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Normalized Distance Along the Colon Centerline: A Method for Correlating Polyp Location on CT Colonography and Optical Colonoscopy

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Abstract

Objective—The ability to accurately locate a polyp found on CT colonography (CTC) at subsequent optical colonoscopy (OC) is an important part of the successful implementation of CTC for colorectal cancer screening. The purpose of this study was to determine if a polyp's normalized distance along the colon centerline (NDACC) derived from CTC data can accurately predict its location on optical colonoscopy.

Patients and methods—The polyp population consisted of 152 polyps in 121 patients. CTC polyp findings were verified by same day segmentally-unblinded OC. Each polyp's NDACC was computed by dividing its distance from the anorectal junction measured along the colon centerline by the length of the colon at CTC. The predicted polyp location at OC was computed by multiplying by the NDACC the colon length at OC (i.e., the distance to the cecum as determined at full colonoscope insertion). The differences between the true and predicted polyp locations at OC were compared using paired t-tests, linear regression, prediction interval assessment and Bland-Altman analyses.

Results—The difference between the true and predicted polyp locations at OC using the supine and prone CTC NDACC were 2.2 ± 10.5 cm (mean $\pm$ standard deviation; $n=136$) and 1.5 ± 10.5 cm ($n=135$), respectively. The predicted location was within 10 cm of its true location for 71.3% (97/136) to 74.8% (101/135) of polyps and within 20 cm of its true location for 93.3% (126/135) to 93.4% (127/136) of polyps.

Conclusions—By computing the NDACC of a polyp found at CTC, the location of a polyp at OC can be predicted to within 10 cm (i.e., 1 colonoscopy mark) for the majority of polyps.

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Potential financial interest.

Authors Summers has pending and/or awarded patents for CT colonography computer-aided polyp detection, a subject matter related to the work described in the manuscript. Author Summers receives grant support and royalty income for a patent license from iCAD. Author Pickhardt is on the medical advisory boards of Viatronix, Inc. and Medicsight, Inc and a consultant to C.B. Fleet Company and Covidien. Author Choi is on the medical advisory boards of Viatronix, Inc and QI and has received research support from E-Z-EM. Viatronix supplied the V3D Colon software free of charge.

Keywords

CT; colon; colonoscopy; normalized distance

Computed tomography colonography (CTC) is a relatively recent screening test for colorectal cancer that has shown increasing effectiveness at detecting colonic polyps [1, 2]. The use of CTC for colorectal screening is likely to increase with its recent addition to the American Cancer Society guidelines and the favorable results of the American College of Radiology Imaging Network multi-institutional clinical trial [3, 4].

Polyps of sufficient size (6 mm or larger, or 10 mm or larger if surveillance of 6 – 9 mm polyps is proven effective) discovered by CTC must be located and removed at optical colonoscopy (OC) [3, 5]. In performing this task, the colonoscopist searches for the polyp using the location data supplied by CTC. The location of a polyp at CTC is typically expressed in two ways: the colonic segment in which the polyp is located and the distance from the anus to the polyp, measured along the colon centerline.

The proper coordination of OC and CTC requires the precise localization of polyps found at each examination. Uncorrected distances to polyps at CTC and OC cannot be used to match polyp findings on the two examinations because of large differences in total colon length, primarily due to telescoping and foreshortening at OC. The use of colonic segments for polyp localization is also limited due to uncertainties in colonic segment boundaries, particularly at OC [6]. In a preliminary work, it was shown that normalization of the distances from the anorectal junction to the polyp using total colon length led to more accurate polyp localization between supine and prone CTC[7]. This study was performed to determine if this method also can improve the ability of CTC to predict the location of a polyp at OC.

MATERIALS AND METHODS

Written informed consent for retrospective research was obtained from all patients during the initial study [8]. The initial study was approved by the institutional review board and the retrospective study used data that was exempt. Both studies complied with the Health Insurance Portability and Accountability Act. The research was performed in part using software donated by Viatronix. Researchers who were not Viatronix board members had full control over the data.

