Three-dimensional Display Modes for CT Colonography: Conventional 3D Virtual Colonoscopy versus Unfolded Cube Projection[1]

Frans M. Vos, PhD
Rogier E. van Gelder, MD
Iwo W. O. Serlie, MSc
Jasper Florie, MD
C. Yung Nio, MD
Afina S. Glas, MD
Frits H. Post, MSc
Roel Truyen, MSc
Frans A. Gerritsen, PhD
Jaap Stoker, MD, PhD

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Abbreviations:
3D = three-dimensional
2D = two-dimensional

[1] From the Department of Radiology (F.M.V., R.E.v.G., J.F., C.Y.N., J.S.) and Department of Clinical Epidemiology and Biostatistics (A.S.G.), Academic Medical Center Amsterdam, Meibergdreef 9, 1105 AZ Amsterdam, the Netherlands; Pattern Recognition Group, Department of Applied Physics (F.M.V., I.W.O.S.) and Computer Graphics Group, Department of Mediamatics (F.H.P.), Delft University of Technology, the Netherlands; and Advanced Development, Medical Information Technology, Philips Medical Systems, Best, the Netherlands (R.T., F.A.G.). From the 2001 RSNA scientific assembly. Received July 12, 2002; revision requested August 29; revision received October 2; accepted December 19. Supported by Philips Medical Systems and ZON-MW grant 2100.0059 from the Dutch Research Council. **Address correspondence to** F.M.V. (e-mail: *f.m.vos@amc.uva.nl*).

Author contributions:
Guarantors of integrity of entire study, F.M.V., R.E.v.G., J.S.; study concepts, F.M.V., R.E.v.G., I.W.O.S., F.H.P., R.T., F.A.G., J.S.; study design, F.M.V., R.E.v.G., I.W.O.S.; literature research, F.M.V., R.E.v.G., I.W.O.S., R.T., J.S.; clinical studies, R.E.v.G., J.F., C.Y.N.; data acquisition and analysis/interpretation, F.M.V., R.E.v.G., I.W.O.S., A.S.G., J.S.; statistical analysis, F.M.V., R.E.v.G., A.S.G., J.S.; manuscript preparation, F.M.V., R.E.v.G., A.S.G., R.T., J.S.; manuscript definition of intellectual content and editing, F.M.V., R.E.v.G., J.S.; manuscript revision/review and final version approval, all authors

The authors compared a conventional two-directional three-dimensional (3D) display for computed tomography (CT) colonography with an alternative method they developed on the basis of time efficiency and surface visibility. With the conventional technique, 3D ante- and retrograde cine loops were obtained (hereafter, conventional 3D). With the alternative method, six projections were obtained at 90° viewing angles (unfolded cube display). Mean evaluation time per patient with the conventional 3D display was significantly longer than that with the unfolded cube display. With the conventional 3D method, 93.8% of the colon surface came into view; with the unfolded cube method, 99.5% of the colon surface came into view. Sensitivity and specificity were not significantly different between the two methods. Agreements between observers were $\kappa = 0.605$ for conventional 3D display and $\kappa = 0.692$ for unfolded cube display. Consequently, the latter method enhances the 3D endoluminal display with improved time efficiency and higher surface visibility.

Computed tomography (CT) colonography is a widely studied technique for surveillance and screening for colorectal cancer. With typical methods for evaluating the data, transverse source images, multiplanar reformatted images obtained along the central colon axis, or a virtual three-dimensional (3D) endoscopic display are applied (1,2). There appears to be no consensus in the literature, however, regarding the appropriate method. Most investigators primarily use transverse source images in combination with multiplanar reformatted images and/or a 3D display for problem solving. Findings in several studies, however, suggest that primary use of 3D views results in higher sensitivity (3,4). Beaulieu et al (3) demonstrate a significantly better outcome with 3D modes after correction for lesion visibility.

The conventional 3D method is similar to colonoscopy. Antegrade and retrograde cine images are generated off line and display forward and backward viewing planes (conventional 3D) (1). However, 3D display methods are time-consuming (5). Although hypotonic agents and adequate distention tend to minimize the problem, haustral folds may occlude the wall, thereby reducing sensitivity (Fig 1). Other 3D concepts have emerged (6–9). Such displays are hampered by distortions that could lead to misinterpretation (7,10). Drawbacks prohibit large-scale use of 3D methods.

To overcome current limitations of 3D imaging, we developed an alternative 3D display method that renders six planar projections (unfolded cube display) at 90° viewing angles from points on the central path (11). The unfolding of such a cube shows the complete field of view at a path position. The aim of the image sequence of unfolded cubes is to facilitate rapid exploration of the entire colon wall.

