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Title: What factors determine specimen quality in colon cancer surgery? – A cohort study

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ABSTRACT

Purpose:

Tenets of 'good-quality' colon cancer surgery include mesocolic plane dissection to preserve an intact mesocolic fascia/peritoneum, and excision of sufficient mesocolon for adequate lymphadenectomy. However, it remains controversial what clinicopathological factors determine 'good-quality' surgery, and whether quality of surgery influences morbidity/mortality. This study documents the quality of colon cancer surgery at a quaternary-referral centre and identifies factors that influence quality of surgery and post-operative outcomes.

Methods:

Consecutive patients who underwent resection for colon adenocarcinoma at St. James's University Hospital, Leeds, UK (2015-2017) were included. Primary outcome measures included: (i) plane of mesocolic dissection, prospectively assessed; and (ii) tissue morphometry (area of mesentery and vascular pedicle length). Other histopathological data were extracted from a prospective database. Clinical data were obtained from the National Bowel Cancer Audit and individual records.

Results:

405 patients were included (mean: 69.6yrs). The majority (67.4%) of specimens were mesocolic plane dissections. Median area of mesentery excised was 12,085.4mm^2. Median vascular pedicle length was 89.3mm. Post-operative complication was recorded in one-third of patients. Mesocolic plane excision was associated with open surgery (OR 1.80, 95%CI 1.05–3.09), especially in emergency colectomy. Open resections also had a greater mesentery

excised (P=0.002), but incurred more post-operative complication (OR 2.11, 95%CI 1.12–3.99). Post-operative complication was not associated with plane of excision or tissue morphometry.

Conclusion:

Majority of resections were 'optimal' mesocolic plane dissections. Open resections yielded better-quality specimens, but incurred more morbidity. There is room for improvement in the quality of laparoscopic colon cancer surgery, particularly those performed as emergency.

KEYWORDS

Colon cancer; quality of surgery; surgical outcomes; minimally invasive surgery; emergency surgery.

INTRODUCTION

There is growing evidence that quality of colon cancer surgery influences patient survival, especially in Stage III disease[1-5]. Previously, our unit developed a grading system for the Conventional versus Laparoscopic Assisted Surgery In Colorectal Cancer (CLASICC) trial[6] to grade the quality of colon cancer surgery with respect to plane of excision (muscularis propria, intramesocolic, or mesocolic), and demonstrated that mesocolic plane surgery is associated with a 15% survival advantage at 5 years when compared to the muscularis propria plane[4].

Since then, the concept of 'complete mesocolic excision' (CME) has been described and cited as analogous to total mesorectal excision for rectal cancer. CME describes excision of the primary tumour and its vascular/lymphatic supply along embryological planes, covered by an intact mesocolic fascia[7]. CME with central vascular ligation (CVL) extends the concept to ligation of the feeding vessels at their root to maximise central lymph node clearance[2,8,1]. However, the advantages of CVL are debated[9], and concerns remain surrounding its technical demands and potential complications (especially vascular). These considerations have led many surgeons to delay uptake of CME with CVL as a standard surgical technique, at least until the technique has been proven in a well-conducted randomised controlled trial.

Nevertheless, the concept of CME as a goal for 'good-quality' colon cancer surgery is accepted, especially mesocolic plane surgery to preserve an intact mesocolic fascia/peritoneum, and excision of an adequate volume of mesocolon *en bloc*[10]. The latter translates practically to ligating the vascular pedicle 'as high as possible' in circumstances where CVL is not practised. What remains unknown, however, is what factors (clinical or pathological) determine 'good-quality surgery', and whether the quality of specimen

achieved can be predicted from the clinicopathological features of an individual patient. Furthermore, it remains unclear whether quality of surgery, and the potentially increased operative time and tissue dissection to achieve 'good-quality surgery', influences post-operative morbidity.

This study aimed to document the current quality of colon cancer surgery as judged by pathological specimen assessment at a quaternary referral centre in an era when CME was routinely practised without CVL, to identify factors that influence quality of surgery, and assess whether quality of surgery affects the incidence of post-operative complication.

METHODS

Study population

This study included all patients who had resections for primary colon adenocarcinoma at St. James's University Hospital, Leeds, United Kingdom between 1 January 2015 and 31 December 2017. Patients were identified from a prospectively-maintained electronic database. Rectal cancers were excluded.

Pathology specimen assessment

The histopathology dissection protocol used has previously been described[4]. Briefly, all specimens were left intact around the level of the tumour and fixed in 10% formalin for 48 hours. The fixed specimens were then photographed alongside a metric scale from anterior and posterior aspects with the mesentery laid out as flat as possible without stretching. Specimen photographs were stored as high-resolution digital images. The tumour segments were serially sliced at 3-5mm intervals. All tumours were staged using the International Union Against Cancer TNM system (5^{th} edition)[11]. Lymph node dissection was performed without additional node-enhancing techniques.