Polyp population

The patients for this study were selected from a larger screening population of 718 patients from two hospitals [8]. All patients underwent a standard 24-hour colon preparation consisting of oral administration of 90 ml of sodium phosphate (Fleet 1 preparation, Fleet Pharmaceuticals) and 10 mg of bisacodyl. Patients also consumed 500 ml of barium (2.1 percent by weight; Scan C, Lafayette Pharmaceuticals) for solid-stool tagging and 120 ml of diatrizoate meglumine and diatrizoate sodium (Gastrografin, Bracco Diagnostics) for the opacification of luminal fluid.[9] Next, they underwent CTC in the supine and prone positions using a four-channel or eight-channel CT scanner (GE LightSpeed or LightSpeed Ultra, General Electric Medical Systems). Scanning parameters were set at 1.25-to-2.5-mm collimation, a table speed of 15 mm per second, a reconstruction interval of 1 mm, and scanner settings of 100 mAs and 120 kV_p.

Following CTC, optical colonoscopy was performed the same day by one of 12 experienced colonoscopists (staff gastroenterologists or surgeons) “. During the optical colonoscopy, the

distances to the polyps and the lengths of the colons were measured by the colonoscopists and recorded in centimeters using the markings on the colonoscope upon scope withdrawal.

As shown in Figure 1, to be included in the study, patients had to have at least one adenomatous, hyperplastic, or malignant polyp 6 mm or larger detected on both OC and CTC. Exclusion criteria included invalid OC distances to a polyp (i.e., distance to polyp greater than colon length, an impossibility) and failure of CTC interpretation software to generate either a valid colon centerline path and/or valid distances to polyp or cecum. 25 CTC scans were excluded for these reasons. The excluded polyps include two outliers for which an error in OC measurement or data recording was strongly suspected. The final polyp population consisted of 152 polyps in 121 patients detected on a total of 217 CTC scans (110 supine, 107 prone); 136 polyps were detected on supine CTC, 135 on prone CTC, and 119 polyps on both supine and prone CTC.

Data Collection – CTC Measurements

CTC measurements of the distance to a polyp from the anorectal junction and of the colon length were acquired from both the supine and prone positions by a medical student, trained by a board-certified radiologist with nine years of CTC research experience, using Viatronix V3D CTC interpretation software, Version 2.1 (Viatronix, Inc., Stony Brook, NY). The data collector was blinded to the optical colonoscopy data while obtaining CTC data to prevent an influence on the determination of the polyp CTC location. As the observer manipulated the software to observe the different parts of the interior of the colon, the software continuously reported the distance from the anorectal junction to the current observation point, as measured along the colon centerline.

The length of the colon on CTC was defined as the distance along the centerline from the anorectal junction to the end of the cecum, which was defined as the endpoint of the fly-through along the colon centerline. In general, the centerline was near but not coincident with the tip of the cecum or the anorectal junction.

The distance to the polyp was defined as the distance along the colon centerline from the anorectal junction to the polyp with the observation point placed on the polyp surface nearest the colon centerline and as close to the polyp as the CTC interpretation software would allow.

Data Analysis

The CTC data was used to determine the normalized distance along the colon centerline (NDACC) for each polyp on both the supine and prone CTC. The NDACC was computed by dividing the distance to the polyp by the total length of the colon. The predicted polyp location at OC was computed by multiplying the NDACC found at CTC by the total length of the colon (the distance to the cecum) found at OC. The differences between the predicted polyp locations and the true location found at OC were analyzed. Comparison of supine and prone CTC true and predicted polyp locations were conducted in a similar fashion.

Statistical Analysis

A two-tailed, paired t-test between the differences in true and predicted OC polyp locations with and without correction of the CTC NDACC values was used to determine whether using the correction factors produced statistically significant differences. $P < .05$ was considered statistically significant.

