Three-Dimensional Endoluminal CT Colonography (Virtual Colonoscopy): Comparison of Three Commercially Available Systems

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Abstract

OBJECTIVE. The purposes of this study were to directly compare 3D endoluminal volume rendering and navigational capabilities of three different CT colonography systems and to assess feasibility of 3D evaluation for primary polyp detection.

MATERIALS AND METHODS. Closely matched endoluminal images from three CT colonography software systems (Navigator, Vitrea 2, and V3D-Colon) and optical colonoscopy were obtained of eight pathologically proven colorectal polyps. All images were then reviewed by 25 physicians (12 radiologists and 13 gastroenterologists) who were not familiar with the three systems. For each polyp, the images yielded by the three systems were rated according to polyp conspicuity, 3D effect (depth), subjective quality, and likeness to optical colonoscopy. For comparison of endoluminal navigation capability, automated or semiautomated flight from rectum to cecum and cecum to rectum was attempted in 10
cases (20 flights) in which a continuous colonic air column could be identified on the 2D images. Additional 3D features were also compared.

**RESULTS.** For polyp conspicuity, 3D effect, and likeness to optical colonoscopy, the V3D-Colon system was favored in 92.0% (184/200), 92.5% (185/200), and 92.5% (185/200) of responses, respectively ($p < 0.001$). For the same categories, the Navigator system ranked second in 73.0%, 74.0%, and 75.0% of cases, and the Vitrea 2 system ranked last in 79.0%, 77.5%, and 76.0% of cases, respectively. Automated or semi automated navigation was successful in eight (40%) of 20 flights with Vitrea 2, in nine (45%) of 20 flights with Navigator, and in 20 (100%) of 20 flights with V3D-Colon ($p < 0.001$). The V3D-Colon system also had more navigational features than the other two systems.

**CONCLUSION.** Pronounced subjective and objective differences in 3D endoluminal rendering and navigational capabilities exist among the systems evaluated. Of the three, effective time-efficient primary 3D evaluation appears to be feasible only with the V3D-Colon system.

**Introduction**

CT colonography is a rapidly evolving technique for the detection of colorectal polyps and may soon play an important role in colon cancer screening [1, 2]. The term "virtual colonoscopy" has been lacking in the recent CT colonography literature, perhaps in part because 2D multiplanar reformations are generally advocated for primary polyp detection [3–7]. Three-dimensional endoluminal rendering is an approach that is mainly reserved for problem-solving; hence, complete real-time virtual fly-through (or virtual colonoscopy) is generally not performed [3, 4, 7]. Although polyp conspicuity is increased and fold characterization is easier on the 3D compared with the 2D display, the main barriers to 3D evaluation as the primary strategy for review have been its time-consuming and labor-intensive nature [5, 7–9]. However, after working with several CT colonography systems side-by-side, it has become apparent that the current reliance on 2D images may be a reflection of the limitations in the software used. In fact, the 3D improvements with some systems now allow time-efficient 3D fly-through of the colon for primary polyp detection, so the 2D display is reserved mainly for confirmation and problem solving [9]. There are not only striking differences in navigational ability among the available 3D systems, but also surprising variability in the subjective quality of the volume rendering, which can directly affect polyp detection. The purposes of this study were to compare the 3D endoluminal capabilities of three commercially available CT colonography systems and to determine which system can best support 3D evaluation of the colon for primary polyp detection.
Materials and Methods

The methods used for colon preparation and air insufflation have been previously described [9]. The examinations of all patients selected for this study were performed on a multidetector CT scanner (LightSpeed, General Electric Medical Systems, Milwaukee, WI) using 4 x 2.5 mm configuration, 15-mm/sec table speed (high-speed mode), 1-mm reconstruction interval, 100 mAs (effective), and 120 kVp. All patients included in this study underwent optical colonoscopy immediately after CT colonography.

