Colorectal anatomy in adults at computed tomography colonography: normal distribution and the effect of age, sex, and body mass index

Introduction

The large intestine is a complex three-dimensional (3D) structure that is difficult to accurately measure by conventional radiologic, endoscopic, or cadaveric means. The cecum is the first portion of the colon and is typically located in the right iliac fossa. The ascending colon extends in the retroperitoneum connecting the cecum and the hepatic flexure. The transverse colon extends in an intraperitoneal location between the hepatic and splenic flexures and is a relatively long and mobile portion of the colon. The descending colon extends within the retroperitoneal compartment and returns to an intraperitoneal location as the sigmoid colon, which is a relatively narrow, mobile, and tortuous segment of the colon. The rectum begins as an intraperitoneal structure but its distal two-thirds is extraperitoneal in location, extending to the anal canal.

Background and study aims: Computed tomography colonography (CTC) is an accurate tool for assessing the large intestinal anatomy. Our aims were to determine the normal distribution of in vivo colorectal anatomy and to investigate the effect of age, sex, and body mass index (BMI) on colorectal length.

Patients and methods: Asymptomatic adults who underwent primary CTC examination at a single institution over an 8-month period were evaluated. The interactive three-dimensional map was used to determine total and segmental lengths and number of acute-angle flexures. The two-dimensional multiplanar display was used to measure luminal diameters. The effects of age, sex, and BMI on colorectal lengths were examined.

Results: The study cohort consisted of 505 consecutive adults (266 women, mean age 56.6 years). Mean total colorectal length was 189.5 ± 26.3 cm and mean number of acute-angle flexures was 10.9 ± 2.4. Total length for older adults (>60 years) did not significantly differ from those who were younger than 60 years (P = 0.22), although the transverse colon was significantly longer in older adults (P = 0.04). Women had significantly longer colons than men (193.3 cm vs. 185.4 cm, P = 0.002), whereas overweight adults (BMI > 25) had significantly shorter colons compared with those with BMI ≤25 (187.2 cm vs. 194.5 cm, P = 0.005). Differences in total length were predominately due to differences in the transverse colon.

Conclusions: Our results define the normal distribution of colorectal anatomy in an asymptomatic adult cohort, and may help to facilitate both colonoscopy training efforts and design of novel endoscopic devices. The transverse colon was the major determinant in length differences according to age, sex, and BMI, and was significantly longer in older adults, women, and thinner adults, respectively.

Although the embryology and surgical anatomy of the large intestine is well described, less is known about the precise length and normal distribution of colorectal anatomy in the general population. Most available reports rely on cadaveric, laparoscopic, or barium enema examination, where accurate length assessment is difficult [1–3]. Furthermore, these studies generally pertain to the colon as a whole and do not provide specific information about the different colonic segments. Several studies have compared various anatomic parameters between subjects with successful versus failed or difficult colonoscopic examinations [4–6], but did not aim to determine the normal distribution of colorectal anatomy. Other reports involved either small patient cohorts and focused primarily on the sigmoid colon [7, 8] or did not study a typical Western population [9].

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Compared with cadaveric, surgical, and conventional radiologic approaches, computed tomography colonography (CTC), also known as virtual colonoscopy, represents a more accurate tool for assessing the length and anatomy of the large intestine. The current study aimed to determine the morphologic features of the colorectum within an asymptomatic population undergoing primary CTC examination and to investigate the effect of age, sex, and body mass index (BMI) on total colonic length.

**Patients and methods**

Permission to review the CTC examinations was granted by the institutional review boards at the University of Wisconsin School of Medicine and Public Health and Indiana University-Purdue University Indianapolis/Clarian Health Partners. All patients who underwent primary CTC performed at one tertiary referral center over an 8-month period from May 2007 to December 2007 were eligible to be included in the study. Patients who had a prior incomplete optical colonoscopy or colorectal surgery were excluded. Asymptomatic screening was the overwhelming indication for CTC, with fewer than 3% of primary CTC studies performed for a variety of diagnostic indications. Patient demographics including age, sex, height, and weight were entered into an electronic database. Anatomic features including total colonic length, segmental length, luminal diameter, and number of acute-angle flexures were obtained by CTC, as described below, and entered into the database.

