

# Predictors of Incomplete Optical Colonoscopy Using Computed Tomographic Colonography

Reetika Sachdeva, Salina D. Tsai<sup>1</sup>, Mohamad H. El Zein, Alan A. Tieu, Ahmed Abdelgelil, Sepideh Besharati, Mouen A. Khashab, Anthony N. Kalloo, Vivek Kumbhari

Departments of Medicine, Division of Gastroenterology and Hepatology and <sup>1</sup>Radiology and Radiological Science, The Johns Hopkins Medical Institutions, Baltimore, Maryland, USA

**Address for correspondence:**

Dr. Vivek Kumbhari, Johns Hopkins Hospital, 1800 Orleans St, Suite 2058 B, Baltimore - 21205, Maryland, USA. E-mail: vkumbhari@gmail.com

## ABSTRACT

**Background/Aims:** Optical colonoscopy (OC) is the primary modality for investigation of colonic pathology. Although there is data on demographic factors for incomplete OC, paucity of data exists for anatomic variables that are associated with an incomplete OC. These anatomic variables can be visualized using computed tomographic colonography (CTC). We aim to retrospectively identify variables associated with incomplete OC using CTC and develop a scoring method to predict the outcome of OC. **Patients and Methods:** In this case-control study, 70 cases (with incomplete OC) and 70 controls (with complete OC) were identified. CTC images of cases and controls were independently reviewed by a single CTC radiologist. Demographic and anatomical parameters were recorded. Data was examined using descriptive linear statistics and multivariate logistic regression model. **Results:** On analysis, female gender (80% vs 58.6%  $P = 0.007$ ), prior abdominal/pelvic surgeries (51.4% vs 14.3%  $P < 0.001$ ), colonic length ( $187.6 \pm 30.0$  cm vs  $163.8 \pm 27.2$  cm  $P < 0.001$ ), and number of flexures ( $11.4 \pm 3.1$  vs  $8.4 \pm 2.9$   $P < 0.001$ ) increased the risk for incomplete OC. No significant association was observed for increasing age ( $P = 0.881$ ) and history of severe diverticulosis ( $P = 0.867$ ) with incomplete OC. A scoring system to predict the outcome of OC is proposed based on CTC findings. **Conclusion:** Female gender, prior surgery, and increasing colonic length and tortuosity were associated with incomplete OC, whereas increasing age and history of severe diverticulosis were not. These factors may be used in the future to predict those patients who are at risk of incomplete OC.

**Key Words:** Anatomy, colonoscopy, computed tomographic colonography, factors predicting incomplete colonoscopy, failed colonoscopy, scoring method, screening colonoscopy

Received: 30.03.2015, Accepted: 15.08.2015

**How to cite this article:** Sachdeva R, Tsai SD, El Zein MH, Tieu AA, Abdelgelil A, Besharati S, *et al.* Predictors of incomplete optical colonoscopy using computed tomographic colonography. Saudi J Gastroenterol 2016;22:43-9.

Optical colonoscopy (OC) has been the standard examination tool for decades in colorectal cancer screening and investigation of symptomatic patients.<sup>[1-4]</sup> OC allows excellent visualization of the colon and biopsy/removal of polyps. However, in some patients OC can be technically challenging, with inability to achieve cecal intubation, resulting in inadequate visualization of the entire colon; hence a potential risk of undetected colon cancer and polyps.<sup>[5,6]</sup>

The frequency of incomplete OC decreased from 5–15%<sup>[7]</sup> to <3% over the past decade.<sup>[8,9]</sup> Despite this, the absolute number of patients undergoing OC has increased, making incomplete OC a clinically significant problem.<sup>[10,11]</sup> Factors that were previously shown to contribute to the risk of incomplete OC include: Increasing patient age, low body mass index (BMI), female gender, history of prior abdominal and pelvic surgeries, presence of severe diverticular disease, poor bowel preparation, experience of the endoscopist, and anesthesia-related complications.<sup>[1-4]</sup>

Patients having incomplete OC are often required to undergo additional studies, such as repeat OC, barium enema, or computed tomography colonography (CTC). CTC is the preferred radiological technique for examining the colon due to its excellent ability to evaluate the colon as well as extracolonic abnormalities. Its sensitivity is 90%–95% for detection of polyps >10 mm and 71%–90% for polyps

