because of discomfort or pain [21]. Other investigators have also reported that the examination is well tolerated and assessed by patients to be more acceptable than either full colonoscopy or barium enema [27, 37]. In a study designed to specifically examine patient tolerance of virtual colonoscopy, most of the 221 patients preferred conventional colonoscopy; however, only 80 patients were assessed at 24 h following the procedure, and it is unclear to what extent sedation at colonoscopy interfered with patients' evaluation [38]. A main advantage of virtual colonoscopy is that it does not involve any patient sedation, even if it involves a higher patient awareness of discomfort during the procedure. Fecal tagging agents may have the potential of reducing bowel preparation and substantially improving patient tolerance of the procedure.

Currently, the application of virtual colonoscopy as a screening tool is limited not just by a lack of multicentre data but also by logistical and financial constraints. Access to suitable CT hardware and software is limited in many centres. Patients who undergo virtual colonoscopy and in whom polyps are detected need to be referred for conventional colonoscopic examination on the same day to avoid repeat bowel preparation. This requires prompt interpretation of images, has significant implications in terms of radiologists' time, and requires close collaboration with our gastroenterology colleagues. The cost-effectiveness of virtual colonoscopy as a screening technique has been assessed by Sonnenber et al. [39] on computer models based on a Markov process using current screening strategy recommendations. They described how, with an assumed sensitivity rate of 80%,

virtual colonoscopy would only be cost-effective if it was associated with an initial compliance rate 15–20% better or procedural costs 54% less than conventional colonoscopy. An improved sensitivity rate of 100% would not render the technique cost-effective; however, if the sensitivity fell to < 60% – rates that apply particularly to detection of polyps smaller than 6 mm in diameter – then screening costs would mean that virtual colonoscopy could not compete with conventional colonoscopy [39]. With more widespread access to CT, developments in 3D reconstruction software and more patient-friendly bowel preparation techniques predicted for the future, costs for virtual colonoscopy will surely fall and compliance rates will rise, but at the moment the technique does not appear ready to be included in screening strategies.

---

### The Future

At the First International Symposium on Virtual Colonoscopy in Boston in 1998, commentators urged against disappointing funding agencies, referring physicians and the public by performing large-scale studies before software and imaging strategies have adequately matured. They advised more focused studies in defined population groups before embarking on wider trials on low-risk populations [25]. It was noted at the Second International Symposium on Virtual Colonoscopy in Boston in 2000 that many advances have already occurred. Recent experience with multi-slice CT imaging means that patients can be scanned in a single breath hold, with improved z-axis resolution. There are ongoing developments in software manipulation of acquisition data, leading to shorter reconstruction and interpretation times. Some packages currently offer automated midline tracing of the bowel lumen, which facilitates navigation and significantly shortens the time for performing a virtual “fly through”. Other developments include instant 3D endoluminal views of specific axial images rather than an entire virtual fly through, and automatic computer assessment of colonic wall thickness that alert the interpreting radiologist to specific abnormalities. Using these and similar techniques, viewing times have fallen from initial reports of up to 60 min to as little as 11 min without sacrificing diagnostic performance [40]. As patient compliance is crucial to the success of virtual colonoscopy, there is intense interest in more acceptable methods of bowel preparation. Current research in fecal tagging agents may, in the future, render full colon cleansing unnecessary.

Virtual colonoscopy has already established itself in the imagination of both the medical world and the public as an exciting alternative to colonoscopy for polyp detection and for colorectal screening. Ongoing and future improvements may prove its value in colorectal examination strategies.