The CTC software used for this study (V3D Colon, Viatronix, Inc, Stony Brook, New York, USA) produces an interactive 3D map of the colon, including an automated centerline that allows for precise in vivo colonic length measurements [6]. All examinations were read by one gastroenterology specialist (MAK) who was specifically trained on this CTC software system for the anatomy measurements, etc., by an expert in CTC (PJP). Assessment of colorectal anatomy was performed without knowledge of the specific demographic data of the patients. Length measurements were recorded for the six segments (cecal, ascending, transverse, descending, sigmoid, and rectum) using the automated centerline along the long axis of the colonic lumen. The cecum was measured from the cecal tip to the level of the ileocecal valve and the ascending colon was measured from the ileocecal valve to the hepatic flexure, where the colon becomes intraperitoneal. The transverse colon was measured from the hepatic flexure to the splenic flexure, where the colon returns to the retroperitoneum. The descending colon was measured from the splenic flexure to the descending-sigmoid junction, where the colon flexes anteriorly and returns to the peritoneal cavity, suspended by the sigmoid mesentery. The sigmoid colon was measured from the sigmoid-descending junction to the rectosigmoid junction. The rectosigmoid junction was determined by the proximal rectal valve, with the rectum extending to the anorectal junction. Colonic distention allowed for measurement of maximal luminal diameter, as well as more reliable length measurements.

Rotational manipulation of the colon map by the reviewer greatly facilitates assessing the number of flexures, which are defined as acute-angle (<90°) bends and are indicative of the degree of colonic tortuosity [6]. Obtuse-angle bends (>90°) were not included in the flexure count. Prone or supine views were used at the discretion of the examiner. The two-dimensional multiplanar reconstruction images were utilized for luminal diameter calculations. Transverse, sagittal, and coronal projections were used as needed to optimize luminal measurements. The cross-sectional luminal diameter measurement was obtained at a representative level where the segment was well distended.

The specific methods for colonic preparation, colonic distention, and multi-detector CT scanning have been described previously [10]. To briefly summarize, the standard bowel preparation consisted of oral magnesium citrate or sodium phosphate, 2% barium, and water-soluble iodinated contrast material (diatrizoate) taken the day before CTC examination. Standardized colonic distention was achieved with automated carbon dioxide (CO2) delivery. The equilibrium pressure for inflow was initially set to 20 mm Hg with continuous CO2 delivery to maintain a pressure up to 20–25 mm Hg throughout the examination [11]. The patient is placed in the left decubitus position for the initial 1–1.5 L of CO2, followed by the right decubitus position for up to 1 L, followed by the supine position until a state of equilibrium is achieved before scanning. Breath hold supine and prone CT acquisitions were obtained on 8- and 16-channel multidetector scanners (GE LightSpeed Series; General Electric Medical Systems, Milwaukee, Wisconsin, USA). CT technique entailed 1.25-mm collimation, 1-mm reconstruction interval, 120 kVp, and low-dose mA with dose modulation.

**Statistical methods**

The effects of age (<60 vs. >60 years), sex (male vs. female), and BMI (≤25 vs. >25) on colonic length, number of flexures, and luminal diameter were examined using Kruskal-Wallis nonparametric tests. Multiple-variable prediction models were developed using a backward-elimination procedure with the P-value for removal set at 0.05. Interactions were examined in the multiple-variable analyses, and only kept in the models when significant. The ranks of the outcomes were used in the multiple-variable models to perform them as nonparametric analyses.

**Results**

The study cohort consisted of 505 adults (266 women, 239 men) undergoing primary CTC evaluation with a mean age of 56.6 ± 7.3 years (Table 1). The mean total colonic length was 189.5 ± 26.3 cm (range, 120–299 cm). Fig. 1 demonstrates a range of colorectal lengths and tortuosity.
The transverse colon was the longest segment on average, followed by the sigmoid colon, which together represent the intraperitoneal portions of the colon (Table 2). These two intraperitoneal segments also demonstrated the widest variability in length, with standard deviations in the 12–14 cm range (Table 2). Using 200 cm, 225 cm, and 250 cm total lengths as somewhat arbitrary threshold values for mild, moderate, and severe elongation (dolichocolon), 126 (25%), 33 (7%), and 8 (2%) adults met these levels, respectively (Fig. 2).

The mean number of acute-angle bends or flexures was 10.9 ± 2.4 (range, 5–19), with the maximum number of flexures also seen in the intraperitoneal segments consisting of the transverse colon (4.7 ± 1.2, range 2–9) and the sigmoid colon (4.4 ± 1.2, range 1–9). As expected, the cecum demonstrated the widest luminal diameter, followed by the rectum and the ascending colon (Table 2). The sigmoid and descending colon had the narrowest luminal diameter.

Although the transverse colon was significantly longer in adults over 60 years of age compared with adults younger than 60 years (57.5 ± 13.4 cm vs. 60.9 ± 13.7 cm, \(P = 0.04\)), the total colonic length did not significantly differ between these two age groups (188.6 ± 26.1 cm vs. 192.9 ± 26.9 cm, \(P = 0.22\)) (Table 3).