The purpose of our study was to compare a conventional two-directional 3D display for CT colonography with an alternative method we developed on the basis of time efficiency and surface visibility.

Materials and Methods

Data Acquisition

Patient population.—Thirty patients (13 men, 17 women; mean age, 58 years; age range, 35–82 years) were included in this study. The patients were selected from a population at increased risk for colorectal cancer (a medical or family history of colorectal cancer or polyps) who were referred for colonoscopy. The number of patients with polyps was representative of the prevalence in this surveillance population (54% [27 of 50] was reported earlier [12]). Lieberman et al (13) reported a comparable prevalence (50%) in another screening population. Selection was based on the presence of polyps, irrespective of the location. The sample size (power) was calculated to facilitate our primary aim (ie, to compare the display methods for time efficiency and surface visibility). At colonoscopy, 16 of 30 patients had at least one polyp of any size, with a total of 78 lesions. Eight of 30 patients had polyps that were 5 mm or more in diameter, with a total of nine such lesions. The CT colonography study was approved by the medical ethics committee of the hospital. The patients were informed a priori by letter, as well as verbally, about the purpose of the study, and they gave written informed consent.

CT colonography.—On the day before the examination, each patient drank 4–6 L of macrogol solution (KleanPrep; Helsinn Birex Pharmaceuticals, Dublin, Ireland) for bowel preparation. Directly before image acquisition, 20 mg of butyl scopalamine (Buscopan; Boehringer, Ingelheim, Germany) was administered intravenously to reduce peristalsis. The colon was distended with approximately 2 L of CO_2-enriched air (13.4% CO_2) to enhance resorption and reduce patient discomfort. The air was introduced by means of manual insufflation with a balloon-tipped rectal enema tube. The balloon was inflated with water. The end point of CO_2 administration was at maximum patient tolerance or when colon filling was considered adequate. The adequacy of distention was gauged with a scout view. Multisection spiral CT scans (Mx8000; Philips Medical Systems, Best, the Netherlands) were acquired with the patient in prone and supine positions. Scanning parameters were 120 kV, 167 mA (100 mAs [{mA × rotation time}/pitch]), collimation of 4.0 × 2.5 mm, pitch of 1.25, standard reconstruction filter, and a 180° interpolation algorithm. Effective section thickness was 3.2 mm with an overlap of 1.6 mm. The insufflation procedure (including scout imaging) was repeated after the patient was repositioned. The delay time between insufflation and the start of scanning was at most 30 seconds. All CT scans were obtained within 2 hours before colonoscopy.

Colonoscopy.—Colonoscopy (model CF-140I; Olympus, Tokyo, Japan) was performed by an experienced gastroenterologist. Sedation (5 mg of midazolam, Dormicum; Roche, Basel, Switzerland) and analgesics (0.05 mg of fentanyl, Fentanyl-Janssen; Janssen Pharmaceuticals, Beerse, Belgium) were administered on request. A research fellow, who was not involved in the CT colonography evaluation, was present and recorded the study on videotape. Lesion size was estimated with the aid of an opened biopsy forceps. Lesion shape was characterized as flat, sessile, or pedunculated. The location of a polyp was classified in one of the following segments: cecum, ascending colon, hepatic flexure, transverse colon, splenic flexure, descending colon, sigmoid, and rectum. The endoscopist was unaware of the CT colonography findings.

Conventional 3D Display

Ante- and retrograde cine loops were evaluated for both prone and supine positions of each patient; this represents a conventional 3D display method (EasyVision; Philips Medical Systems). The images were volume rendered at positions that were 4 mm apart on the central colon path (the sampling rate will be clarified later). The method developed by Truyen et al (14) was applied for path generation. With the transfer function, an opacity value of 0 was assigned to voxel values less than −650 HU (making such voxels completely transparent) and an opacity value of 1 to voxel values higher than −650 HU. The viewing angle was set to 120° to compromise between image distortion and surface visibility. Frame rate was fixed at one image per second. Multiplanar reformatted images in any direction were available from the original CT study to verify potential lesions (eg, to check for gas). Typical lung (−1,250 HU) and level (−500 HU) windows were used. Lesion size was measured on the two-dimensional (2D) reformatted images.