Regression and Bland-Altman analyses was conducted to compare the true and predicted polyp locations at OC and for supine and prone CTC [10].

The differences in true and predicted polyp locations were also stratified by colonic segment (cecum, ascending colon, hepatic flexure, transverse colon, splenic flexure, descending colon, sigmoid colon, and rectum). Colonic segment for each polyp was determined by the colonoscopist at the time of colonoscopy.

Outlier Analysis

Data points in the final analysis were considered outliers if the difference they fell outside the limits of agreement on Bland-Altman analysis (i.e., the difference between the true and predicted polyp locations at OC was outside the range of the average difference ± 2 standard deviations). Eleven outliers on supine and seven on prone CTC scans (five polyps were common to both scans) were reviewed to determine their cause.

Investigation of Potential Sources of Error in Computing NDACC

Five potential sources of error in computing NDACC attributable to the CTC colon centerline were identified. For each, we determined the number of affected CTC polyps and the effect on predicted polyp location at OC. Since the number of polyps affected by each of the five error sources was small, we report the results on all affected polyps as a group. These potential sources of error, grouped by the affected portion of the colon, were:

1. *1. Errors at the rectal end of the colon centerline.* The distal end of the colon centerline could begin either within the rectal tube or within a rectal outpouching instead of at the anorectal junction. This error exaggerated both the measurement to the polyp and the measurement of the colon length. To correct for this error, the measurement of the distance from the start of the centerline to the anorectal junction or the extra distance to the rectal outpouching was recorded and subtracted from the distance to the polyp and from the colon length.
2. *2. Errors at the cecal end of the colon centerline.* The proximal end of the colon centerline could curve back into the colon instead of ending at the cecum, could enter the small intestine, or could end in a cecal outpouching instead of at the proximal cecum. This error caused the measurement of the colon length to be greater than the true value. For such cases, the software viewer was placed at the ileocecal valve and the distance from the anorectal junction to this point was recorded as the length of the colon.

Number of Colonic Segments in CTC Colon Verification

The CTC interpretation software allows the user to connect colon segments uncoupled due to intervening collapsed colon with a straight line to estimate the colon length that otherwise would be lost. Because these estimations could affect predicted polyp locations, we performed a separate analysis on the differences between true and predicted polyp locations at OC as a function of the number of uncoupled segments.

Investigation of Error Introduced by OC Measurement Rounding

The colonoscopes used in this study had markers every 10 cm along the outer sheath allowing visual estimation of insertion distance. Using these markers, the colonoscopists rounded the majority of OC distance measurements to the nearest 5 cm, restricting the accuracy of measurements to ± 2.5 cm. To determine the impact of this error, the range of predicted polyp locations at OC ($\text{CTC NDACC} \times [\text{OC length of the colon} \pm 2.5 \text{ cm}]$) was compared to the range of possible true polyp locations at OC (OC true distance to the polyp ± 2.5 cm). If the ranges overlapped, the predicted polyp location at OC was said to match the true polyp location, within the limits of rounding error.

RESULTS

Comparison of Colon Lengths at Optical Colonoscopy and CT Colonography

The lengths of the colons were 96.9 ± 22.3 cm (mean $\pm$ standard deviation, $n = 121$) on optical colonoscopy; 173.6 ± 23.9 cm ($n=110$) on supine CT colonography; and 179.4 ± 22.6 cm ($n=107$) on prone CT colonography ($P<.001$ for all three pair-wise comparisons using paired t-tests on only those scans with matched colon lengths).

Comparison of True and Predicted Polyp Locations at Optical Colonoscopy

The differences between the true and predicted polyp locations at OC are shown in Table 1. The differences between the true and predicted polyp locations at OC using the supine and prone CTC polyp locations were 2.2 ± 10.5 cm and 1.5 ± 10.5 cm, respectively. The maximum difference was found for polyps in the splenic flexure using the supine CTC data. The maximum standard deviations were also for polyps in the splenic flexure. While there was a statistically significant difference in the biases (offsets) of the large (> 10 mm) and medium (6–9 mm) polyps ($p=.03$ and $.02$ for supine and prone, respectively), this was due to different spatial distributions of the polyps by size (low fraction of large and high fraction of medium polyps were located in the sigmoid). The overall standard deviations were comparable for large and medium polyps as expected.