Access this article online	
Quick Response Code: 	Website: <a href="http://www.saudijgastro.com">www.saudijgastro.com</a>
	DOI: 10.4103/1319-3767.173758

between 5 and 9 mm.<sup>[5,12,13]</sup> This is superior to barium enema, which has a sensitivity of 80%–95% for detection of polyps >10 mm.<sup>[2,5,7]</sup> CTC uses 3D reconstruction techniques, creating a virtual image of the colon allowing endoluminal navigation of it, similar to a gastroenterologist navigating the colon during OC. This provides the radiologist, the ability to describe colonic anatomy including length, flexures, and strictures.<sup>[14]</sup>

The aims of this case–control study were to retrospectively evaluate CTC-based quantifiable anatomic factors that predict incomplete OC. Anatomical variations were compared with a control group who had complete OC and CTC. We also propose a scoring method to predict the likelihood of a successful OC based on CTC findings. This information can be used by the gastroenterologist to predict patients who might have incomplete colonoscopy, so that the time required for the OC and the equipment can be well planned leading to an increased efficiency and higher success rates of the procedure.

## MATERIALS AND METHODS

A retrospective review of the database acquired at a tertiary academic center was used to identify patients who underwent CTC between January 2010 and January 2014. The study was approved by the Institutional Review Board for Human Research. Relevant data was obtained from institutional medical records, including age, gender, history of previous hysterectomy (for females), history of prior abdominal/pelvic surgery, date and indication for CTC, and OC procedure reports.

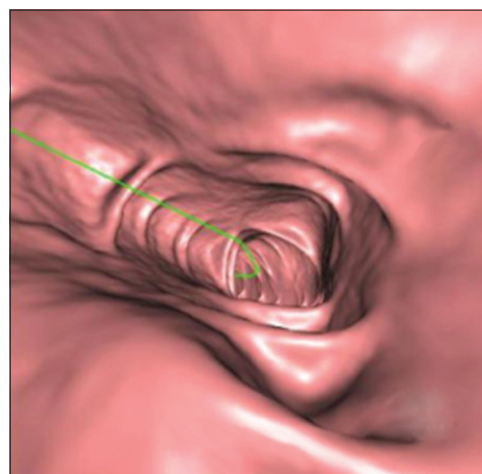
The medical records were reviewed and patients were divided into two groups. The “cases” were those who had an incomplete OC and the “controls” were those who had a complete OC. Both case and control patients had CTC after OC. The indication of CTC among the cases was incomplete OC. Among control patients, the indications of CTC were independent of those of OC such as patient preference for CTC as a screening procedure, patients with cardiac and pulmonary comorbidities, OSA, morbid obesity, not considered fit for anesthesia. The average interval between OC and CTC was 25 days among cases and 4.7 years among control patients. Of those that had an incomplete OC, patients were excluded if the reason was inadequate bowel preparation, luminal mass not permitting passage of the endoscope (tumor), or termination of the procedure due to anesthesia-related adverse events. At our institution, all OC were performed by a variety of gastroenterologists with varied experience, skill sets, and a recorded cecal intubation rate of >95%. An OC was declared incomplete, only after specific criteria was met, which included various maneuvers, such as change in patient position, application of abdominal

pressure, use of lesser diameter endoscopy instruments if indicated, and finally after a trial by a senior endoscopist.

For OC, a standard bowel preparation was used as per the discretion of the ordering physician based on patient’s comorbidities. Every patient (cases and controls) had OC under monitored anesthesia care (Propofol sedation). No additional bowel preparation or fecal tagging was given if the patient underwent CTC immediately following incomplete OC. Bowel preparation for dedicated CTC consisted of polyethylene glycol, 10 mg bisacodyl and ingested oral contrast material. Oral contrast was given to all patients in both the groups. Breath-hold CT images were acquired on a 64- or 128-slice multidetector CT (MDCT) scanner in supine and prone positions following automated rectal insufflation of carbon dioxide. Low CT technique (120 kVp and 50–100 mAs) was used with a section thickness of 0.7 mm or 0.5 mm for MPR and 3-D imaging. No intravenous contrast was routinely given. There was no difference in bowel preparation among either groups.