Unfolded Cube Projection

To avoid extreme deformations while showing the full visible field around a position, we introduced a series of unfolded cube renderings (11). The unfolded cubes were also generated by means of sampling on the central path through the colon. A cube was virtually placed in each such point, and on the cube faces, 90° views from the center were projected (Fig 2 illustrates the principle). By folding out the six images onto a single plane (unfolded cube display), the complete field of view was rendered. The sequence of unfolded cubes was shown as cine images. Reformatted views of the original CT data became accessible by clicking in the displayed images. Then the cine images were stopped, and the physician could manipulate the reformatted images for closer inspection of suspicious areas. Lesion size was measured on the 2D reformatted images. Real-time rendering of the corresponding wall part also facilitated local inspection of the surface by means of adaptation of the virtual camera position and orientation. Parameters of the volume-rendering transfer function, sampling and frame rate, were identical to those used with conventional 3D inspection. Figure 3 shows the interface.

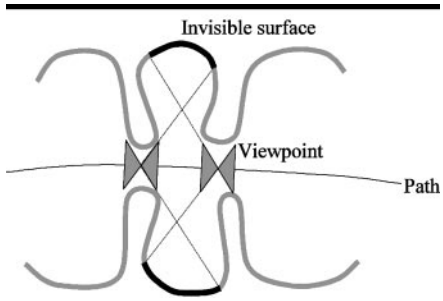


Figure 1. Schematic shows areas in black that are missed in conventional 3D view.

Evaluation

An abdominal radiologist (C.Y.N.) (observer 1) and a research fellow (J.F.) (observer 2) independently evaluated the data with both display methods. The observers had previous experience with more than 50 CT colonography examinations at the start of the study. Both were blinded to findings during colonoscopy, including those for themselves for the same patient (conventional 3D display vs unfolded cube display) and those for each other. Additionally, they were unaware of the prevalence of polyps. We implemented the display methods with a proprietary experimental version of the workstation (11). Currently, the unfolded cube view is also commercially available. The median interval between

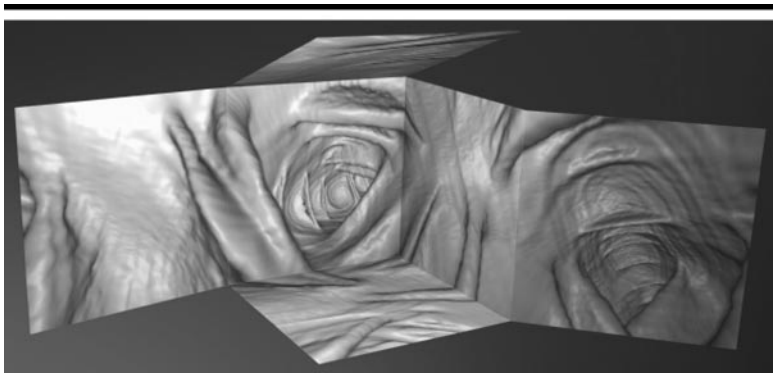


Figure 2. Unfolded cube display shows cubic rendering.

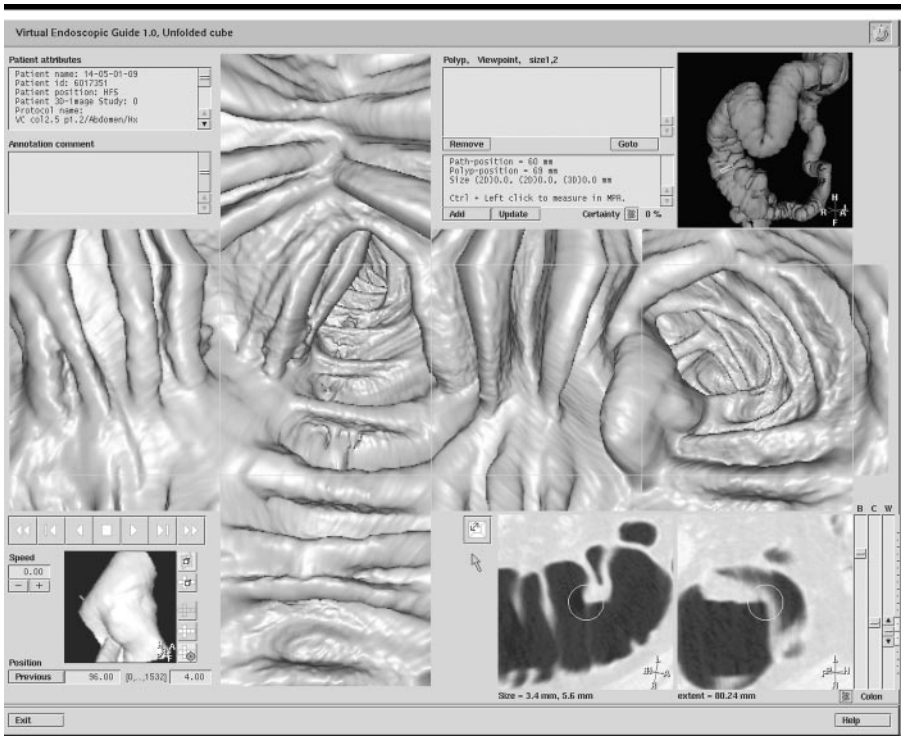


Figure 3. Graphical user interface shows the sequence of unfolded cubes.

two evaluations of the same patient for observer 1 was 21 weeks (interquartile range, 12–28 weeks) and that for observer 2 was 11 weeks (interquartile range, 11–13 weeks). Evaluations with an unfolded cube display preceded those with conventional 3D display. The cases were presented in random order. Each suspected polyp was scored with respect to size, morphology, and location. Figure 4 shows the same polyp in conventional 3D and unfolded cube display.

