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FULL PAPER

CT colonography evaluation of the relationship between colon anatomy and diverticula

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Objectives: In this study, we aimed at investigating the relationship between diverticula and *in vivo* colonic features such as total colon length (TCL), using CTC. We also evaluated polyps, neoplastic lesions and the correlation among them.

Methods: This retrospective study considered a series of patients who underwent CTC in our Hospital from 2010 to 2018. We evaluated TCL, the length of each colon segments and sigmoid colon diameter using dedicated software. We verified the presence of diverticula, polyps and neoplasm and measured the number of diverticula using a five-point class scale, evaluating the colonic segments involved by the disease and the number of diverticula for each segment. A logistic regression model was used to analyse the relationship between diverticula and the patients' age, sigmoid colonic diameter and the length of each colonic segments.

Results: The population finally included 467 patients, 177 males and 290 females (average age of 67 ± 12 ;

range 45–96). The mean TCL was 169 ± 25 cm (range 115–241 cm). Out of the 467, 323 patients (69%) had at least one analyse. The patients with diverticula had a mean TCL significantly shorter than patients without diverticula (164 ± 22 vs 181 ± 27 cm; $p = 0.001$). Among the different variables, sigmoid colon length, sigmoid colon diameter and patient's age were correlated with diverticula ($p < 0.01$). Otherwise there is no association among diverticula, polyps and neoplasm.

Conclusions: The presence of colonic diverticula was significantly inversely correlated with TCL. The TCL was not significantly correlated with polyps and cancers.

Advances in knowledge: The presence of colonic diverticula was significantly inversely correlated with total colon length, and in particular they significantly decreased with increasing colon length; our observation could contribute to the comprehension of diverticula pathogenesis.

INTRODUCTION

Reading CT colonography (CTC) examinations in daily practice is common to come across colonic diverticula considering that diverticulosis is present in approximately 30% of individuals aged 50–59 and 70% of those aged 80 and more.¹ Despite this high incidence, from a personal experience of thousands of CTC exams, we were impressed by an apparent low presence of colonic diverticula in patients with colon longer than average. Few papers were written on this relationship; in 1975, Ewing² first stated that it was very unusual to discover volvulus in a patient known to have diverticular disease, whereas Goulston³ revealed rarity in the incidence of diverticular disease in a survey of hospital admissions at a psychiatric centre in 1976, and a

greatly increased frequency of idiopathic megacolon. More recently, Cuda et al⁴ found an inverse correlation between colon redundancy and diverticulosis based on colonoscopy reports. It is worth noticing that these studies, based on barium enema and colonoscopy, suffer of limitations in evaluating colon anatomy, and colon length in particular.

CTC represents an excellent tool to evaluate colon anatomy, and in particular it provides a number of advantages in measuring colon length and diameter^{5–7} compared to other techniques (barium enema or colonoscopy). Moreover, CTC is also a robust test to detect the presence of colonic diverticula, given its exclusive ability to analyse the whole endoluminal and extraluminal colon.^{8,9}

Thus, the aim of this study is to investigate the relationship between diverticula and colon length with a quantitative analysis, using CTC as diagnostic test. We also evaluated if the colon length and the presence of diverticula are correlated with the presence of colonic neoplasms.

METHODS AND MATERIALS

Population

This retrospective observational study was approved by our institutional review board and written informed consent for CTC was obtained from all patients. To obtain a large patients' cohort, the study included all patients who consecutively underwent CTC at our Hospital¹⁰ from November 2010 and May 2018. Exclusion criteria were any previous colon surgery altering the colon anatomy and the colon length (e.g., right or left hemicolectomy; partial colon resection) and examinations with inadequate distension of colon. Moreover, patients aged 45 or less were excluded to avoid statistical bias. Only the first study was included for those patients who had undergone several CTCs.

Patients underwent CTC for different indications: incomplete colonoscopy, positive FOBT (fecal occult blood test), follow-up of acute diverticulitis, CRC staging, and CRC screening.