The CTC images were independently re-reviewed by a single CTC radiologist using *Syngo Colonography* CT software (Siemens Healthcare Global, Erlangen, Germany). The radiologist was blinded to the outcome of the OC, and re-evaluated the colons using 2D multiplanar axial images and 3D reconstructed endoluminal “fly through” views [Figure 1]. Total colonic length, colonic tortuosity based on number of acute colonic flexures (defined as <90° focal bends in colon), diverticulosis (site and grade), abdominal wall hernia, malrotation, and strictures were recorded. Presence of external colonic compression was recorded if it subjectively could contribute to an incomplete colonoscopy.

Primarily, supine images from CTC were used for evaluation. For patients who had poor colonic distention, prone views



**Figure 1:** 3-D endoluminal view in a 52-year-old patient with incomplete colonoscopy for severe anemia shows normal colonic mucosa

were reviewed. The length of colon was determined using endoluminal navigation or fly through, marking the anal opening and tip of cecum, and measuring distance between them [Figure 2a and b], using only complete fly throughs. In the event that the colon was not sufficiently distended in the supine or prone views, the fly through would be incomplete hence the length of the colon was not recorded. However, in such cases, other anatomical features were still noted.

The number of acute flexures (defined as <90° focal bends in the colon) were recorded on 3-D images using the multiplanar rotational ability of the reviewing software [Figures 3 and 4].

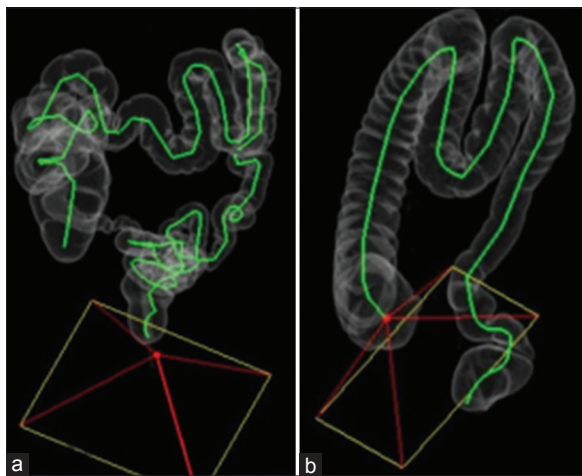
In patients with the presence of severe diverticular disease, the site of the diverticulosis was noted. In patients with sigmoid diverticular disease, the severity was graded from 1 to 4, in increasing order of severity [Figure 5]. The grading

system was based on the maximum wall thickness and the minimum diameter of the lumen using Diverticular Disease Severity Score (DDSS) in CTC [Table 1].<sup>[15]</sup>

### Statistical methods

Descriptive statistical methods (means, standard deviation (SD) and percentages) were used to summarize the data.

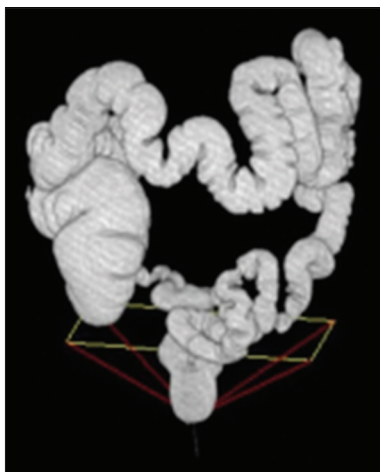
Bivariate analysis methods were used to compare the summarized data between cases and controls. Categorical variables were summarized using their respective frequencies (%) and compared using Pearson's Chi-square test (using Yates correction wherever necessary), and the odds ratios were reported. Continuous variables were presented as mean ± SD and compared using the unpaired Student's *t*-test.



**Figure 2:** (a and b) 3-D volume rendered colon two patients with incomplete OC, showing measurement of colonic length, as the distance between two points (anal opening and tip of the cecum)



**Figure 3:** 3-D volume rendered view in a 46-year-old patient with complete OC for screening of colorectal cancer shows moderately tortuous colon



**Figure 4:** 3-D volume rendered view in a 65-year-old patient with incomplete OC for abdominal pain shows severely tortuous colon



**Figure 5:** 2D CTC axial image in a 57-year-old patient with incomplete OC for hematochezia shows severe diverticulosis in sigmoid colon

The observed data was fitted to a multivariate logistic regression model to evaluate the effect of the variation of each independent variable on the outcome of the OC, adjusted for the effect of each other, using a forward-backward stepping technique (after checking for collinearity among the independent variables using Kendall's Tau-b correlation coefficients). Finally, the odds ratio, P values, and 95% confidence intervals were reported, after checking for confounding variables (by checking the Variance Inflation Factors). We also determine a scoring method, to find the chances of success of the colonoscopy on a patient, based on radiological parameters. This was done using Euclidean transformations on a plot of probabilities generated by the logistic regression model.