Outcome Parameters and Statistical Analysis

Evaluation time.—Evaluation time per patient was recorded for both observers and display modes. Evaluation time included measuring a lesion, imaging it, and generating the report. Outcome was stratified according to the presence of colonoscopically proven polyps. The classifications were compared by means of a Student paired *t* test. A *P* value of less than .05 was considered to indicate a statistically significant difference. Initialization time for generating the conventional 3D and unfolded cube display sequences was disregarded in the analysis.

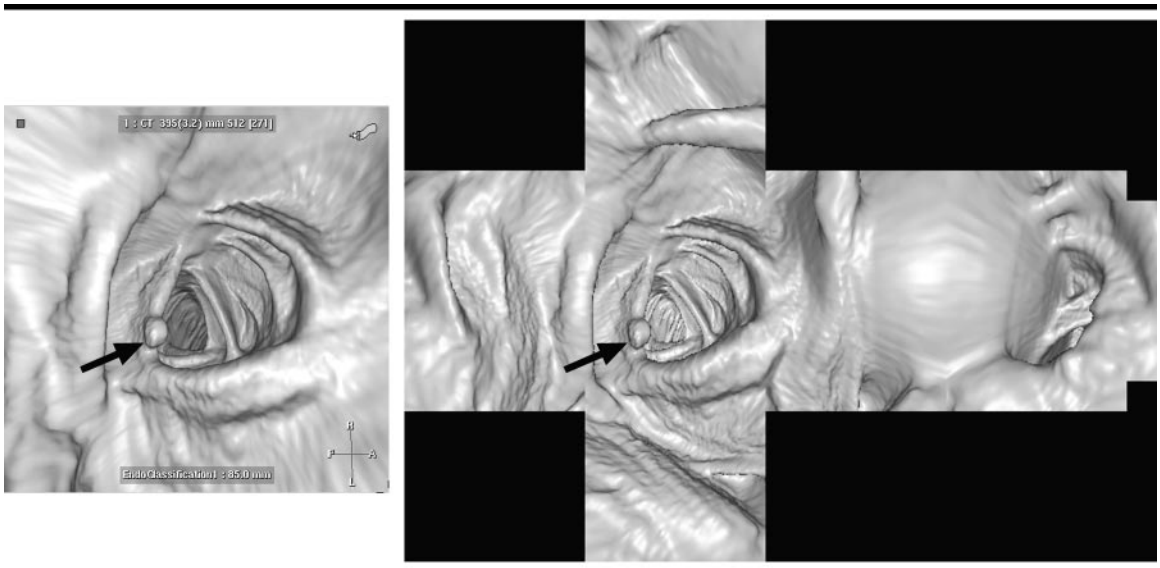
Surface visibility.—Surface visibility was tested with a method described previously (10); it was defined as the percentage of colon surface voxels coming into view (3). To measure the visibility, the interior volume of the colon was obtained by means of thresholding of the CT volume at −650 HU. Subsequently, the surface voxels were identified on the basis of their adjacency to the interior. A surface voxel was defined as visible if a line could be drawn to a position on the central path that was not obstructed by another surface voxel. The Wilcoxon signed rank test was used to compare differences in surface visibility for the unfolded cube display and the conventional 3D display.

Sensitivity, specificity, and user agreement.—Lesions detected during CT colonography were matched with the findings at colonoscopy by a research fellow (R.E.v.G.) on the basis of the colonoscopic findings and the video registration. The fellow was not involved in reading the CT colonography studies.

A polyp detected at CT colonography was considered true-positive if it matched a finding at colonoscopy on the basis of size, shape, location (ie, colonic segment), and anatomic interrelation to haustral folds. A deviation in size of no more than 5 mm was accepted to accommodate the inherent inaccuracy of colonoscopic size measurement. A false-negative finding was defined as a polyp that was detected at colonoscopy but was not found at CT colonography. A patient was identified correctly as having polyps if there was at least one true-positive finding. The absence of lesions at CT colonography was considered true-negative if lesions were also absent at colonoscopy.