Histopathological data for all specimens were entered prospectively into an electronic database. This database is maintained by a consultant histopathologist (NS), and has captured consecutive colorectal cancer resections performed at our unit since 2014. The database contains relevant histopathology data including tumour site and size, TNM stage, lymph node harvest, and mesocolic grade of excision.

Plane of Surgery

The plane of mesocolic dissection was routinely prospectively assessed by consultant gastrointestinal histopathologists during macroscopic dissection of the fixed resection specimen. The mesocolic grading system was that used in the CLASICC trial[6]: muscularis propria plane (little bulk to mesocolon with disruptions extending to the muscularis propria), intramesocolic plane (moderate bulk to mesocolon with irregularities deeper than 5mm but which did not reach the muscularis propria), or mesocolic plane (intact mesocolon with a smooth peritoneal-lined surface and only very minor or no defects)[4]. The final grading was always based on the poorest area, regardless of its relationship to the tumour.

Tissue morphometry

Following calibration with the metric scale included in the photograph, the area of mesentery resected, distances of the high vascular tie (HVT) from the tumour and closest bowel wall, and lengths of large and small bowel (where present)[3], were accurately measured (Figure 1) using Image J software (NIH, Maryland, USA). Tissue morphometry was performed blinded to patient outcome and mesocolic grading. Excisions were excluded from quantitation if specimen fixation resulted in such gross anatomical distortion that precluded reliable tissue morphometry. To understand tissue morphometry data in the context of other published data, these measurements were then compared with those from resections performed at Hillerød Hospital, Denmark, which utilised an identical protocol of tissue fixation and morphometry[12].

Collection of clinical data

Clinical data were obtained from linkage of pathology records with the hospitals' National Bowel Cancer Audit Program (NBOCAP) data. The NBOCAP captures clinical information including age at surgery, ASA grade, surgical urgency (elective, urgent, or emergency procedure), surgical access (laparoscopic or open), management intent (curative or palliative resection), and use of adjuvant therapy[13]. Data not captured on the NBOCAP database were obtained by hand-searching patient records; these included admission and discharge dates from which length of stay was calculated, and any post-operative complication (classified by Clavien-Dindo grade[14]). Clinical data collection was censored at 30 April 2019. For the purposes of this study's analyses, surgical access was dichotomised to laparoscopic / robotic and open, with patients who underwent conversion from laparoscopic to open included the 'open' group.

Outcome measures

The primary outcome measures were (i) plane of mesocolic excision and (ii) tissue morphometry measurements, specifically the area of mesentery and HVT to tumour length, as these two measurements were felt to have greatest oncological importance. The secondary outcome measure was the presence of post-operative complication (Clavien-Dindo Grade 1 and above).

Statistical analyses

Descriptive statistics and univariate analyses using *t*-test, Wilcoxon rank-sum test and contingency analysis for parametric, non-parametric, and categorical data, respectively, were used to assess clinicopathological characteristics and the 'crude' association with outcome

measures. Linear regression was used to assess association between continuously distributed variables. All variables associated with study outcomes (P<0.20) were included in multivariable models to assess the association while considering potential confounding by patient and clinical risk factors. All analyses were conducted using Stata version 15 (StataCorp, Texas, USA). P<0.05 was considered statistically significant.

Ethics

Ethical approval for the storage and measurement of specimen photographs was granted by the North East–York Research Ethics Committee (Jarrow, UK; Unique Reference Number: 07/MRE03/24). Clinical data was obtained as part of service evaluation to determine current standards of colon cancer surgery at our unit.

RESULTS

The initial search identified 480 colon cancers, of which 75 had insufficient images for reliable tissue morphometry. Therefore, 405 resections were included in this study.

Clinicopathological characteristics

Demographic, histopathological, and clinical characteristics of the study population are presented in Table 1. Overall, 273 (67.4%) specimens were judged to have been resected in the mesocolic plane, 129 (31.9%) in the intramesocolic plane, and only three (0.7%) in the muscularis propria plane. The median area of mesentery excised was 12,085.4mm^2 (range 3,877.9–70,232.9). The median lengths of HVT to tumour and bowel wall were 89.3mm (range 29.1–190.5) and 67.7mm (range 18.7–168.9), respectively. The comparisons of these measurements with those previously documented at Hillerød Hospital are presented in Table 2; across all the parameters measured and the various tumour sites, the morphometric data are comparable.

A post-operative complication was recorded in one-third of patients (n=155, 38.3%), but the majority of these were Clavien-Dindo Grade I (n=50, 32.3%) or II (n=71, 45.8%). The most common complication was ileus requiring nasogastric decompression (n=49, 31.6%). Higher ASA grades were associated with an urgent/emergency resection (P=0.019) and an open operation (P=0.002). Urgent/emergency resections were strongly associated with an open approach (P<0.001). The median length of follow up was 32.5 months (range 16.2–52.5). During this period, there were 96 (23.7%) deaths recorded, and 78 (19.2%) patients were diagnosed with disease recurrence.