A two-tailed probability value of <0.05 was considered statistically significant. All analyses were done using SPSS Statistics software, version 19 (International Business Machines Corporation, Armonk, NY).

### RESULTS

A total of 150 patients had CTC and OC during our study period. Of these, 80 had recorded prior incomplete OC. Patients in whom OC was incomplete due to poor preparation (n = 2), luminal mass causing obstruction (n = 6), and anesthesia-related complications (n = 2), were excluded. Thus, our study population consisted of 140 patients, among whom 70 patients met our inclusion criteria as cases and the remaining 70 served as controls.

**Table 1: Computed tomographic colonographic diverticular disease severity score<sup>a</sup> of sigmoid colon**

DDSS	Maximum wall thickness (mm)	Minimum lumen diameter (mm)
1	<3	≥15
2	3-8	≥5
3	≥8	≥5
4	≥8	<5

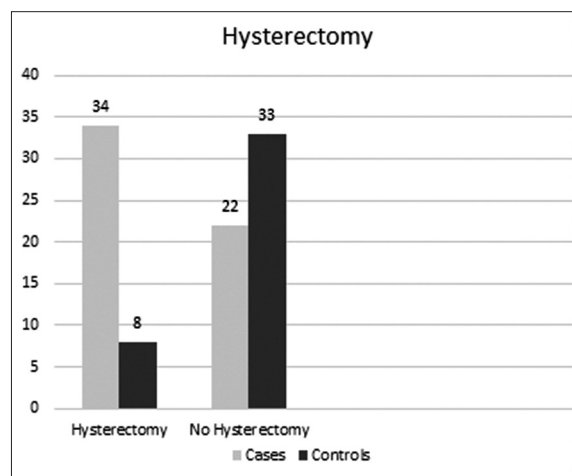
CTC: Computed tomographic colonography, DDSS: Diverticular disease severity score of sigmoid colon. <sup>a</sup>DDSS scoring system obtained from Perry J Pickhardt, et al. Diverticular disease severity score based on CT colonography. Eur Radiol 2013;23:2723-29

The reasons behind incomplete OC, as stated by endoscopists were redundancy or tortuosity (n = 34, 48.6%), severe diverticulosis (n = 11, 15.7%), fixed loops and adhesions (n = 16, 22.9%), strictures (n = 2, 2.9%), spastic colon (n = 2, 2.9%), and undefined (n = 5, 7.1%). The most proximately intubated colon segment was reported as sigmoid in 33.6% cases.

The mean age of our study population was 62.8 ± 9.9 years (for cases) and 63.1 ± 13.0 years (for controls). Analysis showed that patient age was not significantly associated with incomplete OC (95% CI = -4.2 to 3.6, P = 0.881) [Table 2]. Bivariate analysis revealed that female gender was a significant predictor of incomplete OC (80% vs. 58.6% with OR = 2.3, 95% CI = 1.3-6.0, P = 0.007) [Table 2].

Females with prior history of hysterectomy showed a significant association with incomplete OC (60.7% vs. 19.5% with OR = 6.4, 95% CI = 2.5-16.3, P < 0.001) [Figure 6]. A strong association was also noted between prior abdominal surgical history and an incomplete OC (51.4% vs. 14.3% with OR = 6.4, CI = 2.8-14.4, <0.001) [Table 2].

The mean length of colon among cases was 187.6 ± 30.0 cm compared with 163.8 ± 27.2 cm among controls [Figure 7].