The three commercially available CT colonography systems evaluated included the Navigator system on the Advantage Workstation (version AW4.0, General Electric Medical Systems), Vitrea 2 (version 3.1, Vital Images, Plymouth, MN), and V3D-Colon (version 1.2.4, Viatronix, Stony Brook, NY). The primary investigator for this study had previously received training from each vendor for the CT colonography systems evaluated. For comparison purposes, attempts were made to use the recommended default settings for each system. The "smooth protocol" with a threshold setting of –800 H was used for the Navigator. For the Vitrea 2 workstation, the colon CT "3D lit fly-through" was used with "direct light-shiny" rendering and "CT fat–muscle–bone" coloring. The default settings for the V3D-Colon were also used. Because the V3D-Colon system allows "electronic cleansing" or digital subtraction of opacified luminal fluid, whereas the other two systems do not, submerged polyps or flight paths were excluded because inclusion would give the V3D-Colon system an unfair advantage.

Comparison of 3D Endoluminal Rendering of Polyps

CT colonography studies of eight patients with a pathologically proven colorectal polyp (five adenomas and three hyperplastic polyps) were selected for review. The polyps ranged in size from 6 to 15 mm and in location from rectum to cecum. Volume-rendered endoluminal images of each polyp were captured from the same CT data set (supine or prone) with each software system. The endoluminal vantage for each polyp was matched as closely as possible by one radiologist experienced with all three CT colonography systems. The endoluminal vantage was chosen primarily to approximate the view from optical colonoscopy.

Digital images of similar resolution from the three systems were projected simultaneously for each polyp. The matched polyp images were sequentially reviewed by 12 radiologists and 13 gastroenterologists, representing virtually all levels of training. The reviewers were unaware of the identity of the vendor for each image shown (i.e., specific vendor information was completely withheld). Furthermore, for bias to be avoided, none of the 25 physicians was familiar with any of the three CT colonography systems, none of the radiologists had experience interpreting CT colonography studies, and none had any financial relationship with any of the vendors. For each polyp, the reviewers rated the 3D endoluminal views according to polyp conspicuity, 3D effect (depth), and overall quality.
(general appeal). Overall quality was based on a subjective 10-point scale. A digital image from optical colonoscopy was then displayed of each polyp, and the reviewers rated each CT image according to its likeness with the endoscopic image.

Comparison of Endoluminal Navigation

For luminal navigation capability to be assessed, 10 additional supine or prone CT colonography studies with each system were evaluated. CT studies were selected only if a continuous luminal air column (pneumocolon) could be traced from rectum to cecum on the 2D images. For each case, automated or semiautomated navigation from rectum to cecum and cecum to rectum was attempted with each 3D colonography system. If navigation was initially unsuccessful (i.e., failure to reach the cecum or rectum), additional attempts were made. For successful navigations, the transit times were recorded. All navigation attempts were made by the primary investigator.

With the Navigator system, semiautomated navigation was attempted by placing the cursor in the rectum (or cecum), aligning the cursor along the luminal axis, and creating a path by pressing the "Insert and Seek Step" button as many times as necessary. With the Vitrea 2 system, the cursor was again placed in the rectum (or cecum) and aligned with the luminal axis, and navigation was attempted by pressing both the "Shift" key and right mouse button while simultaneously dragging the mouse to initiate automated flight. With the V3D-Colon system, an automated centerline flight path is created as a preprocessing step before radiologist interaction; automated navigation was attempted by double-clicking the left mouse button.

In addition to automated flight performance, additional 3D endoluminal features were evaluated. These features included the ability to handle discontinuous colonic segments, ability to view both supine and prone data sets without exiting the viewer, ease of 2D correlation, ability to place bookmarks on a colon map, ability to perform 3D measurement, effectiveness (and documentation) of visualized surface coverage, translucency rendering, and electronic cleansing of fluid. Not all features were present on all systems. A limited comparison of the 2D displays was also performed.