Factors associated with mesocolic plane excision

The univariate analyses of clinicopathological factors and their associations with mesocolic plane of excision are presented in Table 3. Only ASA grade was significantly associated with mesocolic plane surgery, with mesocolic plane surgery being over-represented amongst ASA grade 1 patients (P<0.001); this association persisted on multivariate analysis (Table 4). Notably, surgical access was found to be significantly associated with plane of surgery after multivariate modelling, with an open approach having almost twice the odds of a mesocolic excision than a laparoscopic/robotic approach (OR 1.80, 95%CI 1.05–3.09).

On subgroup analysis, the influence of surgical access on plane of surgery was greatest in patients undergoing urgent/emergency surgery; in this subgroup, patients undergoing open colectomy had an almost three-fold higher odds of mesocolic plane surgery on multivariate analysis (aOR 2.61, 95%CI 1.05–6.49). In the elective subgroup, ASA grade remained strongly associated with plane of surgery, but surgical access was not significantly associated in this subgroup.

Factors associated with area of mesentery

Several factors were associated with area of mesentery on univariate analyses (Table 3), but some of these were expected based on type of resection performed and anticipated body morphometry. For example, area of mesentery was expectedly greatest in subtotal colectomy specimens (P<0.001), for transverse colon tumours (P<0.001), and in males (P=0.006). Other factors found to be significant were not necessarily expected, though. Urgent/emergency resections yielded a greater area of mesentery compared with elective resections (median 13,257.7 [range 3,877.9–66,350.4] vs 11,385.0 [range 4,042.4–70,232.9], P=0.002), as did

resections performed through an open approach (median 14,698.6 [range 4,042.4–66,350.4] vs 11,314.8 [range 3,877.9–70,232.9]). ASA grade was also associated with area of mesentery, with increasing ASA grade demonstrating an increased area of mesentery excised (P=0.003).

These interactions were tested in a multivariable model (Table 4). The associations between area of mesentery and primary procedure performed, tumour site, and gender persisted. However, so did surgical access, with open resections being associated with an almost 3,000mm^2 greater resected area of mesentery (adjusted B 2,713.4 [1,040.3–4,386.5], P=0.002). Surgical urgency was no longer associated with area of mesentery after multivariate modelling.

The influence of surgical access on area of mesentery excised was further tested by sub-analysing according to primary procedure. Even within procedure subgroups, open surgery was associated with a larger area of mesentery excised, especially in patients undergoing subtotal colectomy (median 27,554.6 [range 9,595.8–66,350.4] vs 20,535.8mm^2 [8,146.1–70,232.9], P=0.021) and left-sided resection (i.e. left hemicolectomy, sigmoid colectomy, anterior resection, or Hartmann's procedure) (median 12,933.1 [range 4,042.4–30,447.6] vs 9,673.4mm^2 [4,832.7–24,484.6], P=0.004). It is recognised though, that open resections also yielded specimens with overall greater lengths of bowel (median large bowel length 297.7 [range 104.0–1,436.0] vs 241.3mm [73.6–1,222.3], P<0.001).

Factors associated with HVT to tumour length

Only tumour size was inversely associated with HVT to tumour length on univariate linear regression modelling (P=0.01) (Table 3). In a multivariate model assessing for potential

interaction with TNM stage, gender, and resection margin status (Table 4), tumour size remained significantly inversely associated with HVT to tumour length, with each millimetre increase in tumour size associated with a 0.2mm decrease in HVT to tumour length (adjusted B -0.21 [95%CI -0.39 – -0.04]).

Factors associated with post-operative complications

Post-operative complication was associated with tumour site, tumour size, age at surgery, surgical urgency, surgical access, ASA grade, primary procedure, and resection margin status on univariate analysis (Table 5). Specifically, post-operative complications were over-represented in patients with transverse colon tumours (P=0.041) and those undergoing subtotal colectomy or extended resection (P=0.003). The odds of a complication were two-fold higher in those undergoing open surgery (OR 2.13, 95%CI 1.37–3.30) and urgent/emergency surgery (OR 1.62, 95%CI 1.07–2.44). Post-operative complication was also positively associated with ASA grade (P=0.004). Otherwise, there was no association between post-operative complication and plane of excision, area of mesentery excised, or HVT to tumour length.

The only factors that remained significantly associated with post-operative complication following multivariate modelling were age at surgery, surgical access, ASA grade, and primary procedure performed (Table 6). Each year increase in age at surgery was associated with a 3% increase in odds of complication (aOR 1.03, 95%CI 1.01–1.06). The odds of a post-operative complication were increased two-fold in patients undergoing open surgery (aOR 2.11, 95%CI 1.12–3.99) and six-fold in ASA Grade 3 patients (aOR 6.05, 95%CI 1.76–20.78). Left sided resections had less complications compared with subtotal or extended colectomies (aOR

0.14, 95%CI 0.03–0.63). Otherwise, there was no association between post-operative complication and plane of excision or tissue morphometry.