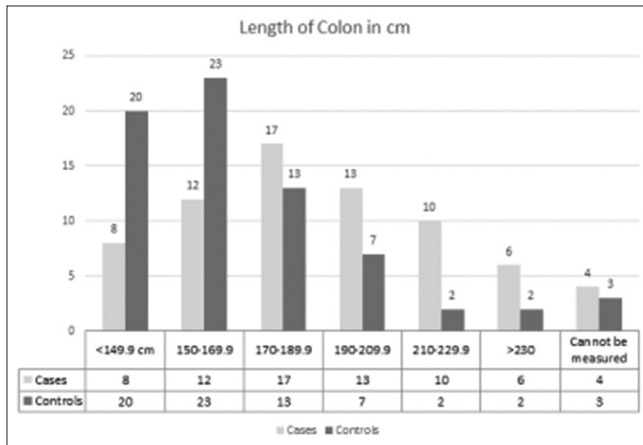


**Figure 6:** Effect of hysterectomy on incomplete OC. Females with prior history of hysterectomy shows lower completion rate of OC, odds ratio 6.35 and P < 0.001

**Table 2: Comparison of demographics and clinical findings among case (incomplete OC) and control patients (complete OC)**

	Cases	Controls	P	OR	95% CI
Mean age	62.8±9.9	63.1±13	0.881	N/A	-4.162 - 3.562
Females n (%)	56 (80)	41 (58.6)	0.007	2.82	1.331-6.016
Prior surgery n (%)	36 (51.4)	10 (14.3)	<0.001	6.35	2.805-14.384
Diverticulosis n (%)	31 (44.3)	30 (42.9)	0.86	1.05	0.543-2.067
Mean flexures	11.4±3.1	8.4±2.9	<0.001	N/A	1.737-3.743
Mean total length of colon (cm)	180.6±28.4	167.2±27.5	<0.001	N/A	4.057-22.743

OC: Optical colonoscopy, CI: Confidence interval, OR: Odds ratio



**Figure 7:** Distribution of total colonic length among cases and controls

The increasing length of colon was significantly associated with incomplete OC (95% CI = 4.1–22.7,  $P < 0.001$ ) [Table 2]. In 4 cases and 3 control patients, colonic length could not be measured due to large amount of retained fluid collapsing the colonic segments. Significant difference was observed between the mean of acute flexures among cases (Mean:  $11.4 \pm 3.1$ ) and controls (Mean:  $8.4 \pm 2.9$ ; CI = 1.7–3.7,  $P < 0.001$ ). On further evaluation, the site of maximum tortuosity among colons of the two groups was found to be at the sigmoid (8 vs. 6), at the sigmoid and transverse combined (37 vs. 34), or involving all the colonic segments (14 vs. 5).

Diverticulosis was present almost equally among either groups and did not significantly predict an incomplete OC (OR = 1.1, 95% CI = 0.5–2.1,  $P = 0.867$ ) [Table 2]. Also the severity grade of sigmoid diverticulosis was not significantly different among either group and was not a predicting factor of incomplete OC.

Our logistic regression model reveals that history of a prior abdominal/pelvic surgery independent of the other parameters increases odds of an incomplete OC by a factor of 10.5 (95% CI = 3.9–32.0,  $P < 0.001$ ). Also, every centimeter increase in colon length (controlling for flexures and history of abdominal/pelvic surgery) independently increases odds of an incomplete OC by a factor of 1.1 (95% CI = 1.0–1.1,  $P = 0.013$ ). Additionally, unit increase in the number of acute flexures in patient's colon independently increases odds of an incomplete colonoscopy by a factor of 1.6 (95% CI = 1.3–2.0,  $P < 0.001$ ). We disregarded history of hysterectomy in the logistic regression model, since it appeared to be highly correlated with the history of abdominal/pelvic surgery (Kendall's Tau-b 0.3). Also patient age ( $P = 0.179$ ), diverticulosis ( $P = 0.705$ ), and gender ( $P = 0.631$ ) were disregarded from the model due to their insignificant  $P$  values. The statistical power of fitting

gender into the model should be considered as inadequate to detect a true difference, due to uneven occurrence of males/females in the studied data, and also, due to a lower sample size being fitted into the Logistic Regression model [Table 3].

We propose a scoring method, where the score is calculated based on the total colonic length and number of flexures obtained by studying CTC, as mentioned earlier. The necessary equation obtained is 4.8% of Colon Length + Number of Flexures. Comparing the obtained value with the ones in table 4, the score is obtained. The scores assigned are 1–5, in incremental order of greater chances of successful OC (score 1 suggests <20% chance of a complete OC and score 5 suggests >80% chance of a complete OC, whereas the remainder follows in between) [Table 4].