Sensitivity of both display methods was determined per patient and per polyp. Specificity of both display methods was determined per patient. Lesions detected at colonoscopy were divided into two categories: medium and large, polyps 5 mm or more in diameter; and small, polyps less than 5 mm in diameter. Analysis was stratified according to polyp diameter.

Differences in sensitivity per patient between the display methods were tested with the McNemar test. Differences in sensitivity per polyp between the methods were assessed with logistic regression with random effects (ie, a generalized version of the McNemar test for clustered data). Logistic regression was used to adjust for clustering of polyps in patients. A McNemar test was also applied to compare the specificities of the display methods. Agreement between the observers was measured with the κ statistic on a per segment basis for all detected lesions. The



a. b.

Figure 4. Typical example of polyp (arrow) in **(a)** conventional 3D display and **(b)** unfolded cube display.

TABLE 1
Evaluation Time per Patient

	Conventional 3D Display		Unfolded Cube Display		Paired Difference	
Findings at Colonoscopy	Observer 1	Observer 2	Observer 1	Observer 2	Observer 1	Observer 2
Proven polyps	38:22 ± 9:21	38:55 ± 17:38	21:32 ± 7:42	21:55 ± 7:34	16:50 ± 9:36	17:0 ± 13:36
No proven polyps	35:1 ± 10:30	30:41 ± 10:10	17:6 ± 4:30	18:8 ± 4:18	17:44 ± 10:46	12:33 ± 9:2
With and without polyps	36:49 ± 9:51	35:5 ± 14:59	19:33 ± 6:40	20:9 ± 6:27	17:15 ± 9:58	14:55 ± 11:43

Note.—Data are the mean evaluation time (minutes:seconds) ± SD.

κ values were interpreted according to the next qualification: $\kappa < 0.20$, poor agreement; $\kappa = 0.21$–0.40, fair; $\kappa = 0.41$–0.60, moderate; $\kappa = 0.61$–0.80, good; and $\kappa = 0.81$–1.00, very good.

Results

Evaluation Time

Mean evaluation time with conventional 3D display (observer 1, 36 minutes 49 seconds; observer 2, 35 minutes 5 seconds) was significantly slower than that with unfolded cube display (observer 1, 19 minutes 33 seconds; observer 2, 20 minutes 9 seconds). The presence of polyps did not lead to significantly longer evaluation time with either technique. Also, the differences in evaluation time between the observers were not significant. Table 1 lists the mean evaluation time and SD per observer for the conventional 3D and unfolded cube displays stratified on the basis of the presence of polyps.

Surface Visibility

With an antegrade view only, on average, 73% of the colon surface came into view. The conventional 3D display (ante- and retrograde views) resulted in 93.8% visibility. The unfolded cube display depicted 99.5% of the bowel surface. All differences were significant ($P < .05$).

A typical outcome that shows the invisible voxels is given in Figure 5 (the unseen parts are marked in black). The example bowel wall consisted of 387,225 voxels. With the conventional 3D display, 25,833 voxels remained invisible, the largest cluster of which contained 10,685 voxels (the next largest cluster contained 2,070 voxels; mean cluster size, 190 voxels). This is considerably more than the surface of a polyp, which is approximately 500 voxels (on the basis of modeling with a sphere that was 5 mm in diameter, with voxel size of $0.6^2 \times 1.6$ mm). The unfolded cube display shows one relatively large area (which consisted of 3,077 voxels) in the rectum, where the path had an open end and the tube with the balloon occluded the wall. Except for these elements, the next largest cluster contained 316 voxels (mean cluster size, 69 voxels).

For one data set, Figure 6 shows the relationship between surface visibility and sampling rate along the central path. The surface area coming into view asymptotically approximates 99.8% for unfolded cube display. The graph illustrates that a sampling rate of once every 4 mm yields optimal visibility with the unfolded cube display. Graphs were similar for other data sets.

Sensitivity and Specificity

Sensitivity on a per patient basis for medium and large polyps was not significantly different between the two methods for each observer: observer 1 with both displays, eight of eight polyps; observer 2 with conventional 3D display, seven of eight polyps, and with unfolded cube display, eight of eight polyps. The