DISCUSSION AND CONCLUSIONS

This study presents a contemporary account of the quality of colon cancer surgery based on pathological specimen assessment at a high-volume quaternary referral centre. It included all patients who had undergone colon cancer surgery over a three-year period, including elective and emergency resections. In this study, over two-thirds of surgery was performed in the 'optimal' mesocolic plane, with mesocolic plane surgery being significantly associated with lower ASA grade and open surgery. Open surgery was also associated with a greater area of mesentery excised, even on subgroup analysis of primary procedure performed, but was associated with increased post-operative complication. Overall, predictors of post-operative complication were clinical rather than pathological factors; there was no association between plane of surgery or tissue morphometry and post-operative complication.

The majority of patients underwent 'optimal' mesocolic plane surgery. Less than one-third of specimens were in the intramesocolic plane, and only three were a muscularis propria dissection. This compares with data previously reported from our unit (1997-2002), when one-quarter of excisions were muscularis propria dissections, 44% were intramesocolic, and less than one-third were mesocolic excisions[4]. This improvement might be attributed to a concerted effort to improve pathological outcomes through the cancer multidisciplinary team process, and recognising the importance of CME surgery even without routine CVL. There is still further room to improve the mesocolic plane rate, accepting that in a proportion of locally advanced/tethered cancers the embryological plane has already been disrupted.

To our knowledge, this study is the first to investigate factors associated with plane of colon cancer surgery. On multivariate analysis, mesocolic plane surgery was associated with lower

ASA grade. It might have been presumed that this was due to a discrepancy between elective and emergency surgeries, with elective patients potentially having lower ASA scores and 'better quality' surgery, but the association between ASA grade and plane of surgery persisted on subgroup analysis of elective patients only. Other possible explanations for the association between lower ASA grade and correct plane surgery might include lower ASA grade patients having more favourable body habitus, but data on body mass index (BMI) were not available to corroborate this.

This study identified that open surgery was more likely to yield a 'good' quality specimen. Open surgery had almost twice the odds of achieving a mesocolic dissection, and was associated with almost 3,000mm^2 greater area of mesentery. Even within procedure subgroups, open surgery was associated with a larger area of mesentery excised. The greater area of mesentery resected with open surgery is probably due to more 'longitudinal mesentery' being excised. This is supported by our finding that open specimens had significantly longer lengths of bowel. The additional 'longitudinal mesentery' may be of lesser oncological relevance, but the association between open surgery and mesocolic plane dissection remains striking.

That open surgery was associated with better specimen quality in this study is difficult to reconcile with the results of randomised trials such as CLASICC[6], COLOR[15], and COST[16], which have all demonstrated oncological equivalence between laparoscopic and open colon cancer surgery. Indeed, on this basis of equivalence, national guidelines advocate that laparoscopic resection be considered for all patients with colon cancer[17]. The answer to this quandary may lie in the recognition that the aforementioned trials included only optimal

elective patients, whilst ours was a population-based study of all patients undergoing colon cancer surgery. Indeed, the association between open surgery and mesocolic plane excision in our study was predominately noted in patients undergoing emergency surgery. In this subgroup, open colectomy had a three-fold higher odds of mesocolic plane surgery. This has implications for the eagerly-awaited results of the Laparoscopic versus open Colorectal Surgery (LaCeS) trial[18], which has sought to clarify the role of laparoscopy in emergency colorectal surgery. Notably, open surgery was *not* associated with plane of surgery in *elective* patients, a finding that sits well with CLASICC, COLOR, and COST which were all restricted to elective patients.

Our finding that open surgery yields a significantly greater *en bloc* area of mesentery warrants discussion. The difference between open and laparoscopic surgeries was significant only in patients undergoing subtotal and left sided colectomies. We postulate that this difference is related to the technical challenges of middle colic pedicle ligation laparoscopically, with many surgeons still preferring to tackle this step through an open approach. This would be consistent with the findings of a recent study which identified that laparoscopic resections for tumours in the transverse colon yielded significantly shorter pedicle lengths and lymph node harvests than in corresponding open resections[19].

This study identified that tumour size was significantly inversely associated with HVT to tumour length, i.e. length of vascular pedicle resected. Each millimetre increase in tumour size was associated with a 0.2mm decrease in HVT to tumour length. This might reflect the situation where advanced tumours exert a fibrosing and tethering effect on the adjacent mesentery.

