Virtual colonoscopy becomes clinical reality

Colorectal cancer ranks as the third most common human malignancy and the second leading cause of cancer-related deaths in the U.S. The overall risk of developing the disease is approximately 5% over a lifetime. Around 130,000 new cases of colorectal cancer were diagnosed and 57,000 deaths were attributed to it in both 1999 and 2000.1,2

Most colon cancer arises from adenomatous polyps, which can take five to 15 years for malignant transformation.3,4 The risk of developing carcinoma from a polyp is directly related to its size: essentially zero risk if the polyp is less than 5 mm, 1% risk if it is between 5 and 10 mm, 10% risk with size 10 to 20 mm, and at least 30% risk with polyps larger than 20 mm.5

Survival rates from colon cancer are related directly to the pathologic staging of the disease and exceed 90% when cancers are limited to the bowel wall.6 Whereas 75% of cancers found by screening in asymptomatic patients are confined to the bowel wall (Dukes' A and B), more than half of those with symptoms have a more advanced stage (Dukes' C and D).

Symptoms of colon cancer, such as anemia and change in bowel habits, are neither sensitive nor specific. Studies have shown that screening can reduce colon cancer mortality.6 The American Cancer Society recommends that screening begin at age 50 for asymptomatic, average-risk patients, with either yearly fecal occult blood testing with flexible sigmoidoscopy or double-contrast barium enema every five years, or a colonoscopy every 10 years.7

Fecal occult blood testing is the safest and least expensive tool, but it detects only 30% to 40% of colorectal cancers and 10% of adenomas.8 Because it examines only to the junction of the descending colon and sigmoid, sigmoidoscopy does not detect 32% of advanced cancers.9 Even one-time screening with fecal occult blood test and sigmoidoscopy would fail to detect 24% of patients with advanced colonic neoplasia.10 Double-contrast barium enema is more time-consuming, requires a good deal of patient positioning and cooperation, and has variable reported diagnostic accuracies.11

Standard optical colonoscopy can biopsy and/or remove detected polyps, and is generally considered the gold standard, although miss rates of 18% of adenomas >6 mm have been reported on back-to-back colonoscopies.12 Additionally, it is uncomfortable, requires colon cleansing and sedation, is time-consuming and invasive, has a small risk of perforation and death (colonic perforation in one in 500 to 1000 cases and death in one in 2000 to 5000 cases),13 fails to demonstrate the entire colon in up to 10% of patients,14 and is ineffective in examining areas of the colon blocked by masses or in areas of severe narrowing.

Colon imaging with helical CT and virtual reality was first reported by Vining et al15 in 1994. Abdominal axial images of the distended colon are taken in seconds during breath-holding and are used to create two-dimensional multplanar reformation (MPR) or three-dimensional images of the colon. The performance data to date have been encouraging, with sensitivity and specificity for polyps >1 cm ranging from 75% to 91% and 90% to 93% respectively, as reported by per-polyp comparisons.16,17 While most published reports include patients who were either symptomatic or highly suspected to have polyps, the use of virtual colonography for screening is supported in a recent study by Yee et al17 that showed similar performance characteristics in asymptomatic, average-risk patients as compared with high-risk, symptomatic patients.17
and electrolyte abnormalities.\textsuperscript{18,19}

Magnesium citrate oral solution may be an equally effective, potentially safer agent, and it can be combined with bisacodyl tablets and suppository for a less vigorous laxative program (LoSo Prep, E-Z-Em). The additional use of a modified low-residue diet to help satisfy hunger and cleanse the colon would further increase patient compliance.

A preferred approach to physical cleansing uses oral contrast agents to increase the density of the remaining material, which can then be automatically identified and removed by computer segmentation techniques. Barium sulfate, given with meals the day before the virtual colonoscopy, can be incorporated into residual stool, while iodinated contrast (Gastroview, Malinckrodt) will label the remaining fluid. This approach may make it possible to completely eliminate all physical bowel cleansing.\textsuperscript{20}

The use of spasmolytic agents to prevent segmental collapse and spasm is debatable, although studies have reported no significant benefit for the routine use of glucagon.\textsuperscript{21}

The examination begins by inflating the colon with approximately 1 to 2 liters of either air or carbon dioxide, introduced through a small rectal tube. Carbon dioxide, which is better tolerated by the patient, can be delivered through a handheld insufflator bulb or laparoscopic-type pressure-sensitive device.

CT scout views are used to assess colon distension. During a single 35 to 40-second breath-hold, continuous CT images with 100 mA or less are obtained, usually using the following parameters: single-slice CT, 5-mm collimation 1.7 to 2 pitch, 1 to 3 mm reconstruction; or multislice CT, 2.5-collimation with 1.25-mm reconstruction, and an equivalent pitch of 6, yielding as many as 300 to 400 images for each sequence. Images are obtained in both supine and prone positions to improve distension and to move residual fluid, significantly improving performance in polyp detection.\textsuperscript{22}

**PATIENT PREPARATION**

Two approaches to colon evaluation are possible, depending on whether
2-D or 3-D images are used for primary interpretation. CT colonography uses 2-D images, familiar to all radiologists, as the means of initial interpretation. On a computer workstation such as Navigator (GE Medical Systems), Virtuoso (Siemens Medical Systems), Vitrea 2 (Vital Images), Plug n View 3D (Voxar), and Accu-View (Accuimage), scrolling up and down the axial images at lung window settings can sequentially evaluate the air-filled colon for polyps (Figure 1). Zoomed axial images or reconstructed views perpendicular to the colon surface can also be used. Improved detection and characterization of suspected lesions occurs with 2-D MPR images to simultaneously cross-reference one plane to the other two planes. Soft-tissue windows are reserved to evaluate areas of colonic collapse, wall thickening, pericolonic soft-tissue stranding, and extracolonic findings. Narrow windows can be used for tissue characterization to detect fat within a lipoma, or air and retained barium within stool.

