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The effect of increasing Body Mass Index on Laparoscopic Surgery for Colon and Rectal Cancer

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Increasing BMI and laparoscopic colorectal surgery

What does this paper add to the literature?

This is the largest single case series that examines the relationship of body mass index (BMI) to clinical and oncological outcomes. It shows that an elevated BMI is associated with a lower likelihood of attempting laparoscopic surgery (a novel finding), and a higher conversion rate to open surgery when attempted.

Abstract

BACKGROUND: Obesity is common in Western countries and its prevalence is increasing. Colorectal cancer is common, and surgery for colorectal cancer is technically more challenging in obese patients. Laparoscopic surgery for colon cancer has been shown to be oncologically equivalent, with improved short- term outcomes.

Laparoscopic surgery for rectal cancer has proven technically challenging, and recent results have raised concerns about oncologic equivalence.

OBJECTIVE: To evaluate the effect of body mass index (BMI) on the clinical and oncological outcomes of surgery for colorectal cancer, including the rate at which laparoscopic surgery is attempted and the rate at which laparoscopic surgery is converted to open surgery.

METHODS: A retrospective analysis of prospectively collected data from two tertiary institutions was performed. Data from the Cabrini Monash University colorectal neoplasia database for patients having surgical resection for colon and rectal cancers between January 1 2010 and June 30 2015. Surgical and medical complications, tumour recurrence and overall survival and laparoscopic surgery and conversion rates were investigated.

RESULTS: This large case series of 1464 patients undergoing elective surgery for colorectal cancer has demonstrated that an elevated BMI is associated with a lower likelihood of attempting laparoscopic surgery and a higher conversion rate to open surgery when laparoscopy is attempted. Conversion was 1.9 times more likely in obese patients with colon cancer, and 4.1 times more likely in obese patients with rectal cancer. The critical BMI for colon cancer patients was >35, and for rectal cancer patients was >30. Obesity is also associated with increased rates of surgical complications, including anastomotic leakage, wound complications. Pathological parameters, tumour recurrence and survival were not affected by elevated BMI.

CONCLUSIONS: In the surgical management of colorectal cancer, obesity is associated with a lower likelihood of laparoscopic surgery being attempted, a higher likelihood of conversion to open surgery when laparoscopic surgery is attempted, and a higher rate of surgical complications.

Introduction:

Obesity is increasing at an alarming rate in the western world reflecting a global epidemic of sedentary lifestyle and excessive caloric intake.(1-4) In the United States the prevalence increased from 15 to 31% from 1980 to 2010, data that has been mirrored in Australia. (5) Colorectal cancer (CRC) is the second most common cancer in Australia, and the most common following non-melanocytic skin cancers.(5) The number of reported cases in Victoria has increased from 2000-2010, in part due to an increase in the population.(6) As a result of these epidemiological trends there is an increasing requirement to manage and operate on overweight (BMI>25) and obese (BMI >30) individuals.

Morbidity associated with performing colorectal resections in obese individuals is well documented. Publications from North America and Europe show that there are increased rates of surgical site infections (SSI), respiratory complications, and length of stay (LOS) in obese individuals.(7, 8)

Laparoscopic surgery for colorectal disease was pioneered in the late 1980's with subsequent publications proving efficacy and safety in managing colon cancer .(9-12) Since this time the laparoscopic approach has been increasingly adopted in colon cancer. Ongoing research and clinical trials have focused on laparoscopic surgery for rectal cancer.(13-17) In spite of these trends among specialist units, the rate at which laparoscopic surgery is performed in population studies remains low.(18) Laparoscopic surgery for rectal cancer has proven more technically challenging, particularly in the overweight and obese populations. The influence of increased body mass index may have contributed to the recently completed ALaCaRT (Australasian Laparoscopic Cancer of the Rectum Trial) and Z6051 (North American) trials where concerns were raised relating to its pathologic equivalence.(13, 14)

The aims of this study were to evaluate the effect of increasing body mass index (BMI) on the outcomes of surgery for colorectal cancer, including surgical complications, oncologic outcomes and the surgical techniques employed. This included the rate at which laparoscopic surgery is attempted, the rate at which laparoscopic surgery is converted to open surgery.

