CT assessment of right colonic arterial anatomy pre and post cancer resection – a potential marker for quality and extent of surgery?

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Abstract

Background: There is conflicting opinion as to the optimum extent of resection for right sided colonic cancer, which is currently graded by pathological analysis of the resected specimen. It is not known if CT analysis of residual post-resection arterial stump length could be used as an alternative in vivo marker for extent of mesenteric resection. Ileocolic artery stumps have been demonstrated previously on CT after right hemicolectomy, but only in the early post-operative period.

Purpose: To analyze pre-operative right colonic arterial anatomy using portal venous colorectal cancer staging CT and subsequently determine if post-resection arterial stumps (a potential in vivo marker of surgical resection) could be consistently identified using routine follow up CT scans many months after cancer resection.

Material and Methods: A retrospective analysis of routine staging and follow-up CT scans for 151 patients with right sided colorectal cancer was performed. Pre-operative right colonic arterial anatomy and post-operative arterial stumps were analyzed and measured.

Results: Pre-operative ileocolic (98.8%), middle (94.7%) and right colic artery (23.8%) identification was comparable to catheter angiogram studies. Post-operative ileocolic stumps were consistently demonstrated (88.3%) many months (average 2 years and 42 days) after resection and were significantly longer than expected for a standard D2 resection (paired t-test, $t(127)=-11.45$, $p=<0.001$).

Conclusion: This is the first study to successfully demonstrate ileocolic arterial stumps many months (and years) after cancer resection using routine portal venous CT. Further prospective research should assess whether arterial stumps can be used as an in vivo marker of surgical quality and extent.

Key words: Abdomen/GI, CT – Quantitative, Large Bowel, Arteries, Surgery, Neoplasms-Primary

Introduction

Although accepted surgical techniques have been developed for the resection of rectal cancer since the description of total mesorectal excision (1,2), there is conflicting opinion as to the optimum extent of resection for right sided colonic cancer regarding tumor recurrence rates, patient survival and associated surgical morbidity (3,4). Traditional right hemicolectomy for colon cancer involves ileocolic arterial ligation to the right of the superior mesenteric vein (SMV) - so called 'D2' resection (5). However, central lymph node metastases around the origin of the ileocolic artery have been reported in up to 11.1% of patients (6). Certain groups therefore advocate radical resections (complete mesocolic excision with central vascular ligation (CME & CVL) or a 'D3' resection) with arteries ligated at their origin from the superior mesenteric artery (SMA) (4,7).

Adding to the complexity of comparing different surgical techniques is the variable vascular anatomy of the right colon. Only 23.8% of cases conform to a 'classic' middle, right and ileocolic arterial pattern; variation in vessel presence and origin is the norm (8-10). Arteries supplying the right colon must also cross the superior mesenteric vein (SMV), by either an anterior or posterior route (11), with variations in vessel crossing affecting lymph node distribution (12).

Currently, pathological evaluation of the resected specimen is the only way to evaluate the extent and quality of resection. It is not known if CT can be used as an alternative in vivo modality to estimate the extent of mesenteric tissue left behind after right hemicolectomy. The colonic mesentery consists mainly of fat, connective tissue, lymph nodes and vessels. MDCT can accurately map small caliber mesenteric vessels (13) and a prior CT study has successfully analyzed right colonic arterial to SMV anatomy and crossing distances (14). The ileocolic artery is routinely ligated during right hemicolectomy and assessment of post-operative stump length would appear to be a reasonable marker for the amount of residual mesentery post-resection. Spasojevic et al. were the first to successfully identify arterial stumps via CT after right hemicolectomy. In the early post-operative period they successfully identified ileocolic and right colic stumps in the majority of cases (15). It is not known if arterial stumps can still be visualized by CT in the months and years thereafter. The aim of this pilot study was to identify right colonic arterial stumps on standard portal venous follow up CT scans performed many months after resection, and via analysis of pre-operative right colonic arterial anatomy from staging CT scans compare stump length to that expected after a D2 resection (with the ilecocolic artery ligated to the right of the SMV).

