Visualization and Navigation Techniques in CT Colonography

Kenneth R. Hoffmann, Ph.D. and Zhan Zhang, Ph.D.

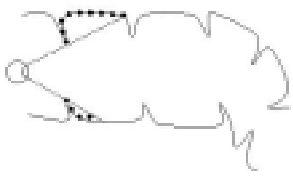
Toshiba Stroke Research Center, Department of Neurosurgery, 3435 Main St.,
University at Buffalo, Buffalo, NY 14214 USA
e-mail: kh9@acsu.buffalo.edu

Introduction

Colon cancer is the second most frequent cause of cancer death in the United States [1-2], and it is associated with colonic polyps, small nodule-like protrusions into the colon lumen. Because the probability of malignancy increases with polyp size and because the polyps develop and grow relatively slowly over time, early detection of colonic polyps and their removal can reduce cancer risk and death [3-5].

The standard procedure for detecting polyps is fiber-optic endoscopy, in which a cable with a video camera at one end is inserted into the colon. Prior to the endoscopy, the patient follows a regimen aimed at clearing the colon of stool, involving laxatives and enemas. During the procedure, the endoscope is snaked through the colon, and as it proceeds the colon is insufflated (puffed up with air), and the colon surface is viewed by directing the camera at the colon surface. The procedure is nominally uncomfortable and takes about one-half hour. Unfortunately, only a few percent of those who should have endoscopy actually have them because of the inconvenience of the colon cleansing, the discomfort of the insufflation, and the embarrassment involved. In addition, standard endoscopy often misses visualizing some of the colon surface because it is basically forward looking, as shown in Figure 1, and sometimes the endoscope cannot proceed to the cecum because a portion of the colon is collapsed.

Figure 1. A cross-sectional view of the colon during endoscopy. Portions of colon surface (circles) are hidden from view by the folds, which protrude into the colon lumen; thus, these portions will not be inspected unless additional perspectives are used.



To overcome some of these negative aspects, it was proposed that computed tomography (CT) scans could be used to inspect the colon [6-14]. The colon is still cleansed and insufflated as in endoscopy, but the procedure lasts only 10-15 minutes, and is seen as less embarrassing. Moreover, efforts are underway to reduce further the inconvenience of the colon cleansing [15, see also below]. The parameters used in the CT scan have evolved over time. At present, collimations of 2.5 - 5 mm is used, with pitches between 1-2, and reconstruction intervals of 1 to 3 mm, on helical CT or multi-detector helical CT scanners.

Visualization Methods of CT Colonography

Radiologic evaluation of the colon is usually performed by inspecting axial images, such as those shown in Figure 2 (a polyp is visible near the center of the image). The colon lumen appears black in the image (low Hounsfield units), and the colon surface is brighter and relatively smooth. The radiologist will inspect these images, e.g., the colon surface, in a serial manner moving “up” and “down” in the axial image stack, following the connected colon centerline, and sometimes changing the window and level in the image (the mapping between CT numbers and display intensity). While this is the most commonly used form of colon image, other views (e.g., saggital and coronal views (see Figure 3)) will sometimes be used for “problem solving” or more careful inspection of a suspicious area. These planes are usually selected such that they intersect at the position of the suspected polyp. Another view, which has been investigated, is an oblique view, which is perpendicular to the estimated colon centerline (Figure 3).

Figure 2. Consecutive axial slices from a CT study of the colon. The polyp (near the center of the image and indicated by the arrow) protrudes into the lumen and lies on and between two folds. The continuity of the polyp and its features across several axial slices facilitates its identification as the radiologist moves “up” and “down” through the axial slices.