Statistical analysis was performed using the chi-square test to compare differences in the survey results and the McNemar test to compare success rates of automated navigation.
Results

Polyp Surveys
Survey forms for evaluation of the eight polyps were completed by 25 physicians (12 radiologists and 13 gastroenterologists), yielding 200 data points for each category. Survey results are summarized in Tables 1,2,3. In general, 3D volume rendering of the polyps with the V3D-Colon system was favored for all categories, followed by Navigator; the Vitrea 2 images ranked last overall for each category (Figs. 1A, 1B, 1C, 1D, 2A, 2B, 2C, 2D, 3A, 3B, 3C, 3D). Similar trends existed between the radiologists' and gastroenterologists' responses without any significant differences. Overall subjective quality assessment of the 3D volume-rendered images (based on a 10-point scale, with 10 representing the highest score) averaged 8.1 for V3D-Colon, 5.4 for Navigator, and 4.4 for Vitrea 2 (Figs. 1A, 1B, 1C, 1D, 2A, 2B, 2C, 2D, 3A, 3B, 3C, 3D). For polyp conspicuity, 92% (184/200) of all respondents favored the V3D-Colon images, 73% (146/200) ranked Navigator second, and 79% (158/200) ranked Vitrea 2 last (Figs. 1A, 1B, 1C, 1D, 2A, 2B, 2C, 2D, 3A, 3B, 3C, 3D). Similar trends were seen with the assessment of 3D effect and likeness to optical colonoscopy (Tables 1,2,3). The higher ranking of the V3D-Colon system compared with the other two systems was statistically significant ($p < 0.001$).

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TABLE 1 Survey Results of 12 Radiologists Who Assessed Eight Matched Volume-Rendered Endoluminal Views on Three CT Colonography Systems

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TABLE 2 Survey Results of 13 Gastroenterologists Who Assessed Eight Matched Volume-Rendered Endoluminal Views on Three CT Colonography Systems
TABLE 3 Survey Results of 12 Radiologists and 13 Gastroenterologists Who Assessed Eight Matched Volume-Rendered Endoluminal Views on Three CT Colonography Systems

Fig. 1A.—Three-dimensional endoluminal views of 6-mm adenomatous polyp in ascending colon found in asymptomatic 62-year-old man undergoing screening for colorectal cancer. Image obtained using Navigator software (Advantage Workstation version 4.0, General Electric Medical Systems, Milwaukee, WI) shows subtle polyp on fold.

Fig. 1B.—Three-dimensional endoluminal views of 6-mm adenomatous polyp in ascending colon found in asymptomatic 62-year-old man undergoing screening for colorectal cancer. Image obtained using V3D-Colon software (version 1.2.4, Viatronix, Stony Brook, NY) shows same polyp as A but with increased conspicuity and depth.
Fig. 1C. —Three-dimensional endoluminal views of 6-mm adenomatous polyp in ascending colon found in asymptomatic 62-year-old man undergoing screening for colorectal cancer. Image obtained using Vitrea 2 software (version 3.1, Vital Images, Plymouth, MN) shows slight contour deformity (arrow) in location of polyp. Even in retrospect, polypoid lesion is difficult to discern. Image also appears out of focus.

Fig. 1D. —Three-dimensional endoluminal views of 6-mm adenomatous polyp in ascending colon found in asymptomatic 62-year-old man undergoing screening for colorectal cancer. Photograph from optical colonoscopy shows same polyp on fold as that seen in A–C and adjacent measuring guidewire.
**Fig. 2A.** —Three-dimensional endoluminal views of 8-mm adenomatous polyp in descending colon found in asymptomatic 58-year-old man undergoing screening for colorectal cancer. Image obtained using V3D-Colon software (version 1.2.4, Viatronix, Stony Brook, NY) shows well-circumscribed sessile polyp between folds.

**Fig. 2B.** —Three-dimensional endoluminal views of 8-mm adenomatous polyp in descending colon found in asymptomatic 58-year-old man undergoing screening for colorectal cancer. Image obtained using Vitrea 2 software (version 3.1, Vital Images, Plymouth, MN) shows same polyp as **A**. Image appears "fuzzy" or out of focus.

**Fig. 2C.** —Three-dimensional endoluminal views of 8-mm adenomatous polyp in descending colon found in asymptomatic 58-year-old man undergoing screening for colorectal cancer. Image obtained using Navigator software (Advantage Workstation version 4.0, General Electric Medical Systems, Milwaukee, WI) shows same polyp as in **A** and **B**. Although conspicuous, polyp lacks complete border and its outline appears to merge with proximal fold.
**Fig. 2D.** — Three-dimensional endoluminal views of 8-mm adenomatous polyp in descending colon found in asymptomatic 58-year-old man undergoing screening for colorectal cancer. Photograph from optical colonoscopy shows same polyp in descending colon as seen in A–C.