Material and Methods

The study involved the retrospective analysis of CT scans performed on patients with right sided colon cancer using scans from the picture archiving and communications system (PACS) in a large teaching hospital. No additional imaging was involved and therefore ethical approval was waived.

Patient selection

Cases were identified by searching the local Radiology Information System (RIS) for all patients undergoing chest, abdomen and pelvis (CAP) CT as follow up for right-sided colorectal cancer in a 12 month period. Patients at varying stages of follow-up (between initial staging and final five year follow up scan) were identified. Patients were included if they had a primary right colonic tumor located lateral to the ligamentum teres, available demographic data, at least one pre-operative and one post-operative CT and had undergone a D2 lymphadenectomy (as per standard UK practice).

CT protocols

The majority of CT scans were performed on a Siemens Somatom Definition 64 (Siemens Medical Systems, Erlangen, Germany) slice scanner using a pitch of 1.4, tube voltage of 120 kVp and quality reference mAs of 180. A minority of scans were performed on two other CT scanners, a Siemens Sensation 64 slice scanner and a GE Lightspeed VCT 64 (GE Healthcare, Milwaukee, WI, USA) slice scanner. A standard colorectal cancer staging / follow up protocol was used which involved 1000 mL of oral water prep over 1 hour and a fixed injection of 100mL of iodinated contrast (Visipaque 270mgI/mL, GE Healthcare, Cork, Ireland) at 3mL/s using a power injector. Imaging was performed in the portal venous phase at a fixed delay of 65 seconds. Datasets were reconstructed at varying slice thicknesses with the majority being 2-3mm (92 out of 151 cases). In 48 cases the reconstructed slice thickness was 5mm and in 11 cases CT colonography was used for staging with a slice thickness of 1mm.

Data collection

CT scans were analyzed using standard axial and coronal reformats from the PACS system using inbuilt three-dimensional image visualisation and analysis tools (VOXAR 3D version 6.4, Toshiba Medical Visualisation Systems Europe, Zoetermeer, The Netherlands). Volume rendered images were created via InSpace (Siemens Medical Solutions, Malvern, USA). Each pre-operative staging CT was assessed and where possible the presence and orientation of the right, middle and ileocolic arteries and their relation to the superior mesenteric vein were recorded. Vessel crossing distances were measured using a caliper tool (Fig. 1). The distance from colic artery SMA origin to where the vessel emerges to the right of the SMV was labelled 'expected stump length' – i.e. the expected post-surgical stump length given a standard D2 resection.

For each patient, all available post-resection CT scans were reviewed (by a post fellowship radiology registrar) to determine which best displayed the post-resection arterial stumps (i.e. thinnest slices, best contrast resolution). A stump was only positively identified as either a visible vessel (which corresponded to the location of the colic artery on the pre-operative study) or a visible vessel terminating in a surgical staple. When successfully identified, arterial stump presence and orientation were documented and stump lengths were measured using a caliper tool. This process was repeated in 20% of cases by a second blinded reviewer (a consultant gastro-intestinal radiologist) to determine inter-observer variability.

Data analysis

Quantitative analysis of post-resection arterial stump lengths was performed using SPSS (v16.0, Chicago, IL, USA). Numerical data was tested for normality using the Shapiro-Wilk method. Subsequently data were analyzed using a paired t-test. P-values less than 0.05 were considered significant. Inter-observer variability was measured using Kappa statistics and Bland-Altman plots.

Results

From the RIS search, 151 patients fulfilled the inclusion criteria and their CT scans were analyzed. The mean elapsed time between the pre-operative staging CT and the most recent analyzed post-resection CT scan was 2 years and 42 days (range 12 days to 2428 days).

Pre-operative right colonic artery anatomy

The classic pattern with three distinct right-sided arteries originating from the SMA was present in only 33 cases (21.9%) with a definitive right colic artery only identified in 23.8% of cases (Table 1). For an extra 27 cases a large branch of the ileocolic or middle colic artery was seen to pass to the ascending colon (Fig. 2). Although CT slice thicknesses varied (between 1mm to 5mm) right colonic arterial anatomy could still be identified on the thicker slice scans (Fig. 3). The average anticipated stump length after a standard D2 resection was 14.4 (SD 6.4) mm for the ileocolic artery (range 0 – 40mm). Mean anticipated ileocolic stump length was significantly longer for arteries crossing anterior (16.1mm), rather than posterior (13.0mm), to the SMV (paired t-test, $t(49) = -2.577$, $p=0.014$).