Methods:

The Cabrini Monash University colorectal neoplasia database was searched for patients that had undergone surgical resection for colon or rectal cancers between January 1

2010 and June 30 2015 at The Alfred (public) and Cabrini (private) hospitals. All data entered into the database were collected prospectively with near 100% complete data entry of surgeries performed at the two centres. Details of the database have been previously published.(19) Human Research Ethics Committee approval was granted at both participating centres prior to the commencement of the study.

Data extracted from the database included demographic information, clinical characteristics including BMI, pre- and post-operative tumour staging, surgical procedures, surgical and medical complications, length of hospital stay following surgery, return to theatre, cancer recurrence and death from any cause. Open surgery was defined as any colorectal surgery for cancer where the operation was commenced with a conventional open incision (usually midline laparotomy); laparoscopic surgery as surgery where the dissection and transection of the bowel was completed using laparoscopic instruments; and conversion of laparoscopy as a change in operative approach from laparoscopic to open to complete the procedure. Conversion to a laparotomy was at the discretion of the individual surgeon for concerns of patient safety, technical difficulties, inability to complete the planned procedure for sphincter sparing or associated conditions requiring treatment.

Outcomes for this study were surgical and medical complications, return to theatre, length of stay post-surgery, readmission to hospital, 30-day mortality, and oncological outcomes of tumour recurrence or metastasis and overall survival.

Descriptive statistics with categorical variables summarised as frequencies and percentages. Quantitative variables were summarised as medians and ranges. Chi-square analysis and t-testing were used where appropriate for comparisons of data. Univariate and multivariable regression analysis was performed to assess the association of BMI, as a continuous variable, with clinical and oncological outcomes. Logistic regression models were used to investigate associations between the specified outcomes and continuous BMI adjusted for associations with other predictor variables. Disease-free and overall survival were assessed using survival analysis techniques with study entry set at the date of surgery. Significance was set as a p value < 0.05. To account for lack of independence between episodes within patients with multiple treatment episodes, all regression standard errors were calculated using the Huber-

White Sandwich Estimator as implemented in Stata 14 (StataCorp LP, College Station, TX, USA).

Results:

There were 1846 treatment episodes involving 1814 patients included between January 1, 2010 and June 30, 2015. After exclusions for emergency and urgent surgery, trans-anal surgery and missing values for BMI, there were 1483 treatment episodes in 1464 patients (983 colon and 481 rectum) available for analysis of short- term outcomes. Long term follow-up was available for 1242 elective surgery patients (831 (67.4%) colon and 311 (32.6%) rectal cancer) undergoing 1248 treatment episodes; 235 treatment episodes in 222 patients were thus excluded from the analyses for overall and disease-free survival. The median follow up was 13 months (range 1-69 months).

For the full cohort including colon and rectal cancer patients, 299 (20.4%) patients had a BMI>30; 81 (5.5%) had a BMI>35, and 22 (1.5%) had a BMI>40. Characteristics of patients, with BMI split at 30kg/m^2, are shown in Table 1, including surgical technique and conversion data separated into colon and rectum cancers. Apart from the expected differences in BMI and weight, the groups differed by age, and surgical entry. Tumor Node Metastasis (TNM) staging was available for all patients and all were elective surgical cases. Of the rectal cancers 240 (49.9%) received neoadjuvant therapy. Eighty-five percent of these received long course chemoradiation (infusional 5-flurouracil and 50.4 Gray). At the completion of the date range there were 151 deaths from all causes (overall mortality 12.7%).