CTC protocol

Our protocol have been described previously.¹¹ To summarise, the standard bowel preparation consisted of an oral mild laxative [Movicol, Norgine Italia srl, Milan, Italy], with water-soluble iodinated contrast material (diatrizoate) taken 3 hours before CTC examination as fecal tagging. Colonic distention was achieved with an automated carbon dioxide (CO₂) delivery. Twenty millilitre of hyoscine butylbromide (Buscopan, Boehringer Ingelheim, Florence, Italy) was intravenously injected just prior to colonic distension in 385/467 (82%) patients; 60 patients had contraindications (recent myocardial infarction or glaucoma), whereas 22 refused the drug.

The patient is placed in the left decubitus position for the initial 1.5 L of CO₂, followed by the supine and right decubitus position for up to 1 L, followed by the supine position. Breath hold supine and prone CT acquisitions were obtained on 64-channel multi-detector scanner (LightSpeed; General Electric Medical Systems, Milwaukee, Wisconsin, USA). A third additional lateral scan had been performed in 129/467 patients (28%) to achieve an adequate distension of the sigmoid colon; an alternative lateral scan has been performed in 108/467 patients (23%) not able to lay in the prone decubitus.

Image analysis and colonic segments subdivision

A board-certified radiologist with 15 years' experience in CTC (with about 4.000 CTC cases read) and two residents in radiology with 4 year of experience in CTC evaluated independently the whole colon length and the length and maximum diameter of each colon segments using a dedicated software (Colon V Car; General Electrics; Milwaukee, USA). In case of doubt, the more experienced reader made the final judgement.

This CTC software produces an interactive 3D map of the colon, including an automated centerline that allows precise *in*

vivo colonic length measurements. All the measurements were performed after selecting one data set between supine and prone (or even lateral) where the colon was better distended, avoiding the potential measurement issue of collapsed segments. Colonic segments entirely filled with residual fluid were included on the analysis; in fact the software used allowed a regular measurement of those segments, thanks to an electronic cleansing of tagged residual fluid. To measure length of six colonic segments (cecum, ascending colon, transverse colon, descending colon, sigmoid colon and rectum), we searched for standard transitional points⁶: the cecum was measured from the cecal tip to the level of the ileocecal valve; 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 retroperitoneal. The descending colon was measured from the splenic flexure to the descending-sigmoid junction. The sigmoid colon was measured from the sigmoid-descending junction to the recto-sigmoid junction. The recto-sigmoid junction was determined searching for the proximal Houston valve, with the rectum extending to the anorectal junction. To obtain the length measures, we put bookmarks at the level of these different transitional points, after matching localisation of these bookmarks using multiplanar and 3D colon map, along the centerline (Figure 1).

In literature, the definition of dolichocolon is based on a subjective evaluation; with the aim of evaluate the prevalence of abnormally long colon (dolichocolon), we have introduced a threshold of 215 cm.

We calculated the number of colonic loops, including hepatic and splenic flexures, defined as those with an angle less than to 90°. The maximum transversal diameter for each colonic segment was assessed accordingly.

Using the same software, we verified on 2D and 3D images the presence of at least one diverticulum; in patients with diverticula, we measured the number of diverticula creating a five-point-classes scale (I: ≤5 diverticula; II: 6–15 diverticula; III: 16–30 diverticula; IV: 30–50 diverticula; V: >50 diverticula) that helped us to obtain their better evaluation of diverticula. The colonic segments involved by diverticula has been assessed and number of diverticula for each segment reported.

The more experienced reader evaluated the presence of ≥6 mm colonic polyps and of colorectal cancer.

Statistical analysis

For statistical reason, the group of patients with diverticula (with at least one diverticulum) was defined as case group, whereas those with no diverticula as control group.

In the study, continuous variables were summarised with means and standard deviations, while categorical variables with counts and percentages (Table 1).

Joint study of variables was performed by Mann-Whitney test for quantitative variables and Chi-square test for categorical data.