Post-operative arterial stumps

In all the cases where an arterial stump was positively identified, it was seen as a thrombosed vessel originating from the SMA corresponding to the anatomical location of the vessel on the pre-operative CT. An unexpected finding, seen in multiple cases where the vessel did not terminate in a metallic surgical clip, was a small soft tissue attenuation nodule at the distal end of the stump. This was termed a 'stump granuloma' and potentially represents local soft tissue reaction to surgical suture material in cases where the vessel was tied off (Fig. 4a and b).

Ileocolic stumps

In six cases a limited right hemicolectomy was performed. Three patients had metastatic disease at presentation, but subsequently underwent surgery for acute obstruction or persistent anemia. One patient underwent a limited resection due to severe medical co-morbidity. In two cases malignancy was unsuspected at the time of operation and a limited ileocecal resection was performed for appendicitis. The long ileocolic artery stumps found in these cases were not included in the data analysis. Of the remaining 145 cases, post-resection ileocolic artery stumps were demonstrated in 128 patients (88.3%) (Table 1). Ileocolic stumps were identified as a visible vessel terminating in a surgical clip in 62 cases (48.4%), and as a visible vessel (+/- stump granuloma) alone in 66 cases (51.6%).

There was a large variation in ileocolic artery stump lengths which ranged from 2.5 – 74.3mm (mean 28.1, SD 13.5 mm). Mean arterial stump length (28.1mm) was significantly longer than anticipated stump length (14.4mm) (paired t-test, $t(127)=-11.45$, $p=<0.001$). The direction of crossing between the ileocolic artery and the SMV (either anterior or posterior) showed no significant relationship with stump length (paired t-test)

$t(42) = -0.54$, $p = 0.957$).

Middle and right colic stumps

Middle colic and right colic artery stumps were only demonstrated in 7 (4.8%) and 8 (5.5%) of cases respectively (mainly when extended or sub-total colonic resections were performed). In many cases these vessels were not routinely ligated for a standard right hemi-colectomy. Further data analysis was not performed in view of the small sample size.

Inter-observer variability

There was perfect agreement on the presence and orientation of the ileocolic artery (Kappa 1.00, 95% CI 1.00, 1.00) and excellent agreement for the middle colic artery (Kappa 0.93, 95% CI 0.808, 1.00). There was only fair agreement (Kappa 0.37, 95% CI -0.160, 0.894) on the presence and orientation of the right colic artery.

A Bland Altman plot showed a clinically acceptable level of inter-observer agreement for quantitative vessel measurements (95% limits of agreement +6.3mm, -6.7mm). Variability in vessel measurement did increase with length of vessel measured.

Discussion

This pilot study has shown that routine staging portal venous CT can reliably demonstrate the presence of the ileocolic and middle colic arteries and their relationship to the SMV with comparable results to other CT, cadaver and catheter angiogram studies (8,10,11,14,16). Although a right colic artery was identified in 23.8% of cases, which is within the range of other published studies (8-10), there was only fair inter-observer agreement for its presence and orientation. It is acknowledged there is a significant degree of error in identifying these small caliber vessels using thicker slice CT scans.

Currently a Norwegian group are investigating whether pre-operative mapping of the right colonic arteries via CT can aid in radical right colonic resections (17). These are advocated by groups in Europe ('CME and CVL') (4,18,19) and for stage II and III disease in Japan ('D3 resection') (7) employing a strategy of 'mesocolic' plane resection with vessel ligation as close as possible to their origin to maximize lymph node yield (20). Pathology-based evidence suggests that these radical resection techniques yield an oncologically superior specimen (21) and may show a survival benefit at five years for stage III disease (22). This has been further supported by a recent population based study demonstrating improved 4 year disease free survival rates with complete mesocolic excision over conventional surgery (23).