Correlations between true and predicted polyp locations at OC were high ($R^2 = 0.9223$ and 0.9257 using the polyp locations on the supine and prone CTC scans, respectively) (Figure 2). The trend lines indicate an offset between true and predicted OC polyp locations of approximately 6 cm. The Bland-Altman plots show that while there is agreement between the true and predicted polyp locations at OC, there is also considerable variance (Figure 3).

There was no gross pattern of the prediction error according to polyp location in the colon (Figure 4). Figure 5 shows that the predicted location of a polyp was within ± 10 cm (i.e., ± 1 colonoscope mark) of its true location for 71.3% (97/136) and 74.8% (101/135) of polyps using supine and prone CTC, respectively. The optical colonoscopy locations of polyps were within ± 20 cm (i.e., ± 2 colonoscope marks) of the predicted locations for 93.4% (127/136) and 93.3% (126/135) of polyps using supine and prone CTC, respectively.

Sources of Error in NDACC Attributable to the CTC Colon Centerline

The incidences of the five centerline errors were relatively infrequent, affecting in total 29 polyps on supine and 26 polyps on prone CTC. Correcting the errors lead to small (between -2.3 and $+1.5$ cm) non-statistically significant changes in the predicted polyp location on OC.

A qualitative review of the 11 supine and 7 prone outliers representing 13 polyps from 12 patients revealed 3 colons with missing (completely collapsed) colonic segments, 4 colons with a large or tortuous sigmoid colon and 1 colon with a highly kinked centerline (Figure 6). For 4 colons, no unusual characteristics were observed; however for 2 of these colons, there were other polyps in the same part of the colon on OC suggesting a problem matching OC and CTC polyp findings.

Number of Colonic Segments in CTC Colon Verification

Uncoupled colonic segments were more common on the supine than on the prone CTC (Table 2). There was no significant difference between the true and predicted polyp locations on OC when comparing colons without and with collapsed segments ($P > .5$). The greatest differences between true and predicted polyp locations were found when using

supine CTC polyp locations in colons with 7 or more uncoupled segments; these are very poorly distended colons (Table 2).

Optical Colonoscopy Measurement Rounding

Of the 152 polyps, 140 (92.1%) reported an optical colonoscopy polyp distance from the anus that was rounded to the nearest 5 cm; 150 (98.7%) polyps had an optical colonoscopy colon length that was rounded to the nearest 5 cm. Considering the rounding error, the range of predicted polyp locations at OC were compared to the range of true polyp locations at OC. 78 (28.4%) of the 271 polyp instances (considering supine and prone separately), had plausible predicted OC polyp location ranges overlapping their corresponding OC true location range (representing 53 individual polyps out of 152, 34.9%).

Comparison of Supine and Prone CTC True and Predicted Polyp Locations

The average differences between true and predicted polyp locations on supine and prone CTC were very small (-1.5 ± 4.6 and 1.6 ± 4.9 cm, respectively) (Table 3). Both the means and standard deviations of these differences were smaller than that found by simply subtracting the true differences on supine and prone CTC (-4.6 ± 6.5 cm), indicating a benefit to using the NDACC to predict polyp location. There was excellent correlation between the true and predicted polyp locations on supine and prone CTC ($R^2 > 0.99$) (Figure 7). The Bland-Altman plots further illustrate the excellent agreement between the true and predicted polyp locations on supine and prone CTC (Figure 8).

Figure 9 shows that there is no gross pattern of the prediction error according to polyp location in the colon aside from two outliers in the central part of the colon. Figure 10 shows that the CTC location of a polyp was predicted to within ± 10 cm for 94.1% (112/119) of polyps on both supine and prone CTC.