Figure 1. CTC 2D-coronal views (a-f) and 3D-colon map (g) images in a 52-year-old-man. Putting six marks at different anatomic colonic landmarks using 2D-coronal views, the software measures the length of the six colonic segments and of the whole colon. The patient has a total colon length of approximately 147 cm, with length of rectum, sigmoid colon, descending colon, transverse colon, ascending colon and cecum of 15, 33, 24, 60, 10 and 5 cm, respectively.

To analyse dependence relations between diverticula and other variables (age, sigma diameter, sigmoid colon length, descending colon length, transverse colon length and cecum length), we applied a logistic regression model of diverticula variable on other variables. To select the model, we have performed a step-wise selection: both forward and backward selections brought to the same model. From this model, we deleted ascendant colon length variable, because the p -value of T-test was greater than 10%.

Finally, we studied if there existed some kind of dependence between colon total length and polyps and cancer, using a Chi-squared test.

The statistical analysis was performed with R v.3.3.3.

RESULTS

Patient characteristics

We considered a series of 730 patients who underwent CTC in our Hospital from 2010 to 2018 for different purposes. We excluded 92 patients who had a previous colon surgery; 48 patients due to inadequate distension of colon; 94 patients aged 45 or less, and 29 patients who underwent more than one CTC.

Finally, the population included 467 patients, 177 males and 290 females, with an average age of

67 ± 12 (range 45–96).

Out of 467 patients, 323 patients (69%) had at least one diverticulum. Out of 323 patients with diverticula, 103 were in class I, 83 in II, 88 in III, 39 in IV and 10 in class V.

Sigmoid colon was by far the most involved colonic segment (311/323; 96%), followed by descending colon (158/323; 49%), ascending colon (84/323; 26%), transverse colon (65/323; 20%), and cecum (12/323; 4%).

Colon length and diverticula

Mean colon length was 169 ± 25 cm (range 115–241 cm). Patients without diverticula had a mean colon length significantly longer than patients with diverticula (181 ± 27 vs 164 ± 22 ; $p = 0.001$). (Examples in [Figures 2 and 3](#)).

Detailed information about mean length of the total colon, mean length of different colonic segments and number of the colonic flexures for the two groups (patients with and without diverticula) are described in [Table 1](#).

Twenty-six 26 patients (5.6%) had a dolichocolon ($TCL \geq 215$ cm).

Dependence relations between diverticula and other variables

The relationship between the overall colonic diverticula and other variables such as age, sigmoid colon diameter, sigmoid colon length, descending colon length, transverse colon length and cecum length was assessed using a logistic regression model. Diverticula were significantly correlated with shorter sigmoid colon length, reduced sigmoid colon diameter and overall the shortening of all colonic segments except the rectum and with patients' age ($p < 0.01$) ([Table 2](#)).

Colon length and colorectal polyps and cancers

Out of 467 patients, 89 (19%) had at least one 6 mm polyp, and 24 (5%) had a colorectal cancer.

The TCL was not significantly correlated with polyps and cancers ($p = 1$); moreover, there was not any correlation between the presence and number of these lesions and diverticula.

DISCUSSION

The main result of our study demonstrates that the presence of colonic diverticula was significantly inversely correlated with total colon length; in particular, we found that diverticula decrease significantly as the colon length increases.

Figure 2. CTC 2D-axial view (a), coronal view (b) and 3D-colon map (c) in a 55-year-old woman. The patient has multiple (11) flexures, with a total colon length of approximately 217 cm. The axial and coronal 2D views with 3D-colon map show the absence of colonic diverticula.

These results rely on a quantitative analysis allowed by CTC in a large cohort of patients (about 500), whereas the few previous reports,²⁻⁴ which focused on the same topic, based their conclusions on barium enema and conventional colonoscopy findings. It is well known that CTC is an excellent test to evaluate colon anatomy as it provides several advantages in measuring colon length and diameter when compared to barium enema and colonoscopy.⁵⁻⁷

In particular, using barium enema and colonoscopy, the definition of a redundant colon or dolichocolon is subjective, owing to colonic tortuosity and to the presence of additional flexures.