There is no current evidence for the benefit of radiological assessment of post resection arterial stumps as an 'in vivo' marker for extent of surgical resection. This is the first study to show that ileocolic arterial stumps can be successfully identified in the majority of patients (88.4%) via follow-up CT scans months, and in many cases, years after the colonic resection. This would allow stump analysis to be performed on routine colorectal cancer follow up CT without the need for additional imaging. Post-operative ileocolic stump length was significantly longer than anticipated stump length (for a standard D2 resection), as was found by a prior study in the early post-operative period (15). There was a large variation in post-resection ileocolic stump length (range 2.5 - 74.3mm, mean 28.1mm, SD 13.5 mm); these results correlate with a pathological study grading colonic resection specimens at our institution, which showed a wide variation in the plane and extent of surgical resection for right colonic tumors (21). This may also explain why we found no relationship between direction of ileocolic artery to SMV crossing and stump length. Anterior or posterior SMV crossing is likely to be of more relevance when stumps are very short, such as after central D3 ligation, which is not routinely performed at our institution.

This pilot study does have several limitations, as it is retrospective in design and we have not evaluated scans in comparison with a gold standard such as surgical resection quality. The measurement of vessel crossing distances and post resection arterial stump lengths from CT scans (with slice thicknesses up to 5mm) inevitably incurs a degree of error and post resection stumps are likely to thrombose and contract with time. Patient body mass index has been shown to affect vessel length (20) and differing colonic distension could alter vessel morphology between scans. Imaging was performed on several CT scanners using fixed contrast injection rates and scan timings, with varying slice thicknesses that were not optimized to aid stump identification. A modified CT protocol with post processing to routinely generate 1mm slice thickness datasets could significantly improve accuracy. An optimized contrast media policy based on patient body weight and cardiac output (bolus tracking) may also be of benefit to analyze vascular anatomy. This could potentially be offered without increasing patient dose. It should also be remembered that arterial stump length only reflects one aspect of the extent of surgical dissection; the theoretical advantages of a short stump would be wasted if tissue planes were damaged and tumor spilled. It is yet to be determined if analysis of arterial stump length will be of value as a marker for extent and quality of surgical resection.

In conclusion, this pilot study has successfully demonstrated that post resection ileocolic arterial stumps can be identified many months (and years) after right hemicolectomy using routine portal venous CT. As part of the ongoing GLiSten trial (which is assessing the role of 5-aminolevulinic acid to highlight malignant nodes intro-operatively) we aim to prospectively compare stump length to quality of mesenteric resection, lymph node yields and tumor recurrence rates to determine if stump analysis can augment pathological grading of specimens as an in vivo marker for quality and extent of surgery.

Declaration of Conflicting Interests:

The Authors declare that there is no conflict of interest

Funding

This short report received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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Figure Legends

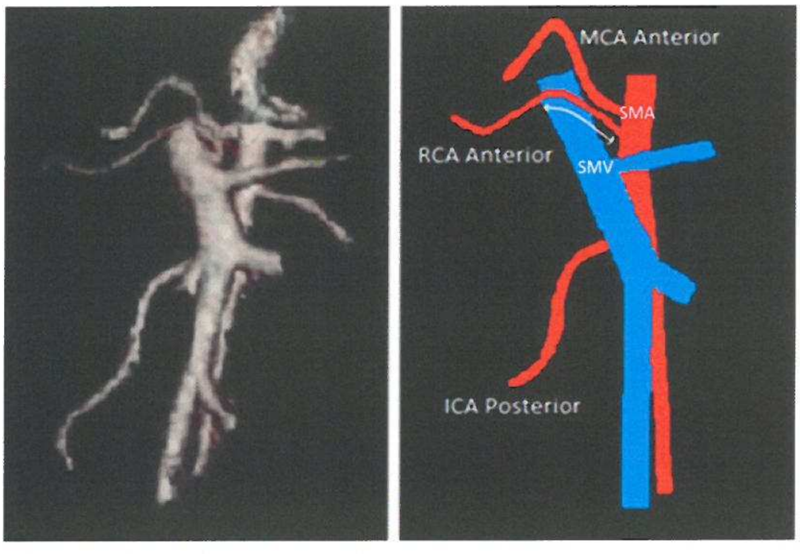

Fig. 1: Volume rendered (VR) image showing middle colic artery (MCA) passing anterior to the SMV, right colic artery (RCA) passing anterior to the SMV and ileocolic artery (ICA) passing posterior to the SMV. Expected stump length is the distance from the vessel SMA origin to the right side of the SMV (white arrow).