Post-operative outcomes

Surgical Complications:

Table 2 shows the postoperative outcomes for both colon and rectum split by BMI at 30kg/m^2. Surgical complications occurred more frequently in patients with a BMI ≥30. Logistic regression (Table 3) indicated a higher likelihood of surgical complications with increasing BMI and for patients with rectal cancer and those undergoing conversion of laparoscopy, hybrid and open surgeries, compared with laparoscopic surgery, but a lower likelihood of surgical complications for females. For patients with BMI ≥35 the odds ratio (OR) for surgical complications was 1.71 (95% CI 1.03-2.85). The individual surgical complications associated with BMI were anastomotic leakage (OR 1.06; 95% CI 1.01-1.12), superficial wound dehiscence (OR 1.16; 95% CI 1.09-1.24), deep wound dehiscence (OR 1.17; 95%CI 1.01-1.35) and wound infection (OR 1.07; 95% CI 1.00-1.14). The CRM was not reported in 57 (12%) rectal cancers. Sixteen of these had had a complete pathological response to neoadjuvant chemoradiotherapy; and 12 of these had undergone rectal resection for a previously endoscopically resected malignant polyp with no residual tumour in the rectal resection. The remaining 29 (6%) had upper third, intraperitoneal rectal cancers and the margin had not been reported.

The risk of medical complications was only associated with an increasing age and not BMI. Eighty treatment episodes required a return to theatre but these were unrelated to BMI. Return to theatre was more likely for patients who experienced surgical complications (OR 34.1; 95% CI 18.5-63.1).

There were six in-patient deaths and five had surgical complications. In-patient death was not related to BMI. There were 4 deaths within 30-days of surgery. Two had experienced surgical complications and there was no association with BMI.

Length of stay in hospital was longer for patients who experienced surgical or medical complications, for older patients, and for males compared with females, and for patients undergoing open surgery. Hospital length of stay was not associated with BMI. Results of regression analyses are shown in Table 4.

Oncologic Outcomes:

Disease progression was more likely with surgical complications, higher Lymph Node (LN) ratio and more advanced post-operative stage but was not related to BMI (Table 5). Death during the follow-up period was not related to BMI but was more likely for older patients (Hazard Ratio (HR) 1.04; 95% CI 1.02-1.06), those having surgical complications (HR 2.28; 95% CI 1.54-3.37) or medical complications (HR 1.63, 95% CI 1.03-2.59) those with a higher LN ratio (HR 10.3, 95% CI 4.36-24.2) and for Stage II (HR 1.98; 95% CI 1.60-2.45) and Stage IV (HR 14.15, 95% CI 4.10-48.8) cancers compared with Stage 0. Disease free and overall survival by BMI <30 and ≥30 are shown in Figure

1, demonstrating no difference between the obese and non-obese populations. Elevated BMI did not affect the likelihood of a positive circumferential resection margin in the management of rectal cancer.

Surgical Strategy and Conversion:

There were few patients in whom an alternative minimally invasive approach was used, including hybrid laparoscopic and robotic surgery. No patients underwent hand port laparoscopic surgery. There were 1344 episodes with open or attempted laparoscopic surgery (966 colon, 378 rectum). Patients with a BMI≥30kg/m^2 were more likely to be offered open surgery and less likely to be offered laparoscopic surgery compared with patients with BMI <30kg/m^2 (Chi-sq p-value 0.002). Laparoscopic surgery was not offered to any rectal cancer patient with a BMI >40kg/m^2. Among the 928 episodes where laparoscopic surgery was attempted (771 colon and 157 rectum), multivariable logistic regression showed that conversion to open surgery was more likely for BMI≥30kg/m^2 (OR 2.30, 95% CI 1.46-3.62), for rectal cancer (OR 2.85, 95% CI 1.80-4.51) and for older patients (OR 1.02, 95% CI 1.00-1.03). Table 6 shows the attempted laparoscopic cases performed and conversion rate according to BMI. Figure 2 demonstrates that as BMI increases the rate at which laparoscopic surgery is offered decreases in both colon and rectal cancer patients. When laparoscopic surgery is offered, increasing BMI is associated with an increasing conversion rate, again in both colon and rectal cancer patients. This effect is pronounced when the BMI is >30 in rectal cancer patients, and the BMI>35 in colon cancer patients.

