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Perfusion CT assessment of the colon and rectum: Feasibility of quantification of bowel wall perfusion and vascularization

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ABSTRACT

The aim was to determine the feasibility of vascular quantification of the bowel wall for different anatomical segments of the colorectum. Following institutional ethical approval and informed consent, 39 patients with colorectal cancer underwent perfusion CT. Blood flow (BF), blood volume (BV), mean transit time (MTT), and permeability surface area product (PS) were assessed for different segments of the colorectum: ascending, transverse, descending colon, sigmoid, or rectum, that were distant from the tumor, and which were proven normal on contemporary colonoscopy, and subsequent imaging and clinical follow up. Mean (SD) for BF, BV, MTT and PS for the different anatomical colorectal segments were obtained and compared using a pooled *t*-test. Significance was at 5%. Assessment was not possible in 9 of 39 (23%) patients as the bowel wall was ≤5 mm precluding quantitative analysis. Forty-four segments were evaluated in the remaining 30 patients. Mean BF was higher in the proximal than distal colon: 24.0 versus 17.8 mL/min/100 g tissue; $p = 0.009$; BV, MTT and PS were not significantly different; BV: 3.46 versus 3.15 mL/100 g tissue, $p = 0.45$; MTT: 15.1 versus 18.3 s; $p = 0.10$; PS: 6.84 versus 8.97 mL/min/100 tissue, $p = 0.13$, respectively. In conclusion, assessment of bowel wall perfusion may fail in 23% of patients. The colorectum demonstrates segmental differences in perfusion.

1. Introduction

The blood supply of the large bowel is complex. The proximal colon, derived from the midgut, receives its blood supply via mesenteric arcades from branches of the superior mesenteric arteries. The distal colon and rectum, derived from the hindgut, receives its supply from the inferior mesenteric artery with a contribution from the internal iliac artery. Changes in bowel wall blood flow occur as part of normal physiological regulation but will also occur with disease. For example, blood flow may be elevated in inflammatory bowel disease, or lowered in ischemic colitis. There has been interest in *in vivo* quantitative assessment of small [1] and large bowel blood flow [2–5] using CT, for example, assessment of diverticulitis [2] and colorectal cancer [3–5] as CT is commonly performed in the acute setting, and is relatively non-invasive compared to methods, such as laser Doppler flow-meter assessment during optical colonoscopy [6].

To date there has been little data of the feasibility of bowel wall assessment or range of bowel wall measurements in the absence of pathology. 'Normal' small bowel [1] and rectal perfusion [3,4] have been assessed in a small number of patients. However studies have not established how feasible this is, and whether values differ across the different anatomical segments of the colorectum. Thus our aim was to determine this and the values of blood flow, blood volume and vascular leakage for different anatomical segments of the normal colorectum.

2. Materials and methods

2.1. Patients

39 patients (18 male, 21 female, mean age 68.6 years) with a proven colorectal cancer attending for a prospective perfusion CT study of the primary tumor from 2003 to 2005, and in whom normal large bowel was also visible on the perfusion CT study were analyzed retrospectively. All visible bowel segments that were distant from the tumor site (>15 cm), and demonstrated no evidence of mural thickening, abnormal enhancement, pericolonic inflammatory change, or a synchronous tumor on the accompanying diagnostic portal venous phase abdominal-pelvic CT were selected. All patients underwent contemporary optical colonoscopy which

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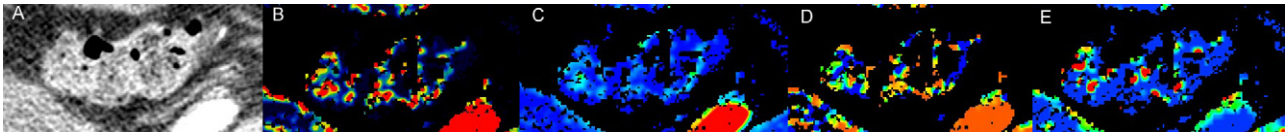

Fig. 1. Contrast enhanced image (A) of the sigmoid colon and corresponding blood flow (B), blood volume (C), mean transit time (D) and permeability surface area product (E) maps shown.

confirmed that there was no evidence of abnormality or synchronous tumor in the evaluated segments. Clinical case note review confirmed that these evaluated segments were disease-free 6 months after the initial examination. All patients were fasted for 4 h prior to the perfusion CT. No patient had undergone colonic cleansing or air insufflation.