Other variables noted by the radiologist on CTC that could contribute to incomplete colonoscopy in the cases were strictures in sigmoid colon due to severe diverticulosis ( $n = 5$ ), malrotation ( $n = 1$ ), inguinal hernia containing sigmoid bowel ( $n = 2$ ), abdominal hernia containing sigmoid and small bowel ( $n = 1$ ), and ventral hernia containing transverse colon ( $n = 1$ ). None of these were found in our control group.

## DISCUSSION

This study revealed that multiple patient and anatomical variations of the colon exist, which can predict the likelihood of an incomplete OC. We also propose a novel method to predict the outcome of OC based on colonic length and number of flexures, determined by CTC.

Incomplete OC is defined as the inability to advance the colonoscope to the cecal caput/ileocecal valve.<sup>[1,2]</sup> The percentage of incomplete OC, in the last decade is <3%<sup>[8,9]</sup> with reasons for failure being increasing patient age, female gender, history of prior abdominal or pelvic surgeries, presence of severe diverticulosis, increased tortuosity of colon and longer colonic length, poor bowel preparation, experience of endoscopist, and anesthesia-related complications.<sup>[1–4,16]</sup> The primary reason stated by our endoscopist for incomplete OC was excessive looping and tortuosity (48.6%). Excessive looping is a dynamic finding of OC and cannot be detected by CTC.

OC completion rates vary based on experience/skill of the endoscopist. Additionally, type of endoscope used, maneuvers performed, adequate and type of sedation, and bowel preparation also play a role.<sup>[11]</sup> Anatomical variations of colon are also major determinants. These are identifiable by imaging techniques such as barium enema and CTC. For decades, barium enema or CTC were used to visualize

**Table 3: Table showing the odds ratios, confidence intervals and P values from estimates obtained from the logistic regression model, for case (incomplete OC) and control patients (complete OC)**

Model variables (units)	95% Confidence interval			P
	Odds ratio (per unit change)	Minimum	Maximum	
Colon length (cm)	1.121	1.005	1.040	0.013
Positive history of previous abdominal/pelvic surgery	10.468	3.862	32.015	<0.001
Number of acute flexures in colon	1.559	1.289	1.957	<0.001

OC: Optical colonoscopy

**Table 4: Scoring method to predict outcome of OC based on radiological parameters obtained on CTC**

Score	4.8% of colon length (cm) + number of flexures	Interpretation (chances of successful OC) (%)
1	>22.8	<20
2	Between 20.6 and 22.8	20-40
3	Between 18.9 and 20.6	40-60
4	Between 16.5 and 18.9	60-80
5	<16.5	>80

OC: Optical colonoscopy, CTC: Computed tomographic colonography

portions of colon, which were inaccessible during OC. Recently, CTC is the preferred method for completion of visualization of colon due to higher efficiency and sensitivity for detecting colonic polyps, and its ability to produce detailed 2D multiplanar and 3D reconstructed images. It can also evaluate extraluminal pathology, which might contribute to a patient's symptom.<sup>[2,6,7,16,17]</sup>

Our results demonstrate association of female gender with significant risk of incomplete OC (OR = 2.8,  $P = 0.007$ ), in accordance with multiple previous studies.<sup>[1,3,4,7,10,18]</sup> Prior studies have also shown that among patients with incomplete OC, 59%–66% are females.<sup>[1,10]</sup> This is thought to occur because of larger pelvis volume in females, owing to lesser fat and lower BMI compared with males, causing increased mobility and looping of the sigmoid colon, thereby increasing the difficulty of the procedure. Also, females have been reported to have longer colon lengths compared with males, which may lead to a difficult OC.<sup>[3,10,19]</sup> A relationship between hysterectomy and incomplete OC has also been demonstrated.<sup>[1,2,4,18]</sup> It is postulated that hysterectomy leads to colonic adhesions, and removal of uterus increases the female pelvic volume causing increased tortuosity in sigmoid.