**Fig. 3A.** — Three-dimensional endoluminal views of 8-mm hyperplastic polyp in sigmoid colon found in asymptomatic 52-year-old man undergoing screening for colorectal cancer. Image obtained using Vitrea 2 software (version 3.1, Vital Images, Plymouth, MN) shows sessile polyp.
Fig. 3B. —Three-dimensional endoluminal views of 8-mm hyperplastic polyp in sigmoid colon found in asymptomatic 52-year-old man undergoing screening for colorectal cancer. Image obtained using Navigator software (Advantage Workstation version 4.0, General Electric Medical Systems, Milwaukee, WI) shows polyp more clearly than A, but polyp still lacks complete border.

Fig. 3C. —Three-dimensional endoluminal views of 8-mm hyperplastic polyp in sigmoid colon found in asymptomatic 52-year-old man undergoing screening for colorectal cancer. Image obtained using V3D-Colon software (version 1.2.4, Viatronix, Stony Brook, NY) shows same polyp as in A and B. Note complete circumscribed border.
Automated Navigation
Ten CT colonography studies of a well-distended colon were chosen: seven supine and three prone scans. Attempts at semiautomated (Navigator) or automated (Vitrea 2 and V3D-Colon) navigation yielded success in eight (40%) of 20 flights with Vitrea 2, nine (45%) of 20 flights with Navigator, and in 20 (100%) of 20 flights with V3D-Colon. The navigational success rate of the V3D-Colon system was significantly higher than those of the other two systems ($p < 0.001$). Several of the successful flights with Vitrea 2 required multiple attempts before completion. With the V3D-Colon system, a successful flight was evident in each case before it began because of the predetermined centerline path. Because of its electronic fluid cleansing capability, the V3D-Colon system was able to complete flights in additional cases with fluid-filled segments, but these cases were not included for comparison. Electronic cleansing, however, may have contributed to the success of the V3D-Colon system by increasing the luminal diameter at narrowed points in some of the included cases.

All successful flights were completed in less than 3 min with all three systems (maximum, 140 sec). With the Navigator system, however, 20 min or more was required per flight to save the sequence before it could be reviewed. With the Navigator and V3D-Colon systems, an automated flight path could be repeated (once saved in Navigator), but with Vitrea 2, review of a flight required storing it as a movie. The saved movie could then be played only with an external media player, which resulted in the loss of manual navigation.

For unsuccessful Navigator flights, the semiautomated path was disrupted at the sigmoid colon in eight cases and in one case each at the descending colon, splenic flexure, and ascending colon. For unsuccessful Vitrea 2 flights, the automated path was disrupted at the sigmoid colon in seven cases, descending colon in two cases, transverse colon in two cases, and splenic flexure in one case. The point of disruption for all unsuccessful flights was at a point of relative luminal narrowing from a variable combination of interhaustral folds, luminal fluid, and hairpin turns.
Subjectively, the endoluminal flight appeared smooth on both the Navigator and V3D-Colon systems, but it had a stuttered or staccato feel with the Vitrea 2 system. In addition, the automated flight path with Vitrea 2 often appeared to hug a sidewall too closely, which resulted in poor visualization of the remaining surface. In comparison, the Navigator and V3D-Colon systems seemed to take a truer centerline path, with improved surface visualization. However, because only the V3D-Colon system documents luminal coverage, a quantitative comparison is not possible.