Over one-third of patients incurred a post-operative complication in this study, but the majority of these were Clavien-Dindo Grade I or II. Only clinical factors were predictive of post-operative complication, *viz*. age at surgery, surgical access, ASA grade, and primary procedure. There was no association between plane of excision or tissue morphometry and post-operative complication, suggesting that more extensive tissue dissection potentially associated with 'good' quality surgery does not increase post-operative morbidity. Indeed, one concern over CME is the potential morbidity associated with the extensive tissue dissection that comes with central vascular ligation[20]; that said, as our surgeries were not routinely 'CVL dissections', this study cannot specifically add to this debate. The odds of post-operative complication were increased two-fold in patients undergoing open surgery. This is consistent with the results of a previous randomised trial[21] and recent systematic review[22], which both concluded that a minimally invasive approach to colon cancer surgery has advantages for reduced general and wound-related complications.

Although this study utilised prospectively collected data through our hospital's pathology and NBOCAP databases, it was limited by the unavailability of certain clinical parameters, such as BMI which was not accurately recorded. This compromised our ability to adjust tissue morphometry measurements according to body habitus. Furthermore, tissue morphometry measurements were based on fixed rather than fresh specimens, which suffer from inevitable shrinkage artefact. This makes our measurements difficult to compare with other studies which utilised fresh specimens for morphometry[23,24]. However, in the past we and others have generated important knowledge from such routine specimens[12,4]. Finally, as the median follow-up in this study was less than 3 years, we are unable to present meaningful

data relating to 5-year recurrence and survival rates, although their relationship to quality of surgery has been robustly explored previously[4].

This study provides a contemporary assessment of the quality of colon cancer surgery based on standardised assessment of resection specimens linked with relevant clinical data. The majority of resections were performed in the 'optimal' mesocolic plane. There was an association between mesocolic plane excision and open surgery, evident particularly in patients undergoing emergency colectomy. An open approach also yielded a greater *en bloc* area of mesentery. Unfortunately, while open resections were associated with a better-quality specimen, this came at the cost of increased post-operative complication. However, neither plane of excision nor tissue morphometry were associated with post-operative complication, suggesting that more extensive tissue dissection potentially associated with 'good' quality surgery does not increase post-operative morbidity. This study highlights there is still the need for routine photographs and assessments to assist in understanding what surgeons do with colon cancer in the 21st century. There remains room for improvement in colonic cancer surgery, in particular the quality of laparoscopic colectomies performed for colon cancer and those in the emergency setting. The question of the particular role of CVL requires a large international randomised trial.

FIGURE LEGEND

Figure 1. Method of morphometric quantitation including (A) area of mesentery, (B) distance from the high vascular tie to tumour, (C) distance from high vascular tie to closest bowel wall, and (D) length of the large bowel.

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TABLES

Table 1. Clinicopathological characteristics of study population (n=405)

Variable	**N (%), median (range), mean (SD)**
Demographics	
Age at surgery (years)	69.6 (SD 12.5)
Gender	
Male	230 (56.8%)
Female	175 (43.2%)
Pathology characteristics	
Tumour site	
Caecum	80 (19.8%)
Ascending colon	80 (19.8%)
Transverse colon	64 (15.8%)
Descending colon	34 (8.4%)
Sigmoid colon	147 (36.3%)
Tumour size (mm)	40 (3-115)
T-stage	
1	18 (4.5%)
2	52 (12.8%)
3	216 (53.3%)
4	119 (29.4%)
N-stage	
0	210 (51.9%)
1	120 (29.6%)
2	75 (18.5%)
TNM Stage	
I	49 (12.1%)
II	155 (38.3%)
III	168 (41.5%)
IV	33 (8.2%)
Lymph nodes harvested	20 (3-132)
Resection margin status	
R0	365 (90.1%)
R1	39 (9.6%)
R2	1 (0.3%)
Mesocolic grade	
Mesocolic	273 (67.4%)
Intramesocolic	129 (31.9%)
Muscularis propria	3 (0.7%)
Tissue morphometry	
Area of mesentery resected (mm^2)	12,085.4 (3,877.9 – 70,232.9)
HVT to tumour length (mm)	89.3 (29.1 – 190.5)
HVT to bowel length (mm)	67.7 (18.7 – 168.9)

Large bowel length(mm)	249.1 (73.6 – 1436.0)
Small bowel length (mm)	94.7 (27.7 – 539.0)
Clinical characteristics	
ASA Grade	
1	40 (11.0%)
2	186 (51.2%)
3	123 (33.9%)
4	14 (3.9%)
Surgical urgency	
Elective	258 (63.7%)
Urgent	79 (19.5%)
Emergency	68 (16.8%)
Surgical access	
Laparoscopic	279 (69.1%)
Laparoscopic to open	25 (6.2%)
Open	92 (22.8%)
Robotic	8 (2.0%)
Intent of surgery	
Curative	387 (95.6%)
Palliative	18 (4.4%)
Primary procedure performed	
Subtotal / total colectomy	31 (7.7%)
Extended right hemicolectomy	38 (9.4%)
Right hemicolectomy	175 (43.2%)
Left hemicolectomy	29 (7.2%)
Sigmoid colectomy	26 (6.4%)
Anterior resection	96 (23.7%)
Hartmanns	10 (2.5%)
Adjuvant chemotherapy	
Yes	154 (38.0%)
No	251 (62.0%)
Length of stay (days)	8 (1-118)
Post-operative complication	
Yes	155 (38.3%)
Grade I	50 (32.3%)
Grade II	71 (45.8%)
Grade III	22 (14.2%)
Grade IV	6 (3.9%)
Grade V	6 (3.9%)
None	250 (61.7%)