Discussion:

The current study is the largest single case series that examines the relationship of body mass index (BMI) to clinical and oncological outcomes in the surgical management of colorectal cancer. To date, this is the first study that reported an association between an elevated BMI to a lower likelihood of attempting laparoscopic surgery and a higher conversion rate to open surgery when laparoscopy is attempted. The data also demonstrates at what BMI conversion becomes more likely in both the rectal cancer and colon cancer cohorts. Obesity is also associated with increased rates of surgical complications (including anastomotic leakage and wound complications). In rectal cancer an elevated BMI is not associated with a higher rate of CRM positivity, and is not associated with local, distant recurrence or survival.

The finding that fewer cases are attempted laparoscopically in obese patients has not been previously published. Laparoscopic conversion has been variably associated with obesity in the published literature. Denost et al., reported a higher laparoscopic conversion rate in a series of 490 patients,(20) however, other publications have failed to demonstrate this association.(21) A meta-analysis of eight observational studies performed by Zhou et al., was able to demonstrate an association between elevated BMI and conversion to open surgery. (7)

There is some cultural variation in reporting, including the fact that many Asian populations have lower BMI's, and some Asian publications define obesity at lower levels of BMI compared to Western publications.(21, 22)

The conversion rate in this study is comparable to previous published series, including major clinical trials investigating laparoscopic surgery in colon and rectal cancer. (11, 13-16)

This study has identified at what numerical value of BMI results in higher rates of conversion. Colon cancer patients with a BMI>35 had a significantly higher conversion rate of 24.1% (compared to 9.9% in the <35 cohort). Interestingly, rectal cancer patients with a BMI>30 had a higher conversion rate of 50.0% (compared to 19.5% in the <30 cohort). Only eight patients in this series had laparoscopic surgery attempted with a BMI >35, and none of these had a BMI >40. This highlights the significant technical differences associated with rectal compared to colon surgery.

Alternative minimally invasive surgical approaches available in current colorectal practice include, laparoscopic, hybrid, hand port, and robotic abdominal approaches, along with trans-anal total mesorectal excision (taTME). There are emerging data that these approaches, particularly robotic rectal surgery and taTME, are associated with fewer conversions.(23) (24). They offer technical advantages over routine laparoscopic techniques when operating on the extraperitoneal rectum. For the cohort of patients in this study, the robot was only available in one of the hospitals, and not all surgeons were credentialed for robotic surgery during this time period. Equally, taTME surgery was introduced late in the time period of this study and only two surgeons were credentialed to perform this technique. It is conceivable that as these alternative approaches are used more widely that the impact of obesity on conversion to open surgery will be reduced, however the data on the colon only cohort also suggest that conversion will remain probable in the obese population.

Obesity has been shown to negatively impact morbidity and mortality in the management of colorectal cancer in North American, British and European data,(8) Morbid obesity (BMI>40) was shown to be associated with higher rates of mortality and complications in 85,300 patients from the 2012 National Inpatient Sample in the USA.(8) There were 4385 morbidly obese patients (5.14%) in whom there was a higher rate of surgical complications, and conversions from laparoscopic to open surgery. There was also an increased peri-operative mortality (OR 1.85), which remained significant even after adjusting for surgical complications (OR 1.79). These patients also had a prolonged hospital stay (+1.22 day).

A British study investigated reduced muscle mass (myopenia), and increased infiltration by intermuscular and intramuscular fat (myosteatosis) in 805 patients with colorectal cancer. Myopenia was found to be an independent prognostic factor for disease-free survival (HR 1·53) and overall survival (HR 1·70). Myosteatosis was associated with prolonged hospital stay (P = 0·034), and myopenic obesity was related to higher 30-day morbidity (P = 0·019) and mortality (P < 0·001). (25)

A Cochrane review published in 2007 identified good evidence that obesity is a risk factor for wound infection, and that it may increase the risk of wound dehiscence, hernia formation and stomal complications.(26) Obesity was also linked to anastomotic leak, particularly in patients with rectal cancer, and conversion of laparoscopic to open surgery. The authors called for future studies to examine grades of obesity, which we have addressed in this study. The results from these larger studies are somewhat off-set by those from smaller case series, which have not universally supported the findings of worsened clinical outcomes and higher complication rates. Some studies have identified specific associations, most commonly with wound complications.