**Other 3D Features**

A comparison of additional features offered by at least one of the three CT colonography systems is summarized in Table 4. The V3D-Colon system creates an automated centerline path, which skips over collapsed segments and continues on; the Navigator and Vitrea 2 systems do not have this feature. The V3D-Colon system allows one to flip back and forth between the supine and prone scans without exiting the viewer, whereas only one series can be viewed at a time with the other two systems. Both the Vitrea 2 and V3D-Colon systems can display an overview colon "road map," which can be used for placing bookmarks or arrows at points of interest. With the V3D-Colon system only, the colon map also displays a real-time position indicator that smoothly updates during 3D navigation. Estimation of the percentage of colonic mucosal surface visualized during 3D evaluation is available only on the V3D-Colon system. Finally, translucency rendering, which allows internal density evaluation of a polypoid lesion, and electronic cleansing of opacified residual fluid are available only on the V3D-Colon system.

All three systems offer comparable 2D displays and allow manual cine review of axial, sagittal, and coronal images. Scrolling through 2D images seems easiest with the Vitrea 2 system (press the right mouse button), followed by the V3D-Colon system (tab below the image), and is least convenient with the Navigator (move the cursor from a different orthogonal view). The V3D-Colon system also includes a fourth 2D view that represents the plane orthogonal to the luminal centerline.

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<th>TABLE 4 Three-Dimensional Features Available on Three CT Colonography Systems</th>
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The 2D and 3D displays for CT colonography are complementary, and both will remain vital as the technology evolves. Although there was some early debate as to which display would be best suited for primary polyp detection, the 2D approach is currently favored by most, as attested to by numerous published reports [1–3, 5, 8]. However, an assessment of the CT colonography studies that helped shape this currently accepted reviewer strategy reveals that most use Navigator [5, 6, 8], Vitrea [4, 10], or customized "home-grown" software [11, 12]. These systems have been largely designed on the basis of the primary 2D paradigm and, as shown in this study, are simply not suitable for time-efficient 3D evaluation. Hence, the prevailing notion that primary 3D evaluation is not feasible may be more a reflection of design limitations in the available technology than of the feasibility of 3D evaluation.

Although I also started out as a primary 2D reviewer, I soon realized that time-efficient primary 3D evaluation was readily achievable and was preferable to 2D evaluation with the V3D-Colon system [9]. My 3D approach typically includes a complete real-time retrograde and antegrade fly-through on either the supine or prone set, followed by either a retrograde or antegrade fly-through on the remaining set. Intermittent manual 3D navigation off the automated centerline, 3D translucency rendering, and 2D correlation can all be rapidly performed for suspicious lesions, as needed [9]. Using manual cine viewing of the axial 2D images, performed either before or after 3D fly-through, I evaluate for extramucosal findings. The 2D images also play a secondary role in polyp detection, but I think that true lesions hidden among the folds are generally more obvious on 3D evaluation. The 2D images, however, remain vital for subsequent correlation of suspicious polypoid lesions detected on the 3D display [9].

Compared with a 2D approach, a 3D fly-through approach involves a less complex visual search pattern for polyp detection [13]. Not only are lesions more conspicuous on 3D display, but they can also be viewed for a longer period of time and distance as a result of volume rendering. Because of its cross-sectional nature, a 2D cine approach allows a polyp to be visualized for only a small fraction of time compared with a 3D approach. Effective 2D detection of these transiently visible polyps is possible but can be demanding especially if one is faced with interpreting multiple examinations per day, which is very likely to occur if CT colonography gains acceptance for screening. Although some studies have shown no significant difference between the 2D and 3D approaches for polyp detection, quantifying factors such as polyp conspicuity and ease of detection is difficult. Both approaches may ultimately result in finding the same polyps with some systems, but the path to success may vary widely in the level of difficulty. It is also worth noting that these studies used systems that were designed with a primary 2D approach in mind.
I concur with previous reports that time-efficient 3D evaluation for primary polyp detection is not currently feasible with other systems, such as Navigator (version AW4.0) or Vitrea 2 (version 3.1) [1, 4, 5, 7]. Furthermore, the differences in polyp conspicuity and depth shown in this study could further diminish polyp detection on 3D display with these systems. What is not readily apparent from the study results is that these differences are even more pronounced on real-time evaluation. Nonetheless, one study using Vitrea 1.1 and another using Voxel View (version 2.5.1, Vital Images) still showed improved polyp characterization and detection for the 3D approach compared with the 2D approach [4, 13].