DISCUSSION

Since the total colon lengths computed at CTC are approximately 84% longer than those computed at OC, the absolute distance values cannot be used to locate at OC polyps found at CTC. Instead, one can use the NDACC calculated at CTC to accurately map polyp locations at OC to within ± 1 colonoscope mark for over 71% of polyps and to within ± 2 colonoscope marks for over 93% of polyps. Either the supine or the prone CTC polyp locations can be used. The NDACC calculation is easy to perform and to incorporate into routine clinical practice at both CTC and OC. After full colonoscope insertion to the cecum, the standard first step in OC, the colonoscopist need only record the colon length and determine the OC distance to the polyp based on the CTC NDACC. For polyps not found using the NDACC, the colonoscopist can revert to the current practice of searching for the polyp within ± 1 colonic segment.

Polyp locations on the complementary CTC scan can be accurately predicted using the NDACC. The CTC location of a polyp can be predicted to within ± 10 cm for 94.1% of polyps on both supine and prone CTC. The use of the NDACC for this purpose will likely be of greatest practical benefit during the interpretation of a CTC examination.

Although errors in the rectal and cecal termini of the CTC colon centerline were observed, these errors were deemed too small to be clinically important. This simplifies the calculation of the NDACC, since in clinical practice, there is little benefit to correcting these errors. In addition, the presence of multiple collapsed colonic segments did not adversely affect prediction of polyp locations, except in the most poorly distended colons.

We observed an offset between the true and predicted polyp locations at OC of 6 cm at regression analysis. The offset can be attributed to the length of the anal canal that is included in the OC but not the CTC polyp location measurements (i.e., measurement starting at the anal verge versus the anorectal junction).

Five characteristics of outliers were observed that potentially contributed to the large difference between true and predicted polyp locations at OC observed in these cases. These were missing (collapsed) colonic segments, large or tortuous sigmoid colons, highly kinked colon centerlines, poorly distended rectosigmoid and mismatched polyps. When there are missed colonic segments, the CTC interpretation software generates a straight line estimation of the missing colon length that might be shorter than the true colon length due to the twisting and curving of a normal colon. If the missing segment was actually curved rather than straight, the software could underestimate colon length and anal-polyp distance. When the sigmoid colon is long or tortuous, it may bunch up or telescope around the colonoscope. In this situation, optical colonoscopy distance measurements could be substantially shorter than their values at CTC, leading to inaccuracies in the predicted polyp location at OC. A highly kinked centerline at CTC may lead to expansion of the NDACC coordinate system in local areas of the colon.

We found that by considering OC measurement rounding error alone, over 1/3 of polyps could be located within a plausible range of the true location at OC using the CTC NDACC. This can be understood by considering the propagation of errors. The $\text{var}(A-B) = \text{var}(A) + \text{var}(B)$, where A and B are the true and predicted polyp locations at OC and $\text{var}(A-B)$ is the variance in the difference of A and B. We can estimate the variance due to rounding to the nearest 5 cm by assuming that the true measurements are evenly distributed over the 5 cm range.

$$\text{var} = \int_{-t/2}^{t/2} (x - m)^2 p(x) dx$$

where p is the probability density function, m is the mean and t is the rounding error. In this case, $m=0$, $t=5$ and $p(x)=1/5$ and $\text{var}=2.1 \text{ cm}^2$. Therefore, $\text{var}(A-B) = 4.2$ and the standard deviation of $A-B = 2.0 \text{ cm}$, a substantial portion of the observed difference between the true and expected polyp locations.

Similarly, the position of the colonoscope may introduce error into prediction of polyp location at OC. CTC measurements were taken with the viewer directly on the polyp and immediately next to the end of the cecum. OC measurements were likely not obtained with similar precision, as indicated by the data on the subset of cecal polyps. If measurements were not taken immediately next to each target, optical colonoscopy data may not appear to match CTC data as close as reality. Future studies should ensure that optical colonoscopy measurements are recorded with high precision. This can be facilitated by use of latest generation colonoscopes that have markings every 5 cm instead of every 10 cm. It is also unknown to what extent OC polyp location measurements differ when made during advancement versus withdrawal of the endoscope.