A single centre Australian study of 255 rectal cancer operations did not show a difference in overall complication rates between the obese and non-obese groups, although they did demonstrate a higher rate of wound complications (16% vs. 8%), small bowel obstruction (4% vs. 0%) and prolonged ileus (18% vs. 8%). (27) A single centre study involving 1048 patients with colon cancer showed a higher rate of wound related complications in obese patients undergoing laparoscopic colorectal surgery, where for every increase of BMI by one World Health Organization category, the odds ratios were 1.61 (P < 0.001) for wound infection and 1.54 (P < 0.001) for slow healing. Additionally, right colectomies had an OR of 3.23 (P = 0.017) for wound dehiscence.(28) Numerous other case series have not shown an association between obesity and complications. (20, 29, 30)

Elevated BMI was not associated with a higher positive circumferential resection margin (CRM) rate in rectal cancer patients, and this also did not relate to any difference in local recurrence rate, distant recurrence rate and overall survival. A number of case series publications have not identified an association between elevated BMI and poorer pathological markers (CRM positivity and LN yield)(20, 22, 31, 32) These findings have also been supported by a meta-analysis of eight observations studies. (7)

Limitations

This study is limited by its retrospective nature, however the data is derived from a prospectively maintained database with almost 100% complete data entry.(19) The appropriateness of BMI as a marker of obesity and its relationship to surgical outcomes has been challenged by some authors.(33) There have been other markers of obesity that have been proposed, and some authors have suggested that these correlate more closely with surgical outcomes compared to BMI. These include hip: waist ratio, pelvic adipose tissue and visceral adipose tissue .(33) These parameters have not been collected on this current data set. BMI is the most commonly recorded measure of obesity, and is easy and reliable to record. Despite its potential limitations it remains the most commonly reported measure of obesity.

This study, along with numerous previous publications have documented a clear association between obesity and worse outcomes in the surgical management of colorectal cancer. This observation should lead to every effort to identify if reversing obesity is possible in the pre-operative setting, and if this then leads to improved outcomes. Very Low Energy Diets (VLED) are routinely used prior to bariatric surgery. A number of colorectal surgeons have used this approach in colorectal surgery, however this has never formally been studied in colorectal cancer. As such, a randomised controlled multi-centre clinical trial has begun in Australia and New Zealand to investigate a number of aspects around acute weight loss prior to surgery for rectal cancer patients. (34)

Conclusions

This large case series of 1464 patients undergoing elective surgery for colorectal cancer has demonstrated that obesity is associated with a lower likelihood of laparoscopic surgery being attempted, a higher likelihood of conversion to open surgery when laparoscopic surgery is attempted and a higher rate of surgical complications. Obesity was not associated with a higher rate of CRM positivity, a higher local recurrence rate, nor worse disease free or overall survival in both colon and rectal cancer patients. This study has led to the development of a randomised controlled multi-centre clinical trial to investigate the possible benefits of acute weight loss by the use of a very low energy diet in the obese population.

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Table 1. Pre-operative patient characteristics by BMI grouped as <30 and ≥30 kg/m²

	BMI<30				BMI≥30				
	N	Median	Range		N	Median	Range		p-value‡
Age at surgery (yrs)	1165	71.66	18.38	99.27	299	68.27	30.38	91.93	**0.005**
Height (cm)	1165	168	140	196	299	167.5	136	194	0.12
Weight (kg)	1165	70	37	113.2	299	94	63	152	**<0.001**
BMI	1165	24.6	14.1	29.9	299	32.9	30	55.2	**<0.001**
	N		%			N	%		p-value§
Male	610		51.7			152	50.3		0.68
Female	571		48.3			150	49.7		
Colon	787		66.6			787	66.6		0.24
Rectal	394		33.4			394	33.4		
Tumour type									0.17
Adenocarcinoma	893		75.8			234	77.5		