Because obtaining 3-D images is often cumbersome and time-consuming, they are reserved to confirm or further characterize 2-D findings, often to differentiate small polyps from folds. For technical reasons, these 3-D endoluminal views are frequently of only a small segment of the colon (Figure 2A), or even a small cubed section that can be rotated in different planes (Figure 2B). To reduce interpretation time with these particular systems, complete navigation throughout the colon is often not done. As a result, it is suggested that the radiologist primarily rely on the axial 2-D images for adequate interpretation of CT colonography, and use the supplemental 3-D images only for problem-solving.

A second approach to colon evaluation, known as virtual colonoscopy, uses a computer visualization system for image segmentation to construct a clean colon model and computer graphics to virtually navigate through the 3-D colon model. The V3D Colon Module (Viatronix) uses this approach, enabling both automatic and interactive endoluminal navigation as the primary method to evaluate the colon surface.

A colon model is created after electronic bowel cleansing in which oral contrast and specified residual fluid/stool are removed. The fully automatic system segments the colon and generates its centerline to reduce the time needed for "setting up" the CT images for viewing and analysis (Figure 3). Guided navigation smoothly follows the centerline, like a flight path, toward the end of the colon. The direction of navigation can be selected and the current distance from the rectum displayed for all points along the centerline.

With real-time volume rendering at more than 10 frames/sec, interactive navigation of the endoscopic views can analyze the inside of the colon—even behind haustral folds—and obtain accurate 3-D measurements of suspicious structures. Two-D views corresponding to the navigation viewpoint are available for verification purposes. The specific image within any plane is easily correlated to the endoscopic view (Figure 4).

By turning, zooming, and rotating during the "fly-through" examination of the endoscopic views, the radiologist can view the entire colon surface instead of examining only a movie that can be played in forward and reverse. The visualized colon surface can be marked and measured during guided fly-through navigation (Figure 5). Areas of the surface not directly viewed by the observer are presented for direct evaluation. Suspected abnormalities could be further evaluated using translucent rendering, a semitransparent view beneath the surface that represents structures of various densities in different colors.
Improved characterization of individual cases has been shown with 3-D display techniques. Even if it is still preferable to initially evaluate the 2-D images, there is now a seamless, simultaneous correlation with the endoluminal views (Figure 6). Unlike the 2-D approach, it is also feasible to internally view within suspected abnormalities to help distinguish residual stool balls containing barium from true polyps, which appear similar during endoscopic evaluation, and possibly to differentiate adenomas from hyperplastic polyps (Figure 7). Rather than paging through hundreds of axial CT images to find small polyps that may be difficult to distinguish from colonic folds, a more realistic virtual endoscopic examination of the colon is possible. Only now can a legitimate comparison of the two different approaches to colon evaluation be performed.

References for this article are available at diagnosticimaging.com

EXTRACOLONIC FINDINGS

Using both CT colonography and virtual colonoscopy, the colon wall itself, as well as extracolonic tissues, can be evaluated on 2-D images similar to standard CT exams. This is a unique benefit compared with other colorectal cancer screening techniques. In a group of patients with a high risk for polyps, one-half had some type of extracolonic abnormality, while 11% had highly clinically important findings, including lung nodules, abdominal aortic aneurysm, renal adenocarcinoma and bowel containing inguinal hernia. Additional workup was often worthwhile and did not substantially increase the examination cost per patient.

MORE REALISTIC VIRTUAL EXAM

Many of the early recommendations for examining virtual colonoscopy studies were based on workstations that could not easily perform 3-D endoluminal evaluation, making the reliance on axial images the only feasible approach. Researchers at Stanford University have shown, however, that if all surfaces of the colon lumen have been seen, 3-D endoscopic navigation has a higher sensitivity for polyp detection than 2-D axial images, allowing complete viewing of the entire colon surface, even behindhaus-

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**FIGURE 5.** Endoscopic view of colon looking back along areas marked. Green areas are the only surfaces seen during initial fly-through. Orange areas show obscured surfaces not visible (e.g., behind sharp bends) during first fly-through. Next fly-through in reverse direction will be able to evaluate most of these areas. **FIGURE 6.** Simultaneous correlation of polyp in 2-D axial (A) and 3-D endoluminal (B) views.

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**FIGURE 7.** Use of translucent rendering mode applied to endoscopic views shown on top images. Adenoma (B) has a gradual change in density toward the center shown by the color change from blue to green to red. Hyperplastic polyp (D) has uniform blue colors similar to the mucosa and colonic folds. Stool ball with barium (F) is dark red, indicating high density, extending to the surface.