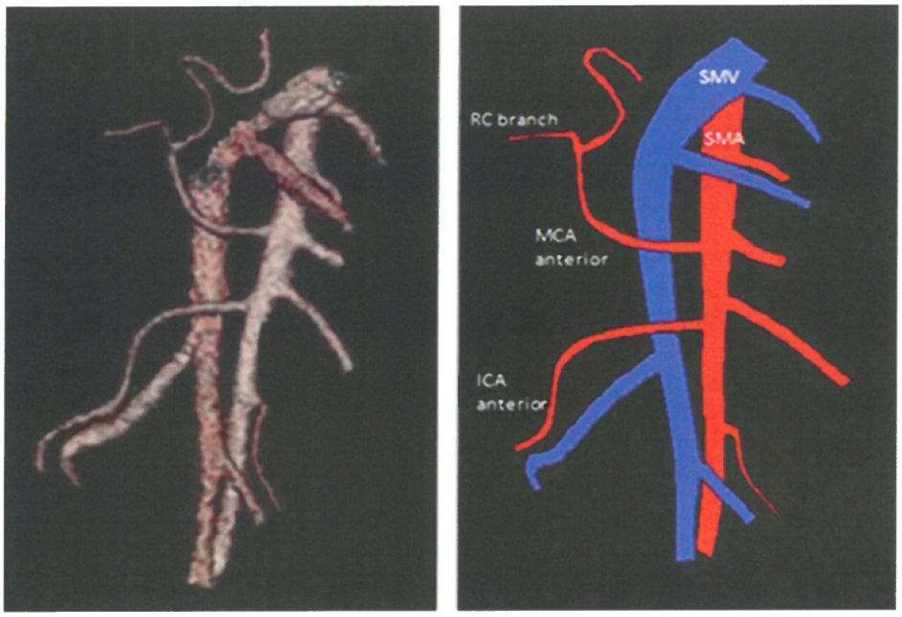

Fig. 2: VR image showing middle colic and ileocolic arteries passing anterior to SMV. A right colic branch passing to the ascending colon was seen to originate from the middle colic artery. Note excellent image quality using 1mm slice thickness CT.