## References

- Winawer SJ, Zauber AJ, Ho MN et al. (1993) Prevention of colorectal cancer by colonoscopic polypectomy. *N Engl J Med* 329: 1977–1981
- Winawer SJ, Fletcher RH, Miller L et al. (1997) Colorectal cancer screening: clinical guidelines and rationale. *Gastroenterology* 112: 594–642
- Vining DJ, Gelfand DW (1994) Noninvasive colonoscopy using helical CT scanning, 3D reconstruction, and virtual reality. Presented at a 1994 meeting of the Society of Gastrointestinal Radiologists, Maui, Hawaii; 13–18 February 1994
- Gryspeerd S, Van Holsbeeck, Baekelandt M, Lefere P (2000) Colonic cleansing with tagging of fecal residues prior to virtual CT colonoscopy. *ESGAR 2000. Eur Radiol* 10:D2
- Rogalla P, Schmidt E, Korves M, Hamm BK III (1999) Optimal colon distension for virtual colonoscopy: room air versus CO<sub>2</sub> insufflation. *RSNA 1999. Radiology* 213(P):341
- Taylor PN, Beckly DE (1991) Use of air in double-contrast barium enema: Is it still acceptable? *Clin Radiol* 44: 183–184
- Morrin M, Kruskal JB, Farrell RJ, Reynolds BS, Raptopoulos VD (1999) Does glucagon improve colonic distension and polyp detection during CT colonography? *RSNA 1999. Radiology* 213(P):341
- Fenlon HM, Ferrucci JT (1997) Virtual colonoscopy: What will the issues be? *AJR* 169: 453–458
- Dachman AH, Kuniyoshi JK, Boyle CM, Samara Y, Hoffmann KR, Rubin DT, Hanan I (1998) CT colonography with three-dimensional problem solving for detection of colonic polyps. *Am J Roentgenol* 171: 989–995
- Hara AK, Johnson CD, Reed JE, Ahlquist DA, Nelson H, MacCarty RL, Harmsen WS, Ilstrup DM (1997) Detection of colorectal polyps with CT colonography: initial assessment of sensitivity and specificity. *Radiology* 205: 59–65
- Hara AK, Johnson CD, Reed JE et al. (1997) Reducing data size and radiation dose for CT colonography. *Am J Roentgenol* 168: 1181–1184
- Hara AK, Johnson CT, Reed JE et al. (1996) Detection of colorectal polyps by computed tomographic colography: feasibility of a novel technique. *Gastroenterology* 110: 284–290
- Springer P, Stoher B, Giacomuzzi SM et al. (2000) Virtual computed tomography colonoscopy: artifacts, image quality and radiation dose load in a cadaver study. *Eur Radiol* 10: 183–187
- Laghi A, Panebianco V, Baeli I, Iannaccone R, Luccichenti G, Catalano C, Passariello R (2000) Multislice spiral CT colography technique optimization. *ESGAR 2000. Eur Radiol* 10:D2
- Vining DJ, Gelfand DW, Bechtold RE, Scharling ES, Grinshaw EK, Shifrin RY (1994) Technical feasibility of colon imaging with helical CT and virtual reality. *Am J Roentgenol* 162:S104
- Royster AP, Fenlon HM, Clarke PD, Nunes DP, Ferrucci JT (1997) CT colonoscopy of colorectal neoplasms: two-dimensional and three-dimensional virtual-reality techniques with colonoscopic correlation. *Am J Roentgenol* 169: 1237–1242
- Morra A, Medure S, Ammar L, Ukmar M, Pozzi Muscelli R (1999) Colonoscopy with computed tomography with volume reconstruction. The results and a comparison with endoscopy and surgery. *Radiol Med (Torino)* 98: 162–167
- Yee J, Hung RK, Akerkar GA, McQuaid K, Wall SD, Steinauer-Gebauer AM (2000) Performance of CT colonography for colorectal polyp detection in screening patients. *ESGAR 2000. Eur Radiology* 10:D1
- Foster N, Wood C, Rosenberg M, Forbes G, Mendelson R (2000) A comparison of CT virtual colonoscopy and conventional colonoscopy in the detection of colorectal polyps and cancer. *ESGAR 2000. Eur Radiol* 10:D2