Table 2. Tissue morphometry data for resection specimens according to site of tumour (right, transverse, or left), comparing St. James's University and Hillerød hospitals

	St. James's University Hospital	Hillerød Hospital
Right-sided tumours		
Area of mesentery resected		
Median (mm^2)	11,451	9,967
IQR	8,620 – 14,841	6,550 – 11,904
HVT to tumour length		
Median (mm)	90	89
IQR	73 – 111	70 – 104
HVT to bowel length		
Median (mm)	68	76
IQR	53 – 86	48 – 92
Length of LB resected		
Median (mm)	215	254
IQR	181 – 268	219 – 318
Length of SB resected		
Median (mm)	97	52
IQR	72 – 131	43 – 64
Transverse tumours		
Area of mesentery resected		
Median (mm^2)	16,460	16,070
IQR	12,543 – 24,596	8,845 – 21,635
HVT to tumour length		
Median (mm)	85	76
IQR	61 – 104	60 – 86
HVT to bowel length		
Median (mm)	63	54
IQR	51 – 83	36 – 60
Length of LB resected		
Median (mm)	395	448
IQR	284 – 534	323 – 554
Left-sided tumours		
Area of mesentery resected		
Median (mm^2)	10,795	7,292
IQR	8,385 – 15,815	5,874 – 11,044
HVT to tumour length		
Median (mm)	90	82
IQR	71 – 116	70 – 97
HVT to bowel length		
Median (mm)	68	69
IQR	50 – 91	60 – 88
Length of LB resected		
Median (mm)	260	227

IQR	223 – 338	167 – 338

IQR = interquartile range; LB = large bowel; SB = small bowel; HVT = high vascular tie

Table 3. Clinicopathological factors and their associations with mesocolic grade, area of mesentery excised, and HVT to tumour length