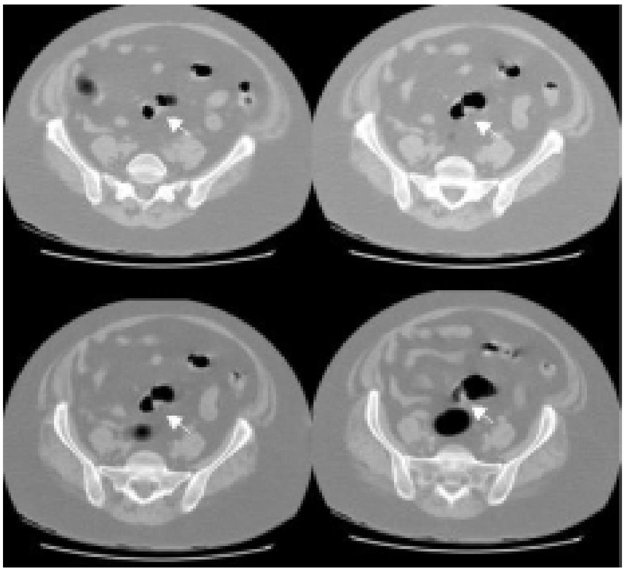
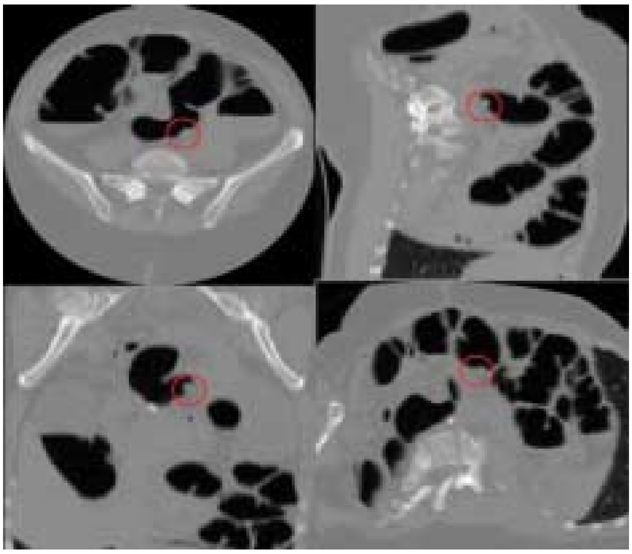
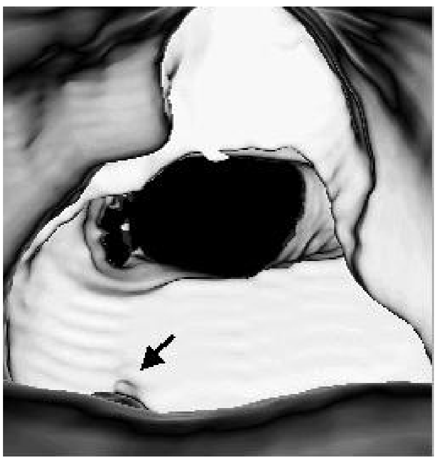


Figure 3. Axial (top left), saggital (top right), coronal (bottom left), and oblique (bottom right) views of the colon data. The polyp is indicated by the circles.



In addition, a "virtual colon" view (Figure 4) can also be generated for inspection of the colon surface [16]. The time for inspection ranges from 10 ~ 30 minutes per case. Longer times are required when supine and prone data are acquired or when multiplanar inspections or volume rendering are used [16].

Figure 4. Endoluminal view of the colon, generated perpendicular to the local colon centerline. A polyp is visible on the lower left side of the image (arrow).



To facilitate the inspection of the colon, Vining [8] proposed a method which presented the colon data in a manner similar to that of endoscopy. The colon lumen is segmented from the CT colon data using thresholded-region-growing techniques [17-19] (a segmented colon is shown in Figure 5).

Figure 5. A rendered view of the segmented colon lumen. The various portions of the colon are readily recognizable, i.e., the rectum, the sigmoid colon, the descending, transverse, and ascending portions of the colon. Rendering techniques can be used to "fly" inside this structure and inspect the surface more closely.