- Lefere P, Van Holsbeeck B, Baekelandt M, Gryspeerd S (2000) Virtual CT colonoscopy: initial results. *ESGAR 2000. Eur Radiol* 10:D3
- Fenlon HM, Nunes DP, Schroy PC III, Barish MA, Clarke PD, Ferrucci JT (1999) A comparison of virtual and conventional colonoscopy for the detection of colorectal polyps. *N Engl J Med* 341: 1496–1503
- Waye JD, Lewis BS, Frankel A, Geller SA (1998) Small colon polyps. *Am J Gastroenterol* 83: 120–122
- Chantreau MJ, Faivre J, Boutron MC et al. (1992) Epidemiology, management and prognosis of malignant large bowel polyps within a defined population. *Gut* 33: 259–263
- Glick S, Wagner JL, Johnson CD (1998) Cost-effectiveness of double-contrast barium enema in screening for colorectal cancer. *Am J Roentgenol* 170: 629–636
- Fenlon HM, Ferrucci JT (1999) First International Symposium on Virtual Colonoscopy: meeting summary. *Am J Roentgenol* 173: 565–569
- Dasmahapatra KS, Lopyan K (1989) Rationale for aggressive colonoscopy in patients with colorectal neoplasia. *Arch Surg* 124: 63–66
- Morrin MM, Kruskal JB, Ferrell RJ, Goldberg SN, McGee JB, Raptopoulos V (1999) Endoluminal CT colonography after an incomplete endoscopic colonoscopy. *Am J Roentgenol* 172: 913–918
- Fenlon HM, McAneny DB, Nunes DP, Clarke PD, Ferrucci JT (1999) Occlusive colon carcinoma: virtual colonoscopy in the preoperative evaluation of the proximal colon. *Radiology* 210: 423–428
- Morrin MM, Farrell RJ, Raptopoulos V, Bleday R, Kruskal JB (2000) Role of virtual computed tomographic colonography in patients with colorectal cancers and obstructing colorectal lesions. *Dis Colon Rectum* 43: 303–311
- Miao YM, Healy JC, Burn P, Murugan N, Westaby D, Allen-Marsh TG, Amin Z (2000) A prospective single centre study comparing CT pneumocolon against colonoscopy in detection of colorectal neoplasms. *ESGAR 2000. Eur Radiol* 10:D2
- Mandel JS, Bond JH, Church TR et al. (1993) Reducing mortality from colorectal cancer by screening for fecal occult blood. *N Engl J Med* 328: 1365–1371
- Bond JH (1999) Screening guidelines for colorectal cancer. *Am J Med* 106 (Suppl 1A):7S–10S
- Zauber A (1994) National Polyp Study. Presented at Digestive Disease Week, New Orleans, May 1994
- Winawer SJ, Stewart ET, Zauber AG, Bond JH, Ansel H et al. (2000) A comparison of colonoscopy and double-contrast barium enema for surveillance after polypectomy. National Polyp Study Work Group. *N Engl J Med* 342: 1766–1772
- Rex DK, Cutler CS, Lemmel GT, Rahmani EY et al. (1997) Colonoscopic miss rates of adenomas determined by back-to-back colonoscopies. *Gastroenterology* 112: 24–28

- 
36. Rex DK, Vining D, Kopecky KK (1999) An initial experience with screening for colon polyps using spiral CT with and without CT colography. *Gastrointest Endosc* 50: 309–313
37. Hara A, Johnson CD, Reed JE et al. (1996) Colorectal polyp detection using CT colography: initial assessment of sensitivity and specificity (abstract). Presented at the Annual Meeting of the Radiological Society of North America in Chicago, Illinois, 1996
38. Akerkar GA, Hung RK, Yee J, Terdiman JP, McQuaid KR (1999) Virtual colonoscopy: real pain. *Gastroenterology* 116:A44
39. Sonnenberg A, Delco F, Bauerfeind P (1999) Is virtual colonoscopy a cost-effective option to screen for colorectal cancer? *Am J Gastroenterol* 94: 2268–2274
40. Johnson CD, Ahlquist DA (1999) Computed tomography colonography (virtual colonoscopy): a new method for colorectal screening. *Gut* 44: 301–305