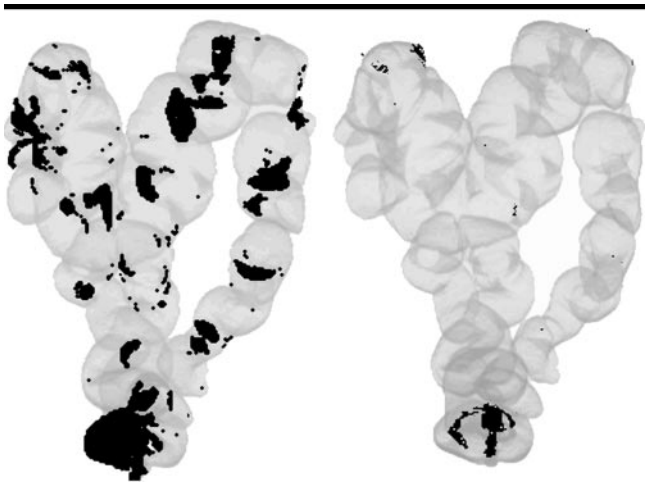


Figure 5. Left: Conventional 3D display. Right: Unfolded cube display. Areas in black were missed.

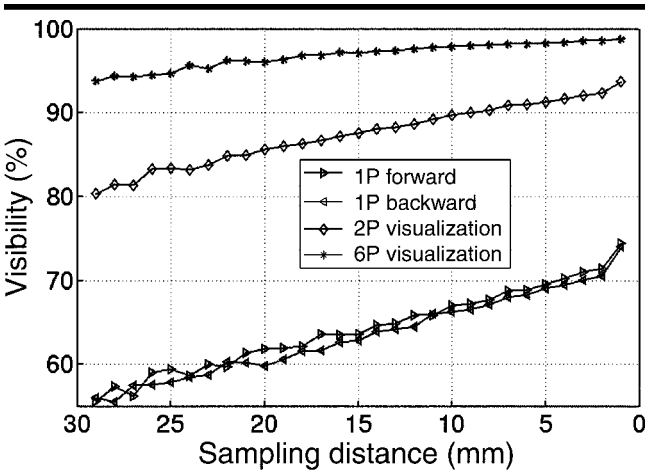


Figure 6. Line graph shows relationship between surface visibility and sampling rate along the central path for one data set. Surface area coming into view asymptotically approximates 99.8% for unfolded cube display (*6P*). *1P* = forward or reverse viewing, *2P* = conventional 3D display.

difference in sensitivity per patient for small polyps between the conventional 3D and unfolded cube displays was not significant for each observer. Table 2 contains sensitivities per patient.

Sensitivities for medium and large polyps were not significantly different between conventional 3D and unfolded cube displays for both observers: observer 1 with both displays, nine of nine polyps; observer 2 with both displays, eight of nine polyps. Sensitivity for small polyps for observer 1 was significantly worse with conventional 3D display (16 of 69 polyps) than with unfolded cube display (27 of 69 polyps) (logistic regression, $P < .003$). Sensitivity per small polyp for observer 2 was not significantly different with the two displays (conventional 3D display, 26 of 69 polyps; unfolded cube display, 24 of 69 polyps). Table 3 lists sensitivities per polyp.

Specificity regarding the correct identification of patients without medium and large polyps for observer 1 was 16 of 22 patients with conventional 3D display and 15 of 22 patients with unfolded cube display. For observer 2, these findings were 16 of 22 patients with conventional 3D display and 19 of 22 patients with unfolded cube display. Differences between display methods were not significant for each observer. Also, differences in specificity for patients without any polyp were not significant between the methods for each observer. Table 4 summarizes the outcome regarding specificity per patient.

On a per segment basis, agreement between the observers with conventional 3D was $\kappa = 0.605$ (standard error = 0.052) and with unfolded cube display was $\kappa = 0.692$ (standard error = 0.048). Both κ values indicate good agreement. The difference in κ values between the methods was not significant.

Discussion

Findings in the present study show that CT colonography with the unfolded cube display enables time-efficient inspection (about 15–20 minutes per patient) and comprehensive visibility (99.5%) that is superior to that with conventional 3D display. Sensitivity and specificity of the technique are high with a cutoff value of 5 mm, a threshold that is commonly applied to distinguish possibly relevant polyps.

Various alternative display techniques have been introduced to evaluate CT colonography data. Initially, the complementary use of 2D and 3D images was reported to provide the best sensitivity (15,16). Later, evidence was given that reformatted 2D images can be just as effective as fly-through 3D images (17,18). We opted for a 3D method because significantly better sensitivity was found for the 3D modes after correction for lesion visibility (3).

In previous articles, evaluation times per patient are 20–26 minutes with only transverse reformatted images (16,18), 15 minutes with only 3D images (16), and 16–35 minutes with a combined approach (primarily 2D and 3D display for problem solving) (17,18). Evaluation times were not specifically recorded by Hara et al (15), but no data set evaluation lasted longer than 10 minutes. Beaulieu et al (3) report that the exploration per data set was 8 minutes with 2D display and 12 minutes 5 seconds with 3D cine images.