The radiologist can then "fly into" and "fly through" the colon, inspecting the surface for polyp-like structures as he/she proceeds. Because of its similarity with colonoscopy and its use of the computer to "virtually" fly-through the colon, this approach is commonly called "virtual colonoscopy". This approach could suffer from the coverage deficiencies encountered in endoscopy, but the radiologist can fly both directions easily, and should an area look suspicious, the view can be adjusted to inspect that area; inspections of areas will increase the reading/inspection time per case.

Since the introduction of virtual colonoscopy, a number of groups have developed methods for inspection of the colon surface with the goal of reducing inspection time and improving sensitivity. Most fly-through techniques employ a movie format, in which the centerline is generated (either automatically [17-22] or by hand), and the 3D virtual views are generated and stored for points along the colon centerline, usually from rectum to cecum and then back (to improve the coverage). To improve the speed and coverage of virtual colonoscopy inspections, the group at Stanford [23-25] have proposed rendering techniques, which depart from the standard colonoscopy model of viewing, which employ various geometric mappings of the colon surface to the viewing plane. In their techniques, the viewer still moves along the centerline, viewing the rendered high-resolution local colon surfaces in a sequential manner. Their results are very promising, even though the colon surface appears warped, with shapes in the periphery of the view changing as they move toward the center. They report sensitivities of 90% with their panoramic view versus a sensitivity of 68% obtained using the standard endoscopic view [24]. Others [26, 27] have proposed techniques to flatten the colon surface and present the data more quickly. In a flattened image, the effort is to provide an image which preserves the shape information while providing a reduction of the amount of data that must be viewed, presenting the entire colon surface as a single or a few images (1024x1024 pixels) with lower resolution than that used in the rendering techniques. With the flattened image, image processing techniques can then be used to facilitate differentiation between polyps, folds, and background structures.

So far, we have been talking about inspection of the colon surface by the radiologist. However, the radiologist is making use of information (e.g., shape, size, curvatures, texture, CT number) about polyp, folds, and background structures to detect the polyps in the CT data. This information could be used by the computer to perform the detection task in a manner similar to the radiologist. Such techniques fall under the umbrella of computer-aided diagnosis (CAD), which have had great success in mammography and chest radiology. Summers [28] and Yoshida [29] have proposed using the local curvature of the colon surface to detect polyps, Hopper et al. [30] proposed using the CT numbers near the colon surface to facilitate polyp detection. With CAD, the computer would "inspect" the CT data either before or while the radiologist inspects the data. Once the radiologist has completed his inspection, the suspicious areas found by the computer could be highlighted for additional inspection. As with 2D-CAD, issues as to how to use the 3D-CAD results will have to be addressed. However, even with CAD, the colon would still need to be inspected by the radiologist, thus, while CAD might improve specificity, it may not reduce the time for inspection in the near future.

Navigation through the colon data

Most if not all, radiologists (and visualization techniques (above)) follow the colon centerline. This approach may allow the radiologist to make use of his/her intuitive 3D perception of the colon as well as facilitating inspection of areas neighboring suspicious regions. Most radiologists navigate through the colon by hand (some literally by placing their finger on the centerline when tracking the centerline becomes difficult) and inspecting the colon surface for polyp-like bulges. In this approach, centerline determination/tracking and inspection occurs simultaneously. Most of the visualization techniques above make use of indicated points along the colon axis, which are then connected by a region-growing/centerline-finding method. If the colon is well cleansed and insufflated, a continuous path from rectum to cecum can be automatically found [17-22], however, user indicated points are still required for collapsed colons.

Once the centerline exists, the "path" through the colon is determined. For most of the visualization techniques, navigation involves watching movies which are generated in advance of inspection because 3D rendering is time and compute intense; this limits the flexibility of the radiologist in inspecting suspicious area, suspicious areas must be inspected using additional viewing software, either planar or 3D-based. Viatronix (www.viatronix.net) offers real-time fly-throughs in which the viewer can adjust the position and orientation of the viewpoint in real time. This is achieved through specific visualization hardware developed at SUNY-Stonybrook. In addition, to address the coverage issue they monitor the surface voxels inspected to allow complete coverage. They indicate that inspection of the complete colon surface with their technology requires approximately 10 minutes, which many feel is about the right amount of time.