Moreover, our quantitative analysis gave us the opportunity of demonstrating that an inverse relationship between colon length

and diverticula follows a linear path; our initial idea was that this dependence could be valid only for abnormally long colons.

It is not easy to explain the rationale of this inverse dependency between diverticulosis and colon length.

Studies focused on the pathogenesis of diverticula suggested a pivotal role for colonic segmentation and high intraluminal colonic pressures.^{12,13} In case of abnormally long colon, we can assume a lower level of contraction and a reduced effect of endoluminal pressure peaks on the colonic walls, protecting patients from developing diverticula.

By evaluating the impact of different variables by using a logistic regression model, we found that sigmoid colon length, sigmoid

Figure 3. CTC 3D-colon map view (a) and 2D-axial view (b) in a 75-year-old woman. The patient has multiple diverticula located in the whole colon. The total colon length is approximately 139 cm.

Table 1. This table summarise results in terms of mean length of the total colon, mean length of different colonic segments and number of the colonic flexures for the two groups: patients with diverticula and control group (without diverticula)

	Total/Mean	Pts with Diverticula	Control group	p-Value
Sample size (%)	467	323 (69.2)	144 (30.8)	
Male (%)	177 (37.9)	122 (37.8)	55 (38.2)	1
Age, years (mean $\pm$ SD)	67 $\pm$ 12	69 $\pm$ 12	63 $\pm$ 12	<0.01
Total colon length, cm (mean $\pm$ SD)	169 $\pm$ 25	164 $\pm$ 22	181 $\pm$ 27	<0.01
Cecum length, cm (mean $\pm$ SD)	4 $\pm$ 1	4 $\pm$ 1	5 $\pm$ 1	<0.01
Ascending colon length, cm (mean $\pm$ SD)	21 $\pm$ 5	21 $\pm$ 5	22 $\pm$ 6	0.01
Transverse colon length, cm (mean $\pm$ SD)	56 $\pm$ 13	55 $\pm$ 12	59 $\pm$ 14	<0.01
Descending colon length, cm (mean $\pm$ SD)	22 $\pm$ 7	22 $\pm$ 6	24 $\pm$ 8	0.01
Sigmoid colon length, cm (mean $\pm$ SD)	51 $\pm$ 14	48 $\pm$ 13	57 $\pm$ 16	<0.01
Rectum length, cm (mean $\pm$ SD)	14 $\pm$ 2	14 $\pm$ 2	14 $\pm$ 2	0.97
Sigmoid colon diameter, mm (mean $\pm$ SD)	33 $\pm$ 9	31 $\pm$ 8	37 $\pm$ 9	<0.01
Number of colonic flexures (mean $\pm$ SD)	7 $\pm$ 2	7 $\pm$ 2	8 $\pm$ 2	<0.01

colon diameter and patients' age were significant predictors for diverticula.

The key role of the sigmoid colon in the whole colonic length made this result quite predictable, taking into account its intra-peritoneal nature and previous results. In fact, in 1975, Ewing² wrote "we know that when redundancy of the colon is present, the sigmoid is always the most seriously affected part", whereas more recently Phillips et al¹⁴ reported that the length of the rectosigmoid segment always predicted total colonic length.

The main impact of our result is speculative, namely a contribute in the comprehension of pathogenesis of left-sided diverticulosis, the most common benign colonic disease of western world. In fact, the demonstration of an inverse correlation

between redundant colon and diverticulosis should favour further studies investigating its underlying mechanisms (e.g., a loose tone of specific layers of the muscularis propria of the colon). The combination of these data may shed light on the pathogenesis of diverticulosis helping to prevent its development and complications.