For an experienced reviewer using the V3D-Colon system with a 3D approach for primary polyp detection as outlined earlier, interpretation time (including extracolonic 2D evaluation) is approximately 10–15 min [9]. Primary 3D evaluation for an uncomplicated study can generally be completed in less than 10 min. This compares favorably with the 16-min average Macari et al. [5] reported using a 2D approach for primary polyp detection, and that value did not include extracolonic evaluation time. Not surprisingly, in the same study Macari et al. found that full-length 3D evaluation with the Navigator system was temporally prohibitive, with an average interpretation time of 40 min, which apparently does not include the protracted path set-up time.

In addition to superior endoluminal rendering and automated navigation with the V3D-Colon system, many other features support 3D evaluation for primary polyp detection (Table 4). The predetermined centerline that readily "jumps" collapsed segments and continues on is reliable and a significant time-saver. Sites of collapse usually involve different segments on the complementary supine and prone scans, thus allowing endoluminal evaluation of the entire colon. The automated centerline, however, is not infallible because it may infrequently cross over into an adjacent noncontiguous loop. The ease of manual mouse-driven navigation and the real-time position indicator can easily circumvent this path. The ability to rapidly switch back and forth between supine and prone images for correlation is an important feature, the absence of which in the Navigator and Vitrea 2 systems is surprising. Placing bookmarks on suspicious lesions is useful not only for the interpreter, but also for the endoscopist. Measuring polyps directly from the 3D display allows an optimal vantage point that is often not possible with the 2D images. Both translucency rendering and electronic fluid cleansing options with the V3D-Colon system provide unique advantages that can be useful for primary 3D evaluation [9], but the specifics are beyond the scope of this article.

Adequate luminal coverage is of obvious importance for 3D polyp detection. Not surprisingly, visualization of the entire mucosal surface on 3D display yields a higher sensitivity for polyp detection compared with the 2D axial images [13]. The V3D-Colon system provides a real-time estimation of the percentage of mucosal surface that has been visualized, whereas the Navigator and Vitrea 2 systems do not. A combined automated retrograde and antegrade fly-through with the V3D-Colon system views an average of 94% of the colonic surface [14]. This percentage increases during actual interpretation when interactive manual navigations of suspicious areas are included. Additional missed patches can be viewed, if needed, in order of descending cross-sectional area until 100%
surface visualization is achieved. However, I no longer routinely perform this additional function because it has never uncovered any significant lesions in my experience.

As with any novel imaging application, achieving an acceptable diagnostic performance with CT colonography requires a strong commitment from the training radiologist. This is particularly true for primary 3D evaluation, which is less of a direct extension from familiar cross-sectional CT interpretation than primary 2D interpretation. In addition to the initial unfamiliarity with the endoluminal display, new pitfalls exist on 3D that must be recognized [9, 10]. Regardless of the specific reviewer strategy, dedicated CT colonography training is a vital component of any successful screening program.

A meaningful comparison of different CT colonography systems is hindered somewhat by the rapidly evolving nature of the technology. To be sure, this study represents only a single "snapshot in time." By the time the results of this study are published, each of the three vendors will have already released a newer version of their software product. In fact, the Navigator system upgrade on the recently released AW4.1 features several useful improvements in endoluminal navigation; however, the default 3D display remains in black-and-white. In the case of Vitrea 2, changes with version 3.2 will primarily focus on the display of patient information and not on the 3D display. For version 1.3 of the V3D-Colon system, supine–prone correlation will be further streamlined in addition to other less noticeable 3D improvements. Another limitation of this study was that only one radiologist performed the attempted fly-throughs, which could possibly be subject to interobserver variability.

In conclusion, 3D improvements offered by some CT colonography systems, such as the V3D-Colon, have paved the way for effective, time-efficient 3D evaluation for primary polyp detection. Whether a true paradigm shift to primary 3D interpretation is on the horizon largely depends on the results of ongoing studies and multicenter clinical trials. Regardless, the 3D endoluminal display should continue to grow in importance for CT colonography, perhaps putting the "virtual" back into CT colonoscopy.
References