Issues in visualization and navigation

Virtual inspection of the colon is becoming more popular and may lead to a technology for large scale screening for colon cancer. Among the issues remaining before this is achieved are coverage, colon collapse, residual stool, and compliance. The issue of coverage has been raised [31, 25]. For virtual colonoscopy, ensuring that all connected regions larger than 0.25 mm^2, for example, are viewed is critical. In the flattening techniques, care must be taken to ensure that all regions of the colon are rendered. Even if a method to allow automatic inspection of non-collapsed regions of the colon is developed, the collapsed regions cannot be inspected unless the insufflated regions of the patient change, e.g., by turning the patient over (prone vs. supine). However, is the entire colon inspected? Techniques will need to be developed which relate insufflated regions in the two (or more) acquisitions to ensure full coverage. The issue of residual stool is being addressed on two fronts: determination of the characteristics of the retained stool and changing the nature of the retained stool, e.g., patient preparation involves a special diet containing high Z material and specific fiber and liquid content [15]. The "opacified" stool can be "electronically cleansed" [15] using developed algorithms. Electronic cleansing, while primarily a visualization tool, is actually aimed at a more critical aspect of polyp detection, patient compliance. With a simple, easy-to-follow, and palatable diet and with nominal discomfort during the CT scan, patients may be more willing to agree to an inspection of their colon, leading to more polyps detected earlier. Thus, visualization/inspection tools, which can provide higher patient compliance, will ultimately reduce the number of deaths from colon cancer.

Acknowledgments

This work was supported by USPHS grant NCI R21-CA80902.

References

1. Obrien M, Winawer S, Zauber A, "The national polyp study: patient and polyp characteristics associated with high-grade dysplasia in colorectal adenomas," Gastroenterology 98: 371-379, 1990.

2. Potter J, Slatterly M, "Colon cancer: A review of the epidemiology," Epidemiology review15: 499-545, 1993.

3. Thoeni RF, Colorectal cancer. Radiologic staging. Radiol Clin North Am. 35: 457-85, 1997.

4. Kronborg O. Colon polyps and cancer. Endoscopy 32: 124-30, 2000.

5. Bond JH, Colon polyps and cancer. Endoscopy 33: 46-54, 2001.

6. Vining DJ, Virtual endoscopy flies viewer through the body. Diagn Imaging 18: 127-9, 1996.

7. Scharling ES, Wolfman NT, Bechtold RE, Computed tomography evaluation of colorectal carcinoma. Semin Roentgenol. 31: 142-53, 1996.

8. Vining DJ, Virtual colonoscopy. Gastrointest Endosc Clin N Am. 7: 285-91, 1997.

9. Ahlquist DA, Hara AK, Johnson CD, Computed tomographic colography and virtual colonoscopy. Gastrointest Endosc Clin N Am. 7: 439-52, 1997.

10. Luboldt W, Bauerfeind P, Steiner P, Fried M, Krestin GP, Debatin JF, Preliminary assessment of three-dimensional magnetic resonance imaging for various colonic disorders. Lancet. 349: 1288-91, 1997.

11. Johnson CD, Hara AK, Reed JE, Computed tomographic colonography (Virtual colonoscopy): a new method for detecting colorectal neoplasms. Endoscopy 29: 454-61, 1997.

12. Fenlon HM, Barish MA, Ferrucci JT, Virtual colonoscopy--technique and applications. Ital J Gastroenterol Hepatol. 31: 713-20, 1999.