2.2. Perfusion CT

The perfusion CT study was performed on a 4 four-detector row CT scanner (Lightspeed Plus; GE Healthcare Technologies, Waukesha, WI, USA). 20 mg of the spasmolytic hyoscine butylbromide (Buscopan; Boehringer Ingelheim, Ingelheim am Rhein, Germany) were administered intravenously to all patients immediately prior to data acquisition, via an 18G cannula sited in the antecubital fossa, to minimize peristalsis during acquisition. An abdominal band restraint was used to minimize abdominal wall excursion. A limited planning abdominal or pelvic study was performed initially without intravenous contrast in order to identify the tumor using the following parameters: 120 kV, 180 mA, 0.6 s rotation speed, slice collimation 10 mm, scan field of view (SFOV) 50 cm, matrix 512 mm × 512 mm. The dynamic study was obtained at 1 s intervals using a 'cine mode' acquisition (120 kV, 60mA s) 5 s following the start of intravenous injection of 100 mL iopamidol 340 (Niopam 340, Bracco, Milan, Italy); 5 mL/s via a pump injector for a total duration of 65 s.

2.3. Image analysis

The perfusion CT study was analyzed using commercial perfusion software based on modified distributed parameter analysis (Perfusion 4.0; GE Healthcare Technologies, Waukesha, WI, USA) on a commercial workstation (Advantage 4.4, GE Healthcare Technologies, Waukesha, WI, USA). The first of the four 5 mm axial sections was uploaded into the software package. A processing threshold between 0 and 120 Hounsfield units (HU) was selected. An arterial input was defined by using a mouse to place a circular ROI, 10 mm^2 in area, within the best-visualized artery on the selected image, either the aorta, iliac, or femoral arteries, and saved within the software for identical placement in subsequent analyses.

A smoothed arterial enhancement-time curve was displayed by the software, and from the resulting parametric maps produced by the software (Fig. 1), mean parameter values were obtained for the bowel wall by delineating a ROI around the entire visible colonic or rectal wall taking care not to include surrounding fat or intraluminal gas (mean ROI size: 244 mm^2; range 68–445 mm^2) (Fig. 2). Analysis was repeated in the same manner for the remaining three 5-mm axial sections. A mean value was recorded for each normal bowel segment evaluated by averaging values from all four 5mm-slices analyzed. The quantitative parameters, blood flow (BF), blood volume (BV), mean transit time (MTT) and permeability surface area product (PS), were recorded in each patient.

For the purpose of this study, the segments were defined anatomically as follows: (1) the ascending colon was the colonic portion from the ileocecal valve to the midpoint of the hepatic flexure; (2) the transverse colon was the colonic portion between the midpoints of the hepatic and splenic flexures; (3) the descending colon was the colonic portion from the midpoint of the splenic flexure to the pelvic brim; (4) the sigmoid colon was the colonic portion from the pelvic brim to the level of the acetabular roof; (5) the rectum was the portion from the anorectal junction to the level of the acetabular roof.

2.4. Statistical analysis

The mean and standard deviation (SD) of BF, BV, MTT and PS were determined for the ascending colon, transverse colon, descending colon, sigmoid colon and rectum. Data normality was tested using Shapiro–Wilk. The vascular parameters for the proximal (ascending and transverse segments) and distal (descending, sigmoid and rectum) colorectum were compared using two-sample *t*-testing. Statistical significance was at 5%.

3. Results

9 of 39 patients were excluded as the bowel wall was ≤5 mm thick. 44 bowel segments were >5 mm in the remaining 30 patients. 35 of 44 (79.5%) visible segments were analyzed successfully: ascending colon (5), transverse colon (5), descending colon (8), sigmoid (11), rectum (6). Analysis of the following visible segments was unsuccessful: ascending colon (1), transverse colon (4), and descending colon (4). Analysis of at least one bowel segment was possible in each of the 30 patients.

Parameter values for the individual colorectal segments are summarized in Table 1 and Fig. 3. Mean BF was higher in the proximal than distal colorectum (24.0 versus 17.7 mL/min/100 g tissue, $p = 0.009$). Mean BV was higher, MTT shorter, and PS measurements lower for the proximal colon but this was not statistically significant

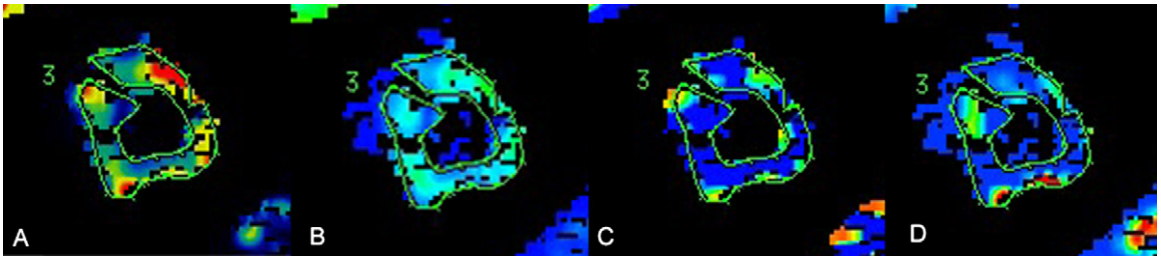

Fig. 2. Region of interest placement shown for the descending colon which is propagated on the blood flow (A), blood volume (B), mean transit time (C) and permeability surface area product (D) maps.