In the current study, outcomes per patient are in the same range for the unfolded cube display (17–22 minutes) but are significantly slower with the conventional 3D display (31–39 minutes). Evaluation time could be reduced with a faster fixed frame rate or with a user-controlled speed. However, this will probably not change the relative time difference between the display methods (the same frame rate was used for both techniques). To our knowledge, in no previously published study was the influence of frame rate on sensitivity explored specifically. We opted to use a "save" frame

TABLE 2
Sensitivity per Patient

Polyp Size (mm)	Conventional 3D Display		Unfolded Cube Display		No. of Patients with Polyps at Colonoscopy
	Observer 1	Observer 2	Observer 1	Observer 2	
Any size	14 (87)	12 (75)	13 (81)	13 (81)	16
<5	6 (75)	5 (62)	5 (62)	5 (62)	8
≥5	8 (100)	7 (87)	8 (100)	8 (100)	8

Note.—Data are the number of patients with polyps. Numbers in parentheses are percentages of findings at colonoscopy.

TABLE 3
Sensitivity per Polyp

Polyp Size (mm)	Conventional 3D Display		Unfolded Cube Display		No. of Polyps at Colonoscopy
	Observer 1	Observer 2	Observer 1	Observer 2	
Any size	25 (32)	34 (44)	36 (46)	32 (41)	78
<5	16 (23)	26 (38)	27 (39)	24 (35)	69
≥5	9 (100)	8 (89)	9 (100)	8 (89)	9

Note.—Data are the number of polyps. Numbers in parentheses are percentages of findings at colonoscopy.

TABLE 4
Specificity per Patient

Polyp Size in Patients without Polyps (mm)	Conventional 3D Display		Unfolded Cube Display		No. of Patients without Polyps at Colonoscopy
	Observer 1	Observer 2	Observer 1	Observer 2	
Any size	7 (50)	4 (29)	3 (21)	5 (36)	14
≥5	16 (73)	16 (73)	15 (68)	19 (86)	22

Note.—Data are the number of patients. Numbers in parentheses are percentages of findings at colonoscopy.

rate of one image per second at 4-mm intervals to yield optimal surface visibility and to ensure detection of lesions.

The methods that we used differ slightly from methods described in the literature. In our method, 3D images are used primarily for inspection, while the 2D reformatted images are used for confirmation. Evaluation time is longer with conventional 3D display versus that with unfolded cube display; this is attributed to increased image distortion near the edge of the conventional 3D display (as a result of the larger viewing angle: 120° vs 90°). For closer observation of these areas, interactive adjustment of the viewing direction is required, which inherently leads to longer evaluation time.

Initialization time, such as the generation of cine images, was disregarded because it was performed off line in batch mode. Preparation for evaluation (specifically, generation of the unfolded cube and 3D cine loops) was initiated by technicians. Exclusion from the analysis of the time for generation is justified because it is done in the background. On average, it took us 35 minutes per patient to render the unfolded cube displays. Conventional 3D displays were generated in approximately 12 minutes (one-third of 35 minutes). Reduced resolution would speed up the generation of displays. If resolution is reduced, however, sensitivity may also be reduced. Other initialization times, such as those for image loading and path tracking, are on the order of a few minutes.

Our results for surface visibility confirm earlier findings (with nine data sets) (10). Paik et al (10) reported approximately 75% visibility with either forward or reverse viewing only, 95% visibility with both, and 98% visibility with Mercator projection. Clearly, visibility is important for its direct influence on sensitivity. Beaulieu et al (3) show that sensitivity improves significantly after correction for lesion visibility.

Several methods have been explored for optimization of the amount of colon surface coming into view. The viewing angle may simply be increased, but this is at the expense of severe deformation toward the edges of the image. A so-called flattening method can be used to straighten the colon mathematically (7). Thus, images of large surface areas of the colon are generated that are similar to gross pathology specimens. Unfortunately, such an approach may yield severe distortion, which causes lesions to appear more than once in different areas (7,10). Such repeated appearances are reported to arise whenever the central path makes a sharp turn (10).

Beaulieu et al (3) propose acquisition of a sequence of unfolded 60° views perpendicular to the central path (panoramic viewing). The latter technique results in lateral images from the colon wall. Panoramic viewing results in higher sensitivity than that with a display of transverse CT images and endoluminal 3D cine loops (3). The method may not yield full visibility, because the forward and backward viewing directions are not included.