13. Royster AP, Fenlon HM, Clarke PD, Nunes DP, Ferrucci JT, CT colonoscopy of colorectal neoplasms: two-dimensional and three-dimensional virtual-reality techniques with colonoscopic correlation. Am J Roentgenol. 169: 1237-42, 1997.

14. Rubin DT, Dachman AH, Virtual colonoscopy: a novel imaging modality for colorectal cancer. Curr Oncol Rep. 3: 88-93, 2001.

15. Chen D, Liang Z, Wax MR, Li L, Li B, Kaufman AE, A novel approach to extract colon lumen from CT images for virtual colonoscopy. IEEE Trans Med Imaging. 19: 1220-6, 2000.

16. Dachman AH, Kuniyoshi JK, Boyle CM, Samara Y, Hoffmann KR, Rubin DT, Hanan I, CT colonography with three-dimensional problem solving for detection of colonic polyps. Am J Roentgenol 171: 989-995, 1998.

17. Paik DS, Beaulieu CF, Jeffrey RB, Rubin GD, Napel S, Automated flight path planning for virtual endoscopy. Med Phys. 25: 629-37, 1998.

18. Samara Y, Fiebich M, Dachman AH, Hoffmann KR, Automated centerline tracking of the human colon. Proc SPIE 3338: 740-746, 1998

19. Samara Y, Fiebich M, Dachman AH, Kuniyoshi JK, Doi K, Hoffmann K, Automated calculation of the centerline of the human colon in CT images. Acad Radiol 6: 352-360, 1999.

20. Ge Y, Stelts DR, Wang J, Vining DJ, Computing the centerline of a colon: a robust and efficient method based on 3D skeletons. JCAT 23: 786-794, 1999.

21. Lee TY, Lin PH, Lin CH, Sun YN, Lin XZ, Interactive 3-D virtual colonoscopy system. IEEE Trans Inf Technol Biomed. 3: 139-50, 1999.

22. Wyatt CL, Ge Y, Vining DJ. Automatic segmentation of the colon for virtual colonoscopy. Comput Med Imaging Graph. 24: 1-9, 2000.

23. Karadi C, Beaulieu CF, Jeffrey RB Jr, Paik DS, Napel S. Display modes for CT colonography. Part I. Synthesis and insertion of polyps into patient CT data. Radiology 212: 195-201, 1999.

24. Beaulieu CF, Jeffrey RB Jr, Karadi C, Paik DS, Napel S Display modes for CT colonography. Part II. Blinded comparison of axial CT and virtual endoscopic and panoramic endoscopic volume-rendered studies. Radiology 212: 203-12, 1999.

25. Paik DS, Beaulieu CF, Jeffrey RB Jr, Karadi CA, Napel S, Visualization modes for CT colonography using cylindrical and planar map projections. JCAT 24: 179-88, 2000.

26. Haker S, Angenent S, Tannenbaum A, Kikinis R. Nondistorting flattening maps and the 3-D visualization of colon CT images. IEEE Trans Med Imaging 19: 665-70, 2000.

27. Zhang Z, Dachman AH, Hoffmann KR: Two-dimensional display of CT colon data for rapid polyp detection. Proc CARS2001 (in press), 2001.

28. Summers RM, Johnson CD, Pusanik LM, Malley JD, Youssef AM, Reed JE: Automated polyp detection at CT colonography: feasibility assessment in a human population. Radiology 219: 51-9, 2001.

29. Yoshida H, Masutani Y, MacEneaney PM, Doi K, Kim Y, Dachman, AH. Detection of colonic polyps in CT colonography based on geometric features. Radiology 217(P): 582, 2000.

30. Hopper KD, Iyriboz AT, Wise SW, Neuman JD, Mauger DT, Kasales CJ. Mucosal detail at CT virtual reality: surface versus volume rendering. Radiology 214: 517-22, 2000.

31. Samara Y, Dachman AH, Hoffmann KR: Surface coverage in CT colography studies. Proc. SPIE 3660: 117-124, 1999.