	Intramesocolic / muscularis propria (n=132)	Mesocolic (n=273)	OR (95%CI)	P-value	Area of mesentery (mm^2) (median (range))	P-value	HVT to tumour length (mm) (mean (SD))	P-value
Tumour site								
Right colon	44 (33.3%)	116 (42.5%)		0.136	11,450.8 (4,441.0 – 62,373.8)	***<0.001***	93.8 (SD 29.4)	0.449
Transverse colon	26 (19.7%)	38 (13.9%)			16,460.0 (3,877.9 – 52,564.6)		87.8 (SD 31.3)	
Left colon	62 (47.0%)	119 (43.6%)			10,795.0 (4,042.4 – 70,232.9)		94.3 (SD 34.3)	
Size	40 (4-115)	40 (3-100)		0.939	19.9 (-27.1 – 66.8)	0.406	-0.23 (-0.40 – -0.05)	***0.010***
TNM Stage (AJCC)								
I	20 (15.2%)	29 (10.6%)		0.461	10,659.7 (4,832.7 – 47,480.5)	0.195	96.4 (SD 41.0)	0.173
II	50 (37.9%)	105 (38.5%)			12,007.6 (3,877.9 – 57,806.7)		89.7 (SD 31.1)	
III	54 (40.9%)	114 (41.8%)			12,493.95 (4,441.0 – 70,232.9)		93.5 (SD 28.7)	
IV	8 (6.1%)	25 (9.2%)			12,606.2 (6,314.3 – 66,350.4)		103.5 (SD 33.1)	
Age at surgery	70.7 (SD 10.4)	69.1 (SD 13.4)		0.233	-22.3 (95%CI -96.2 – 51.5)	0.553	-0.02 (-0.30 – 0.25)	0.868
Gender								
Male	76 (57.6%)	154 (56.4%)			12,859.7 (4,832.7 – 70,232.9)	***0.006***	95.4 (SD 33.5)	0.152
Female	56 (42.4%)	119 (43.6%)	1.05 (0.69 – 1.60)	0.824	10,699.6 (3,877.9 – 47,480.5)		90.5 (SD 29.6)	
Urgency								
Elective	79 (59.9%)	179 (65.6%)			11,385.0 (4,042.4 – 70,232.9)	***0.002***	94.1 (SD 32.7)	0.481
Urgent/Emergency	53 (40.2%)	94 (34.4%)	0.78 (0.51 – 1.20)	0.262	13,257.7 (3,877.9 – 66,350.4)		91.6 (SD 30.4)	
Surgical access								
Laparoscopic /robotic	100 (75.8%)	187 (68.8%)			11,314.8 (3,877.9 – 70,232.9)	***<0.001***	93.5 (SD 32.1)	0.865
Open	32 (24.2%)	85 (31.3)	1.42 (0.88 – 2.28)	0.145	14,698.6 (4,042.4 – 66,350.4)		92.8 (SD 31.3)	
Surgical intent								
Curative	128 (97.0%)	259 (94.9%)			12,085.4 (3,877.9 – 70,232.9)	0.822	93.4 (SD 31.8)	0.563
Palliative	4 (3.0%)	14 (5.1%)	1.73 (0.56 – 5.36)	0.337	12,455.1 (4,042.4 – 66,350.4)		88.6 (SD 32.8)	
ASA grade								
1	2 (1.7%)	38 (15.7%)		***<0.001***	9,432.9 (4,999.1 – 46,744.5)	***0.003***	90.1 (SD 30.8)	0.920
2	67 (55.4%)	119 (49.2%)			11,518.1 (4,042.4 – 47,480.5)		94.1 (SD 31.9)	
3	49 (40.5%)	74 (30.6%)			13,057.2 (4,832.7 – 62,373.8)		92.8 (SD 29.0)	
4	3 (2.5%)	11 (4.6%)			15,231.7 (6,775.1 – 66,350.4)		92.7 (SD 43.4)	
Primary procedure								
Subtotal colectomy / extended resection	28 (21.2%)	41 (15.0%)		0.107	24,049.1 (8,146.1 – 70,232.9)	***<0.001***	96.1 (SD 32.4)	0.644
Right hemicolectomy	48 (36.4%)	127 (46.5%)			11,546.5 (3,877.9 – 30,882.4)		91.6 (SD 29.8)	
Left-sided resection	56 (42.4%)	105 (38.5%)			10,242.4 (4,042.4 – 30,447.6)		94.1 (SD 34.0)	
Resection margin status								
R0	118 (89.4%)	247 (90.5%)			12,236.7 (3,877.9 – 70,232.9)	0.630	94.1 (SD 32.6)	0.128
R1/2	14 (10.6%)	26 (9.5%)	0.89 (0.45 – 1.76)	0.732	11,977.35 (4,967.6 – 36,674.7)		85.6 (SD 23.5)	

Table 4: Multivariate analysis: factors and their associations with mesocolic grade, area of mesentery excised, and HVT to tumour length

Mesocolic excision (n = 273)		
	Adjusted OR (95%CI)	P-value
Tumour site		
Right colon	Ref	
Transverse colon	0.82 (0.40 – 1.72)	0.607
Left colon	1.49 (0.48 – 4.65)	0.492
Surgical access		
Laparoscopic / robotic	Ref	
Open	1.80 (1.05 – 3.09)	***0.032***
ASA Grade		
1	Ref	
2	0.09 (0.02 – 0.40)	***0.001***
3	0.08 (0.02 – 0.34)	***0.001***
4	0.18 (0.03 – 1.23)	0.080
Primary procedure		
Subtotal colectomy / extended resection	Ref	
Right hemicolectomy	2.21 (0.97 – 5.03)	0.059
Left-sided resection	0.91 (0.36 – 2.33)	0.848
Area of mesentery (mm^2)		
	Adjusted B (95%CI)	P-value
Tumour site		
Right colon	Ref	
Transverse colon	3,549.5 (1,322.7 – 5,776.2)	***0.002***
Left colon	7,252.95 (3,920.5 – 10,585.4)	***<0.001***
TNM Stage (AJCC)		
I	Ref	
II	-696.8 (-2,859.2 – 1,465.6)	0.527
III	-314.2 (-2,479.8 – 1,851.3)	0.776
IV	264.3 (-3,047.0 – 3,575.7)	0.875
Gender		
Male	Ref	
Female	-1,524.4 (-2,898.8 – -150.1)	***0.030***
Surgical urgency		
Elective	Ref	
Urgent / emergency	-584.5 (-2,061.4 – 892.3)	0.437
Surgical access		
Laparoscopic / robotic	Ref	
Open	2,713.4 (1,040.3 – 4,386.5)	***0.002***
ASA Grade		
1	Ref	
2	1,248.3 (-996.6 – 3,493.2)	0.275
3	2,886.7 (523.0 – 5,250.4)	***0.017***
4	5,402.4 (1,349.8 – 9,455.1)	***0.009***
Primary procedure		
Subtotal colectomy	Ref	
Right hemicolectomy	-9,117.1 (-11,642.8 – -6,591.4)	***<0.001***
Left-sided resection	-17,242.1 (-19,910.7 – 14,573.5)	***<0.001***
HVT to tumour length (mm)		
	Adjusted B (95%CI)	P-value
Tumour size	-0.21 (-0.39 – -0.04)	***0.019***