Awareness of these sources of error may improve the ability of CTC NDACC values to accurately locate polyps on OC, as more precise OC data and more accurate polyp matching are likely to improve the correlation between OC and CTC NDACC. However, other factors also have a role in the agreement between OC and CTC NDACC. For example, the CTC interpretation software generates a centerline that is optimized for viewing the colonic surface, not for obtaining a precise linear measurement of the colon length or of the distance

to a polyp. In many cases the centerline travels a highly kinked path instead of a straight line to the cecum, resulting in measurements that are greater than their true value (Figure 6). A software feature that allowed a straight centerline optimized for measuring the length of the colon may also improve the correlation between OC and CTC NDACC[11]. Software that flattens and straightens the colon for display may already provide such capabilities but will need to be validated [12, 13].

The original NDACC method has subsequently been improved [14]. The improved method allows limited expansion and compression of the centerline to achieve maximal alignment of corresponding colonic segments. While the improved method decreased the error in matching polyps on supine and prone CTC, compared to the NDACC method, the reduction was not significant. We did not have access to the improved method and so did not use it. Additionally, it is unclear how the improved method could be applied to the problem of matching CTC and OC relative locations along the colon centerline in the absence of data about the shape of the colon during OC. Recent work attempts to model the shape of the colon during OC, and may improve determination of predicted polyp location[11].

In a previous work using a subset of the polyps from this study, polyp localization data for registering the supine and prone CTC exams using uncorrected centerline distances was presented [15]. The 95% prediction intervals for longitudinal polyp locations were within about ± 6 cm for sessile and pedunculated polyps. Since colon lengths on supine and prone CTC are so similar, it is easy to see why uncorrected values can work so well. Nevertheless, we found that the NDACC method enables even more accurate matching.

It might be argued that the standard practice of locating polyps based on colonic segment is just as good as the NDACC method. For a 100 cm long colon divided into 4 major segments (right, transverse, left, rectosigmoid), such matching could limit the search in theory to only 25 cm. In clinical practice, however, colon locations at OC are typically accurate to only ± 1 colonic segment, increasing the search range. Segmental colon locations are probably even less accurate in highly tortuous colons.

The results of this paper are not meant to imply that existing methods of polyp localization be entirely abandoned. The NDACC would be used at OC in association with such features as polyp size and shape (such as sessile, pedunculated or flat) and relationship to a haustral fold (e.g., behind a fold) to locate polyps found at CTC. Similar polyp features at OC and CTC increase confidence of a proper match and may be particularly helpful when multiple polyps are located near one another. Colonic segment information will continue to be useful, particularly when it is unambiguous.

In principle, there could be greater errors of the OC length measurements in the proximal colon due to loops with the endoscope. However, we did not observe greater errors in the proximal colon.

This research is limited since as this was a retrospective study, we could not assess the actual impact of improved measurement accuracy at OC. Future work will be needed to demonstrate that the method proposed here leads to time efficiency and/or greater confidence and yield in locating polyps found at CTC.

We did not investigate the variation in polyp location or length of colon by endoscopist. While there may be variability in these data obtained by different endoscopists, our results came from a variety of endoscopists and do not indicate that this is likely to be an important issue. Future research will be needed to determine the intraobserver and interobserver variability in the length measurements at OC and CTC.

In conclusion, we found that 71.3% to 74.8% of polyps can be accurately located at optical colonoscopy to within ± 1 colonoscope mark (10 cm) using either supine or prone CTC NDACC with minimal additional effort required by the colonoscopist. This method could be easily incorporated into routine OC practice and allow the colonoscopist to begin the exam by targeting locations of potential polyps found at CTC. In the event the polyp is not found at this location, the colonoscopist should revert to the current method of looking in ± 1 colon segment (a broader span) to find the polyp.