Alternatively, Paik et al (10) studied the use of Mercator and stereography projections. They concluded that true-positive findings are better distinguished from the environment with Mercator projection compared with panoramic or stereographic viewing modes because of the extended field of view in Mercator projection, which enables feature tracking over a longer distance. A generally recognized drawback of Mercator projection, however, is that the image becomes distorted away from the equatorial region. Such image deformation would restrict the sensitivity in areas where the colon is strongly curved.

The unfolded cube display that we evaluated in the present study is most comparable to the panoramic technique by Beaulieu et al (3). Note that the unfolded cube mode includes the forward and backward viewing directions, as well as the lateral directions. Consequently, the full field of view is covered, and a feature can be tracked further as it moves through the image planes. At the same time, image distortion is limited by the rather small viewing angle.

Sensitivity per patient in the present study is in the high range compared with values from the literature (65%–94% for polyps larger than 5 mm and 25%–57% for any polyp size) (1–23). Sensitivity per

polyp for polyps larger than 5 mm was reported previously in the range of 46%–90% (1–23). Data from our observers are in the upper range. Sensitivities for smaller polyps (middle row in Table 3) are in concordance with the literature (15%–55% [1–23]) and confirm the poor results with CT colonography for such (perhaps not relevant) lesions.

Specificities for both observers in the present study are low compared with values reported earlier (62%–91% for all polyps and 74%–96% for polyps larger than 5 mm [1–23]). The relatively low specificity in our study may be a result of the rather strict definitions of true- and false-positive findings that we used. We compared findings at CT colonography with those at video colonoscopy on the basis of the anatomic interrelation to haustral folds, anatomic segment, size, and morphology. In most studies, a less strict criterion concerning location was used: A finding was considered to be true-positive if the lesion was found in the same colonic segment at both colonoscopy and CT colonography. Since a colonic segment is between 15 and 40 cm long, this may cause erroneous interpretation of CT colonography findings as true-positive while in fact they are false-positive because they match other lesions in the colonic segment or they are in fact residual stool. Thus, in our opinion, this strategy may result in overestimation of the number of true-positive results and underestimation of the number of false-positive results at CT colonography.

Another explanation for the high rate of false-positive findings is the fact that 27% of small polyps (<5 mm) are missed at colonoscopy (24). Therefore, some small lesions detected during CT colonography may in fact be true-positive findings. Nevertheless, the benefit of detecting lesions smaller than 5 mm in a screening setting is dubious because very small polyps are known to rarely contain malignant tissue (25).

Both the conventional 3D and unfolded cube display yielded good interobserver agreement. Several previous studies were performed with more than one independent observer (3,4,10,15,18,21) with the same evaluation method. Agreement between observers with κ statistics, however, was reported only by McFarland et al (4) (κ = 0.53–1.00) and Pescatore et al (21) (κ = 0.56–0.72). The κ values in the present study are in the same range.

The patient population in the present study included approximately equivalent numbers of patients with and without polyps. This is appropriate for our primary objective—namely, to compare two display methods regarding time efficiency and surface visibility. The sample size (power) was calculated to meet the primary aim. The number of patients is relatively small for addressing the (anticipated) small difference in sensitivity and specificity. A limitation is that the outcome may be different in a screening population. Note that the probability that a polyp resides in an invisible area is only 6.2% with a conventional 3D display because 93.8% of the surface area is visible (the probability is 0.5% with the unfolded cube display). Consequently, a much larger population or a specifically selected population is needed to demonstrate a significant difference in sensitivity. The sample size sufficed to study the unfolded cube display on the basis of time efficiency and surface visibility.

The future role of CT colonography in cancer screening depends on improvement in issues such as imaging efficiency, patient acceptance, and effective radiation dose. Currently, one of the main drawbacks of CT colonography is the long evaluation time. Computer-aided diagnosis is an important development that could support the practical use of CT colonograhy. Although positive early results were reported with automatic polyp detection (26), further research is warranted. We foresee a scheme in which potential lesion sites, suggested by the computer algorithm, are checked by a human observer. Therefore, a primary 3D display method may be superior to a primary 2D technique (as findings in several studies indicate). The unfolded cube display method may contribute to such an evaluation strategy. Consequently, it could facilitate the implementation of CT colonography in colorectal cancer screening.

In conclusion, the unfolded cube display is an alternative method to evaluate CT colonography data. The evaluation time was 19.5–20.0 minutes, during which 99.5% of the colon wall was inspected. The method is more time efficient and yields better surface visibility than does a conventional 3D technique. The sensitivity for patients with medium and large polyps was eight of eight patients, and the specificity for patients without medium and large polyps was 15–19 of 22 patients. The method facilitates good agreement between observers (κ = 0.692).

The unfolded cube display successfully combines time efficiency and high accuracy; thus, it improves the 3D display for CT colonography.

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