Our analysis reflected strong association between prior abdominal/pelvic surgeries and incomplete OC. This is thought to occur because intra-abdominal adhesions produce acute flexures and fixed loops in the colon. A study by

Hanson *et al.* showed 46% of patients with a prior history of abdominal surgery had incomplete OC compared with 26% with complete OC.<sup>[1]</sup> We concur, that the history of a prior abdominal/pelvic surgery (including females with prior abdominal hysterectomy) appears to increase the chances of an incomplete OC by a factor of 10.5.

Our data is indicative of a correlation between increase in colonic length and frequency of incomplete OC. Only one prior study done by Hanson *et al.* used CTC to measure colonic length in patients with incomplete OC, and found that mean colonic length in the group with incomplete OC ( $210.8 \pm 38.2$  cm) was longer than the group with complete OC ( $167.0 \pm 20.8$  cm).<sup>[1]</sup> We agree, because the mean length of colon among our cases was significantly longer than the controls ( $187.6 \pm 30.0$  cm vs  $163.8 \pm 27.2$  cm,  $P < 0.001$ ). The greater length of colon may lead to greater mobility, which can lead to excessive looping and increased tortuosity. We objectively measured tortuosity using acute flexures, which showed that increasing number of acute flexures increases the difficulty of the procedure, as indicated by our results. We found that sigmoid and transverse colons were the most tortuous segments and in most of the patients sigmoid tortuosity was the barrier to completion of OC. Previous studies also indicated the sigmoid as the site of maximum tortuosity.<sup>[2,3]</sup>

We took our analysis one step further and used the data obtained on colonic length and flexures to predict the outcome of OC. In a large number of patients, a probable pathology identified in CTC leads to follow-up OC. In such circumstances, we believe it would be beneficial to stratify our patients based on the score derived from their CTC findings. This can help the gastroenterologist to be prepared well beforehand and anticipate a difficult OC. A difficult colonoscopy thus predicted may also prompt the endoscopist to use balloon-assisted colonoscopy or water immersion/exchange technique instead.

Contribution of severe diverticular disease as a predictor for incomplete OC has always been debated upon. Saunders *et al.* stated that presence of moderate or severe diverticular disease leads to difficult colonoscopy (23% vs 4%),<sup>[20]</sup> whereas Cirocco reported the contrary.<sup>[10]</sup> According to our data, presence of diverticulosis, does not have a significant effect on the outcome of OC among cases and controls (56% and 57%, respectively,  $P = 0.867$ ). When compared, the severity of sigmoid diverticular disease was also not significantly different among cases and controls.

Additionally, we found the rate of incomplete OC independent of the increase in age ( $P = 0.881$ ). However, Shah *et al.* have shown that patients who had incomplete OC were found to be older with OR = 1.20 per 10-year increment.<sup>[21]</sup>

There were several limitations to this study, namely, it is a retrospective case–control design, a single institution study with relatively small number of patients and number of females was not matched in the two study groups because of limited data. A higher number of patients may have resulted in a better population distribution and hence could have led to more precise statistical findings. Especially, the fact that we had to disregard gender from the Logistic Regression model due to its high value, could have been analyzed further in case of a higher number of sampled data. Lastly, the scoring system is predicted from our small retrospective study and only utilized factors found at CTC and not patient demographic factors.

In conclusion, patient factors such as female gender, previous abdominal/pelvic surgeries, and increasing colonic length, are identified as the factors influencing the success of OC. We also confirm that increasing age and history of severe diverticulosis does not increase the rate of incomplete OC. We report a novel scoring system that may predict the difficulty of colonoscopy using CTC findings. These findings could be used to help predict patients who are at risk for an incomplete OC at the time of clinic consultation and may impact the preparation undertaken for OC and choice of equipment used, which may vary from use of water immersion colonoscopy to the use of pediatric colonoscope based on the difficulty predicted by the score.