TNM stage		
I	Ref	
II	-2.7 (-13.9 – 8.5)	0.640
III	2.0 (-9.3 – 13.2)	0.731
IV	12.6 (-3.1 – 28.3)	0.114
Gender		
Male	Ref	
Female	-4.9 (-11.7 – 1.9)	0.160
Resection margin status		
R0	Ref	
R1/2	-10.9 (-22.4 – 0.6)	0.064

Table 5. Clinicopathological factors and their association with post-operative complication(s)

Variable	Post-operative complication		OR (95%CI)	P Value
	No (n=250)	Yes (n=155)		
Tumour site				
Right colon	99 (39.6%)	61 (39.4%)		***0.041***
Transverse colon	31 (12.4%)	33 (21.3%)		
Left colon	120 (48.0%)	61 (39.4%)		
Size	36 (4-100)	45 (3-115)		***0.018***
TNM Stage				
I	34 (13.6%)	15 (9.7%)		0.545
II	97 (38.8%)	58 (37.4%)		
III	98 (39.2%)	70 (45.2%)		
IV	21 (8.4%)	12 (7.7%)		
Age at surgery	68.1 (SD 11.9)	72.1 (13.0)		***0.002***
Gender				
Male	136 (54.4%)	94 (60.7%)		0.218
Female	114 (45.6%)	61 (39.4%)	0.77 (0.52 – 1.16)	
Urgency				
Elective	170 (68.0%)	88 (56.8%)		***0.022***
Semi-elective/Emergency	80 (32.0%)	67 (43.2%)	1.62 (1.07 – 2.44)	
Surgical access				
Laparoscopic /robotic	192 (77.1%)	95 (61.3%)		***0.001***
Open	57 (22.9%)	60 (38.7%)	2.13 (1.37 – 3.30)	
Surgical intent				
Curative	239 (95.6%)	148 (95.5%)		0.956
Palliative	11 (4.4%)	7 (4.5%)	1.03 (0.39 – 2.71)	
ASA grade				
1	34 (14.7%)	6 (4.6%)		***0.004***
2	123 (53.0%)	63 (48.1%)		
3	68 (29.3%)	55 (42.0%)		
4	7 (3.0%)	7 (5.3%)		
Primary procedure				
Subtotal colectomy / extended resection	31 (12.4%)	38 (24.5%)		***0.003***
Right hemicolectomy	108 (43.2%)	67 (43.2%)		
Left-sided resection	111 (44.4%)	50 (32.3%)		
Resection margin status				
R0	232 (92.8%)	133 (85.8%)		***0.022***
R1/2	18 (7.2%)	22 (14.2%)	2.13 (1.10 – 4.12)	
Number of lymph nodes harvested	21 (3 – 132)	21 (4 – 100)		0.628
Plane of excision				
Intramesocolic / Muscularis propria	76 (30.4%)	56 (36.1%)		0.232
Mesocolic	174 (69.6%)	99 (63.9%)	0.77 (0.51 – 1.18)	
Area of mesentery (mm^2)	11,588.1 (4042.4 – 62,373.8)	12,920.0 (3,877.9 – 70,232.9)		0.097
HVT to tumour length (mm)	95.2 (SD 31.5)	89.7 (SD 32.3)		0.123

Table 6: Multivariate analysis: Factors associated with development of post-operative complication(s) (*n*=155)

	Adjusted OR (95%CI)	P-value
Tumour site		
Right colon	Ref	
Transverse colon	1.14 (0.47 – 2.79)	0.772
Left colon	2.89 (0.57 – 14.57)	0.199
Size	1.01 (1.00 – 1.03)	0.067
Age at surgery	1.03 (1.01 – 1.06)	***0.010***
Surgical urgency		
Elective	Ref	
Urgent / Emergency	1.36 (0.78 – 2.36)	0.282
Surgical access		
Laparoscopic / Robotic	Ref	
Open	2.11 (1.12 – 3.99)	***0.022***
ASA Grade		
1	Ref	
2	4.26 (1.29 – 14.06)	***0.018***
3	6.05 (1.76 – 20.78)	***0.004***
4	3.45 (0.59 – 20.38)	0.171
Primary procedure		
Subtotal colectomy / extended resection	Ref	
Right hemicolectomy	0.44 (0.16 – 1.22)	0.116
Left-sided resection	0.14 (0.03 – 0.63)	***0.010***
Resection margin status		
R0	Ref	
R1/2	1.72 (0.72 – 4.11)	0.226
Area of mesentery (mm^2)	1.00 (1.00 – 1.00)	0.210
HVT to tumour length (mm)	0.99 (0.99 – 1.00)	0.233