From the diagnostic and clinical point of view, the depiction by means of CT or CTC of a shortened colon in absence of clearly visible diverticula may represent a risk for diverticula development or may arise the suspicion of CT or CTC false negative for diverticula. Vice versa, the detection of diverticula in a redundant colon could suggest a different pathogenesis or a different risk of complications. However, both scenarios should be verified in further *ad hoc* studies.

Table 2. Relationship between the overall colonic diverticula and other variables such as age, sigmoid colon diameter, sigmoid colon length, descending colon length, transverse colon length and cecum length assessed using a logistic regression model. It is clear that all the variables are significant (with all P-values less than 0.02)

	Estimate	Std. Error	z value	Pr(>z)
(Intercept)	1,03	0,12	8,5	<0.01
Cecum length	-0,27	0,12	-2,35	0.02
Transverse colon length	-0,31	0,12	-2,56	0.01
Descending colon length	-0,26	0,11	-2,36	0.02
Sigmoid colon length	-0,36	0,13	-2,91	<0.01
Sigmoid colon diameter	-0,57	0,13	-4,44	<0.01
Patients age	0,5	0,12	4,01	<0.01

In literature, there are a few papers focused on colon length based on *in vitro*^{14–17} and *in vivo* reports^{5–7,18–20}; these studies report a huge variability with a mean colon length ranging from 131 to 169 cm for the cadaveric ones to 109–189 cm for evaluations based on imaging. The variability of these values can be explained on the basis of several factors: *in vitro* versus *in vivo* studies; different methods employed for the measurements and conflicting definitions for the colonic segments.

The mean total colon length (169 cm) in our study is very similar to the one described by Eickhoff et al.⁵; in fact, they evaluated 100 subjects, who underwent CTC for screening purposes, revealing a mean colon length of about 167 cm. Conversely, Kashab et al.⁶ studying 505 asymptomatic subjects with CTC discovered a significantly higher mean length (189 cm). A possible explanation of this discrepancy could be found by analysing differences between the two populations. Kashab⁶ gathered patients from different ethnic groups, living in the USA, whereas 98% of our patients' population was Caucasian.

Our observation that the total colon length and colorectal lesions (polyps and cancers) are completely independent, indirectly strengthens the fact that colonic diverticula do not represent a risk factor for colonic lesions.^{21–23}

Dolichocolon and its aetiology have been object of interest in the first half of last century. From results of some old reports^{24–26} and of more recent studies,^{27–29} dolichocolon can be mainly described as a congenital anatomic variant, causing constipation and colonic volvulus. However, some authors^{29–31} reported that function and fecal transport may also promote some changes in colonic length.

The definition of dolichocolon is unclear and it has never been associated to precise measurements; its prevalence is not known also considering that population-based investigations have not been made, as suggested by studies et al.²⁹

Assuming a threshold of 215 cm to define a dolichocolon, its prevalence is about 6%, and this result deserves to be further evaluated.

We acknowledge the following limitations in our study.

Firstly, CTC is a test performed for screening purposes or for different reasons (*i.e.*, to evaluate patients with contraindications to conventional colonoscopy or to study patients with diverticular disease) in a clinical setting. In our experience, dealing with CTC in a clinical scenario and excluding patients younger than 45, the average age was about 67. For this reason, it was impossible to correlate anatomic colonic features with a large age group spectrum, and in particular with younger people.

A second potential limitation of our cohort reflects an over exposition to diverticula, that is due to the increasing number of patients referred to CTC in the follow-up of acute diverticulitis; therefore, the estimated prevalence of diverticula is biased. Conversely, keeping in mind the aim of this study, the over exposition to diverticula could have given more robustness to our results. The last limit was the single reading for CT evaluation, however all measurements reported in our study were software-guided so the importance of the single reading was kept to a minimum.

In conclusion, we found that diverticula significantly decrease with increasing colon length.

Our observations could contribute to the understanding of diverticula pathogenesis together with a further in-depth analysis meant to investigate underlying mechanisms of this inverse correlation and other relationships (*e.g.*, between colonic length and wall elasticity and/or endoluminal colonic pressure).

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