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Figure 1.
Polyp Population Flowchart

Figure 2.

Regression analysis of OC True vs. Predicted distances to polyp. Predicted distances were determined from the CTC NDACC for (A) supine and (B) prone CTC datasets. Distances in centimeters. Similar results were found using either supine or prone CTC data.

Figure 3.

Bland-Altman plot of OC true vs. predicted distances to polyp using the CTC NDACC for (A) supine and (B) prone CTC datasets. All data are in centimeters. The solid horizontal line is the mean of the differences and the dashed lines are the mean $\pm$ 2 standard deviations. The 2 standard deviation limits of agreement are approximately $\pm$ 20 cm for both the supine and prone CTC data.

Figure 4.

Difference between true and predicted distance to polyp at OC versus the true distance to the polyp at OC using the (A) supine and (B) prone CTC NDACC. All distances are in centimeters. The predicted distance is the distance from the anus the colonoscopist would use to estimate the polyp location at OC. It is calculated from three pieces of information: the polyp location and colon length at CTC (giving the CTC NDACC) and the colon length at OC; and is computed by multiplying the CTC NDACC to the polyp by the colon length at OC. The graphs show that there is no gross pattern of the prediction error according to polyp location in the colon.

Figure 5.

Cumulative fraction of polyps with a predicted location at OC within a given distance of the true location at OC computed using supine and prone CTC anal-polyp distances. Distances are expressed as the absolute value, in centimeters, of the difference between true and predicted OC distance to polyp. The data show that the optical colonoscopy locations of polyps were within ± 10 cm (i.e., ± 1 colonoscope mark) of the predicted locations for 71.3% (97/136) and 74.8% (101/135) of polyps using supine and prone CTC, respectively. The optical colonoscopy locations of polyps were within ± 20 cm (i.e., ± 2 colonoscope marks) of the predicted locations for 93.4% (127/136) and 93.3% (126/135) of polyps using supine and prone CTC, respectively.

Figure 6. Three-dimensional colon reconstruction from supine CTC of a 59 y.o. man showing example of a highly kinked centerline (green) in the sigmoid colon. The kinking enables maximal visualization of colonic surface detail during a virtual colonoscopy endoluminal fly-through but exaggerates the colon length that would be found by a colonoscope that tends to straighten and telescope the colon..

Figure 7.

Regression analysis of true vs. predicted distances to polyp on (A) supine and (B) prone CTC. Predicted distances were determined from the CTC NDACC from the (A) prone and (B) supine CTC datasets. Distances in centimeters. Similar results are found using either supine or prone CTC data. The supine and prone true and predicted distances are highly correlated ($R^2 > 0.99$)

Figure 8.

Bland-Altman plot of true and predicted distances to polyps on (A) supine and (B) prone CTC. All data in units of centimeters. The solid horizontal line is the mean of the differences between true and predicted distances; the dashed lines are the mean $\pm$ 2 standard deviations. The Bland-Altman limits of agreement are much smaller (approximately ± 10 cm) for supine and prone CTC than those for OC in Figure 3.

Figure 9.

Difference between true and predicted distance to polyp at (A) supine and (B) prone CTC versus the true distance to the polyp at CTC using the (A) prone and (B) supine CTC NDACC to predict polyp location. All distances are in centimeters. The graphs show that there is no gross pattern of the prediction error according to polyp location in the colon aside from two outliers in the central part of the colon.

Figure 10.

Cumulative fraction of polyps with a predicted location at supine or prone CTC within a given range of the true location at CTC as computed using either prone or supine CTC anal-polyp distances, respectively. Distances are expressed as the absolute value, in centimeters, of the difference between true and predicted CTC distance to polyp. The data show that the CTC location of a polyp can be predicted to within ± 10 cm for 94.1% (112/119) of polyps on both supine and prone CTC. A greater proportion of polyps can be localized with smaller differences here compared to the situation for OC polyp localizations shown in Figure 5.