The other segments were remarkably similar in average length between the two groups, with mean values within 1 cm for all other segments. On average, females had significantly longer colons than males (193.3 ± 25.6 cm vs. 185.4 ± 26.5 cm, \(P = 0.002\)) (Table 3), as well as significantly longer transverse colons (62.1 ± 13.1 cm vs. 54.0 ± 12.8 cm, \(P < 0.0001\)). Beyond the transverse colon, all other segments were again remarkably similar in length between males and females. Total colon length was significantly shorter for overweight adults (BMI > 25; 187.2 ± 24.9 cm) compared with thinner adults with a BMI ≤ 25 (194.5 ± 28.5 cm) (\(P = 0.005\)) (Table 3). As with age and sex comparisons, the difference in colonic length was again primarily due to differences in transverse colon length. Patient height was not significantly associated with total length (\(P > 0.05\)). Using a multiple-variable regression model, there was a significant interaction between age and sex (\(P = 0.004\)); older males and younger females had the longest total length, followed by older females and then by younger males. BMI was significantly associated with total colonic length after accounting for age and sex (\(P = 0.027\)).

### Table 2: Colorectal length, flexure, and diameter data by segment.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Mean (cm)</th>
<th>SD (cm)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cecum</td>
<td>67.5</td>
<td>13.4</td>
<td>50.0</td>
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<td>Ascending</td>
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<td>7.2</td>
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<td>Transverse</td>
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<td>28.5</td>
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<td>Descending</td>
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<td>8.0</td>
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<td>Sigmoid</td>
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<td>12.9</td>
<td>18.5</td>
<td>91.3</td>
</tr>
<tr>
<td>Rectum</td>
<td>19.5</td>
<td>3.1</td>
<td>7.5</td>
<td>28.3</td>
</tr>
</tbody>
</table>

### Table 3: Colorectal length, flexure, and diameter data by segment, continued.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Mean (mm)</th>
<th>SD (mm)</th>
<th>Minimum</th>
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<tr>
<td>Rectum</td>
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<td>10.6</td>
<td>31.0</td>
<td>104.3</td>
</tr>
</tbody>
</table>

### Discussion

The barium enema has been used previously to assess colorectal anatomy, including estimation of total and segmental colonic lengths and luminal diameters [1,4,7,9]. However, CTC is a much more accurate and reproducible method for assessment of...
this complex 3D structure. Notably, barium enema and fluoroscopic evaluation provide only planar and not volumetric imaging of the colon, which results in artificial foreshortening of segments seen en face. This may explain the shorter average colorectal lengths reported in previous barium enema studies, ranging from 133 cm to 150 cm, compared with the average length of 190 cm as determined by CTC in the current study [1,4,7]. CTC is not only a volumetric examination, it also provides a map that can be easily rotated and manipulated, as well as an automated centerline that allows precise and unperturbed length measurements. Our results were more in line with findings from another CTC-based study that examined anatomic factors predictive of incomplete colonoscopy in a cohort of 200 patients [6]. By combining the patients with complete versus incomplete colonoscopy from that study, the mean total colorectal length was 189 cm and the average number of acute-angle flexures was 10.8, both of which are nearly identical to our study group.

It should be noted that CTC length measurements are also much longer than the corresponding length measurements obtained at optical colonoscopy. This information is valuable for endoscopy trainees, as it ascertains the importance of “unlooping” and scope straightening, which artificially foreshorten the colon. As such, it is important to avoid reporting polyp findings at CTC according to distance from the anorectal junction, as this may cause confusion at subsequent polypectomy. Rather, it is best to communicate polyp location according to segment and provide a 3D map demonstrating the specific polyp location when correlating between CTC and colonoscopy. We did not correlate colon lengths with actual success of cecal intubation or cecal intubation times during colonoscopy. As the subjects of this study were undergoing CTC for colorectal cancer screening, only about 10% of them actually underwent colonoscopy. However, a previous study [6] did correlate anatomic factors at CTC with incomplete colonoscopy.

It is noteworthy that the two major intraperitoneal segments of the colon – the transverse and sigmoid segments – were the longest and had the most flexure points due to redundancy. Given the relative mobility of these two segments on their respective mesenteric ligaments of attachment (i.e. the transverse and sigmoid mesocolons), it stands to reason that excessive redundancy and tortuosity could give rise to more difficult examination at optical colonoscopy (Fig. 1). Presumably, the more fixed extraperitoneal segments of the large intestine do not allow for the same degree of elongation over time, leading to shorter and straighter segments, as well as less variability.