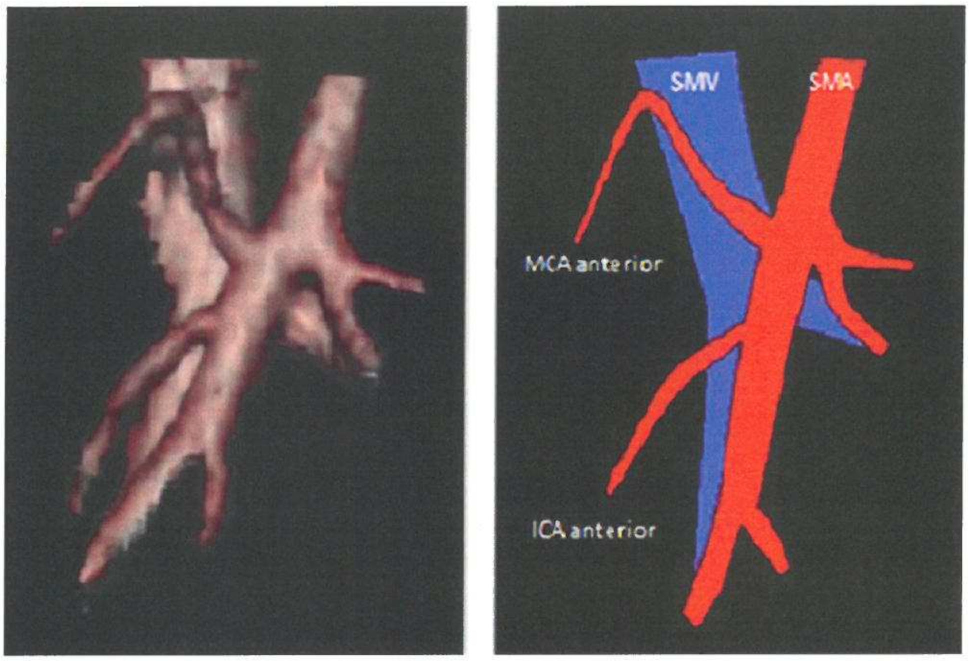

Fig. 3: VR image showing middle colic and ileocolic arteries passing anterior to the SMV. Reconstructed from 5mm slice thickness CT scan. Note that although image resolution is poorer than other VR images, vessels can still be easily identified.

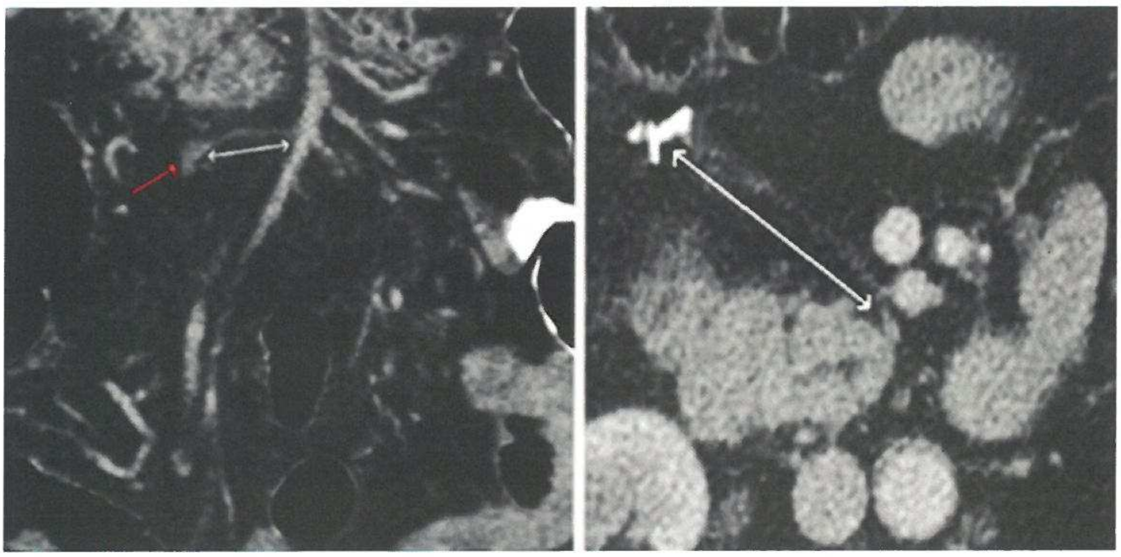

Fig. 4: **a** (Left image) Coronal reformat showing ileocolic stump (white arrow) with stump granuloma (red arrow). **b** (Right image) Axial image showing ileocolic stump coursing to metallic high tie clip (white arrow).

Table 1: Summary of pre-operative anatomy and post-operative stump analysis

	Ileocolic artery	**Middle colic artery**	**Right colic artery**
Identified on pre-op CT	149 (98.8%)	143 (94.7%)	36 (23.8%)
Crossing anterior to SMV	50 (33.6%)	140 (97.9%)	33 (91.6%)
Crossing posterior to SMV	98 (65.8%)*	2 (1.4%)*	2 (5.5%)*
SMV crossing distance (expected stump length) (mean & range)	14.4mm (0 – 40mm)	11.4mm (0 – 34mm)	19.2mm (0 – 28.9mm)
Number of stumps identified	128 (88.3%)	7 (4.8%)	8 (5.5%)
Post resection stump length (mean & range)	28.1mm (2.5 – 74.3mm)		
Actual stump length related to anticipated stump length	Actual stump length significantly longer $t(127)=-11.45$, $p=<0.001$		

**In one case the SMA was located to the right of the SMV due to bowel non rotation, with no vessel crossing*