Table 1

Difference between true and predicted polyp location at OC using supine or prone CTC NDACC.

Colon Segment	Supine CTC		Prone CTC	
	Δ	N	Δ	N
Cecum	0.5±6.7	8	2.7±1.6	6
Ascending	-2.3±9.6	35	-3.6±9.5	30
Hepatic Flexure	-2.2±6.9	5	-2.7±6.7	6
Transverse	1.2±13.0	15	-2.1±12.9	15
Splenic Flexure	-7.0±15.9	5	-5.9±16.1	6
Descending	3.9±11.0	8	1.4±7.9	8
Sigmoid	6.6±10.6	38	5.7±11.0	40
Rectum	5.4±5.6	22	5.9±5.3	24
All Segments	2.2±10.5	136	1.5±10.5	135
All Segments, 6–9 mm polyps only	3.1±10.6	110	2.4±10.7	111
All Segments, 10+ mm polyps only	-1.6±9.6	26	-2.5±8.8	24

Δ = difference between true and predicted polyp location at OC (centimeters); mean $\pm$ standard deviation

The colon segment was designated by the colonoscopist at optical colonoscopy.

N = number of polyps

Table 2

Difference between true and predicted polyp location at OC according to the number of uncoupled colonic segments at supine or prone CTC

Number of Uncoupled Colonic Segments	Supine CTC		Prone CTC	
	Δ	N	Δ	N
1 *	1.5 ± 10.6	59	1.9 ± 10.5	83
2	3.3 ± 10.5	32	0.8 ± 10.0	19
3	1.0 ± 10.6	20	-0.2 ± 8.9	9
4	-0.1 ± 13.9	11	0.3 ± 12.4	12
5	4.6 ± 1.8	3	4.4 ± 11.5	7
6	1.6 ± 3.0	3	-0.9 ± 14.5	4
7	9.2 ± 1.0	2	2.7	1
8	6.1 ± 9.3	3	N/A	0
9	9.3 ± 10.6	3	N/A	0
2 **	2.7 ± 10.5	77	0.9 ± 10.5	52

Δ = difference between true and predicted polyp location at OC (centimeters); mean $\pm$ standard deviation

N = number of polyps

* Indicates a fully distended colon without collapsed areas

** Indicates a colon with one or more collapsed areas

Table 3

Comparison of supine and prone CTC centerline true and predicted distances

Colon Segment	Δ DACC	Δ supine	Δ prone	N
Cecum	-6.9 ± 9.4	1.1 ± 3.4	-1.2 ± 3.7	6
Ascending	-6.9 ± 7.4	-0.8 ± 3.2	0.8 ± 3.3	29
Hepatic Flexure	-5.2 ± 7.5	-0.6 ± 2.1	0.7 ± 2.3	5
Transverse	-4.3 ± 6.7	-1.5 ± 6.0	1.5 ± 6.3	12
Splenic Flexure	-10.1 ± 3.5	-3.1 ± 12.6	2.2 ± 14.7	5
Descending	-3.7 ± 9.6	-2.3 ± 4.5	2.6 ± 4.5	6
Sigmoid	-4.1 ± 4.9	-3.1 ± 4.0	3.2 ± 4.1	35
Rectum	-0.5 ± 3.4	-0.4 ± 3.4	0.4 ± 3.4	21
All Segments	-4.6 ± 6.5	-1.5 ± 4.6	1.6 ± 4.9	119

The colon segment was designated by the colonoscopist at optical colonoscopy.

Abbreviations:

DACC = distance along colon centerline to polyp

Δ DACC = difference between supine and prone CTC DACC values (centimeters) ; mean $\pm$ standard deviation

Δ (supine or prone) = difference between true and predicted polyp location at CTC (centimeters) using prone or supine NDACC; mean $\pm$ standard deviation

N = number of polyps