We have described the normal range of various morphologic features of the large intestine using precise CTC measurements, and these values will help to define the normal distribution of in vivo colorectal anatomy. In addition, this information may help to improve the design of the new devices, such as the Aer-O-Scope (GI View Ltd, Ramat Gan, Israel), or the Invendoscope (Invendo Medical, Kissing, Germany), which are under development as alternative colonoscopy platforms. The potential advantages for these technologies include the need for only minimal training of the operator, reduced pain compared with conventional optical colonoscopy, which may alleviate the need for sedation, and the potential for reduced risk of mechanical perforation because of the measured low-level forces used during insertion [12–14]. This could conceivably translate into increased compliance for colorectal screening [15]. However, these devices are fundamentally different from conventional colonoscopes with regard to propulsion and insertion techniques. As the propulsion forces with these devices are exerted at the instrument tip and the devices do not allow for colonic “shortening” or “accordioning” of the colon over the insertion tube, the actual anatomic length of the colon is of even greater relevance to these technologies than it is for traditional optical colonoscopy. In the case of the Aer-O-Scope, which operates with a gas seal between the device and the colonic wall, the diameter and angulation of colonic segments is also highly relevant. We believe that developers of alternative colonoscopy platforms such as Aer-O-Scope and Invendo, as well as colonoscope assist devices such Softscope (Softscope Medical Technologies, Minnetonka, Minnesota, USA), will find these data quite useful.

By studying the effects of age, sex and BMI on total colorectal length, we have noted several interesting observations. In terms of sex, women have significantly longer colons on average. In conjunction with prior hysterectomy, this may contribute to the increased rate of incomplete colonoscopy in women compared with men. In terms of patient age, the transverse colon was significantly longer in adults over the age of 60 years. In terms of body habitus, total colon length was significantly longer in adults who were not overweight (BMI ≤ 25), even after accounting for age and sex differences. This may contribute to the previously reported observation that colonoscopy is more often incomplete in thinner patients [16]. There was significant interaction between age and sex for their effect on total colonic length.

The explanation for colonic length differences according to age, sex, and BMI are likely multifactorial. The impact of dietary and hormonal differences are worthy of consideration. Sadahiro and colleagues previously analyzed segmental length according to age, sex, and physique in a Japanese cohort undergoing barium enema examination [9]. As with our study, the total colorectal length in males was shorter than in females and the length of the colon tended to increase with age. Another report from the UK [1] investigated possible anatomic reasons for causes of technical difficulty in performing optical colonoscopy in women. In this barium enema-based study, total colonic length was significantly greater in women compared with men, despite the smaller stature of women. | Age, years | Sex | BMI | | --- | --- | --- | | ≤ 60 | > 60 | Male | Female | ≤ 25 | > 25 |
| No. of patients | 393 | 112 | 239 | 266 | 160 | 345 |
| Length | | | | | | |
| Mean, cm | 188.6 | 192.9 | 185.4 | 193.3 | 194.5 | 187.2 |
| SD | 26.1 | 26.9 | 26.5 | 25.6 | 28.4 | 24.9 |
| Minimum, cm | 120 | 140 | 120 | 135 | 120 | 123 |
| Maximum, cm | 299 | 286 | 286 | 299 | 299 | 286 |
| P-value | 0.22 | 0.002 | 0.005 |

Table 3 Effect of age, sex, and body mass index (BMI) on total colorectal length.
Our study has limitations with regard to understanding colonic anatomy and the performance of optical colonoscopy and development of alternative colonoscopy platforms. Our measurements were made with patients in both supine and prone positions. The extent to which length and angulations of intraperitoneal segments might change with position changes, such as the left lateral decubitus position commonly used in colonoscopy, is uncertain. However, we suspect there would be little change by position in the basic trends we have observed with regards to which segments are longest and have the most flexures. We did not report luminal diameters at angulations or flexures, or the “lengths” of such angulations, as we found it difficult to standardize such measurements. However, an understanding of the diameter and “tightness” of angulations is potentially relevant to devices such as the Aer-O-Scope and Softscope, which have sections on the device of fixed diameter and length. We hope to develop additional methodology that can quantitatively describe the anatomy of angulations and which would be relevant to understanding the limits of diameter and lengths of rigid sections of devices that can travel through the colons of patients with various demographic features.

In summary, we have described the normal distribution of colorectal anatomy in a large asymptomatic adult cohort using CTC. The effects of age, sex, and BMI on total colorectal length may have important implications for both endoscopic practice and training. Interestingly, the transverse colon was the major determinant in length differences according to age, sex, and BMI, and was significantly longer in older adults, women, and thinner adults, respectively. Our data may also help enhance the engineering of new devices capable of performing hands-off colonoscopy.

**Competing interests:** Dr. Rex is a paid consultant to Invendo Medical.

**References**