## REFERENCES

- Hanson ME, Pickhardt PJ, Kim DH, Pfau PR. Anatomic factors predictive of incomplete colonoscopy based on findings at CT colonography. *AJR Am J Roentgenol* 2007;189:774-9.
- Gollub MJ, Flaherty F. Barium enema following incomplete colonoscopy. *Clin Imaging* 1999;23:367-74.
- Copel L, Sosna J, Kruskal JB, Raptopoulos V, Farrell RJ, Morrin MM. CT colonography in 546 patients with incomplete colonoscopy. *Radiology* 2007; 244:471-8.
- Anderson JC, Messina CR, Cohn W, Gottfried E, Ingber S, Bernstein G, *et al.* Factors predictive of difficult colonoscopy. *Gastrointest Endosc* 2001;54:558-62.
- Rex DK, Rahmani EY, Haseman JH, Lemmel GT, Kaster S, Buckley JS. Relative sensitivity of colonoscopy and barium enema for detection of colorectal cancer in clinical practice. *Gastroenterology* 1997;112:17-23.
- Pullens HJ, Van Leeuwen MS, Laheij RJ, Vleggaar FP, Siersema PD. CT-colonography after incomplete colonoscopy: What is the diagnostic yield? *Dis Colon Rectum* 2013;56:593-9.
- Morrin MM, Kruskal JB, Farrell RJ, Goldberg SN, McGee JB, Raptopoulos V. Endoluminal CT colonography after an incomplete endoscopic colonoscopy. *AJR Am J Roentgenol* 1999;172:913-8.
- Rathgeber SW, Wick TM. Colonoscopy completion and complication rates in a community gastroenterology practice. *Gastrointest Endosc* 2006;64:556-62.
- Rex DK, Schoenfeld PS, Cohen J, Pike IM, Adler DG, Fennerty MB, *et al.* Quality indicators for colonoscopy. *Gastrointest Endosc* 2015;81:31-53.
- Cirocco WC, Rusin LC. Factors that predict incomplete colonoscopy. *Dis Colon Rectum* 1995;38:964-8.
- Gawron AJ, Veerappan A, Keswani RN. High success rate of repeat colonoscopy with standard endoscopes in patients referred for prior incomplete colonoscopy. *BMC Gastroenterol* 2014;14:56.
- Johnson CD, Chen MH, Toledano AY, Heiken JP, Dachman A, Kuo MD, *et al.* Accuracy of CT colonography for detection of large adenomas and cancers. *N Engl J Med* 2008;359:1207-17.
- Pickhardt PJ, Choi JR, Hwang I, Butler JA, Puckett ML, Hildebrandt HA, *et al.* Computed tomographic virtual colonoscopy to screen for colorectal neoplasia in asymptomatic adults. *N Engl J Med* 2003;349:2191-200.
- Khashab MA, Pickhardt PJ, Kim DH, Rex DK. Colorectal anatomy in adults at computed tomography colonography: Normal distribution and the effect of age, sex, and body mass index. *Endoscopy* 2009; 41:674-8.
- Flor N, Rigamonti P, Pisani Ceretti A, Romagnoli S, Balestra F, Sardanelli F, *et al.* Diverticular disease severity score based on CT colonography. *Eur Radiol* 2013;23:2723-9.
- Gryspeerd S, Lefere P, Herman M, Deman R, Rutgeerts L, Ghillebert G, *et al.* CT colonography with fecal tagging after incomplete colonoscopy. *Eur Radiol* 2005;15:1192-202.
- Leksowski K, Rudzinska M, Rudzinski J. Computed tomographic colonography in preoperative evaluation of colorectal tumors: A prospective study. *Surg Endosc* 2011;25:2344-9.
- Eickhoff A, Pickhardt PJ, Hartmann D, Riemann JF. Colon anatomy based on CT colonography and fluoroscopy: Impact on looping, straightening and ancillary manoeuvres in colonoscopy. *Dig Liver Dis* 2010;42:291-6.
- Brown AL, Skehan SJ, Greaney T, Rawlinson J, Somers S, Stevenson GW. Value of double-contrast barium enema performed immediately after incomplete colonoscopy. *AJR Am J Roentgenol* 2001;176:943-5.
- Saunders BP, Halligan S, Jobling C, Fukumoto M, Moussa ME, Williams CB, *et al.* Can barium enema indicate when colonoscopy will be difficult? *Clin Radiol* 1995;50:318-21.
- Shah HA, Paszat LF, Saskin R, Stukel TA, Rabeneck L. Factors associated with incomplete colonoscopy: A population-based study. *Gastroenterology* 2007;132:2297-303.

**Source of Support:** Nil, **Conflict of Interest:** Mouen A. Khashab is a consultant for Boston Scientific and Olympus America and has received research support from Cook Medical. Anthony Kalloo is a founding Member, equity Holder and consultant for Apollo Endosurgery. All other authors have no relevant disclosures.