Adenocarcinoma mucinous	119	10.1	23	7.6	
Adenocarcinoma signet	14	1.2	0	0	
Dysplastic Adenoma	66	5.6	24	7.9	
Other tumour	2	0.2	1	0.3	
No residual	84	7.1	20	6.6	
Pre-op staging					
T stage					0.19
0	7	2.3	0	0	
1	10	3.2	3	4.1	
2	76	24.4	13	17.6	
3	198	63.7	57	77	
4	17	5.5	1	1.4	
X	3	1	0	0	
N stage					0.51
0	103	33.1	24	32.4	

1	53	17	18	24.3	
2	27	8.7	5	6.8	
X	128	41.2	27	36.5	
M stage					0.46
0	1055	89.4	276	91.4	
1	100	8.5	19	6.3	
X	25	2.1	7	2.3	
Neoadjuvant therapy					0.61
No	200	50.8	43	47.8	
Yes	194	49.2	47	52.2	
Surgical entry (Colon & rectum)					
Conversion of laparoscopic	84	7.1	33	10.9	**<0.001**
Hybrid	83	7	18	6	
Laparoscopic	679	57.5	132	43.7	

Open	306	25.9	110	36.4	
Robotic	29	2.5	9	3	
Operative urgency					-
Elective	1181	100	302	100	
Surgical entry (Colon only)					
Conversion of laparoscopic	57	7.3%	24	11.5%	**0.002**
Hybrid	22	2.8%	7	3.3%	
Laparoscopic	559	72%	122	58.4%	
Open	137	17.7%	54	25.8%	
Robotic	1	0.1%	2	1%	
Total	776	100	209	100	
Surgical entry (Rectum only)					

Conversion of laparoscopic	26	6.6%	9	10%	**0.003**
Hybrid	61	15.5%	10	11.1%	
Laparoscopic	112	28.4%	10	11.1%	
Open	167	42.4%	54	60%	
Robotic	28	7.1%	7	7.8%	
Total	394	100	90	100	

Table 2. Post-operative characteristics

	Colon BMI<30		Colon BMI≥30				Rectum BMI<30		Rectum BMI>30		p-value
Post-operative	N	Medi	N	Media	p-value‡		N	Mean	N	Mean	

characteristics		an		n							
Length of stay (days)	776	7	299	8	**0.005**		394	10.9	90	12.7	**0.01**
LN harvested	1153	16	293	15	0.62		391	15.1	90	15.5	0.76
LN positive	1157	0	296	0	0.73		391	0.9	90	0.8	0.13
Mucosal margins	821	40	210	40	0.33		307	30.0	73	32.7	0.42
	N	%	N	%	p-value§		N	%	N	%	
Surgical complications					**0.002**						**0.02**
No	996	84.3	236	78.1			301	76.4	58	64.4	
Yes	185	15.7	66	21.9			93	23.6	32	35.6	
Medical complications					0.88						0.844
No	1071	90.7	273	90.4			353	89.6	80	88.9	
Yes	110	9.3	29	9.6			41	10.4	10	11.1	

Return to theatre					0.84						0.408
No	1118	94.7	285	94.4			362	91.9	85	94.4	
Yes	63	5.3	17	5.6			32	8.1	5	5.6	
Post-op staging											
T stage					0.41						0.19
0	195	16.5	55	18.2			7	2.3	0	0	
1	109	9.2	36	11.9			10	3.2	3	4.1	
2	206	17.4	56	18.5			76	63.7	13	17.6	
3	558	47.2	135	44.7			198	63.7	57	77	
4	103	8.7	18	6.0			17	5.5	1	1.4	
X	10	0.8	2	0.7							
N stage					0.52						0.51
0	795	67.3	212	70.2			103	33.1	24	32.4	
1	263	22.3	56	18.5			53	17	18	24.3	
2	115	9.7	31	10.3			27	8.7	5	6.8	

X	8	0.7	3	1.0			128	41.2	27	36.5	
M stage					0.07						0.19
0	931	78.8	253	83.8			358	90.9	86	95.6	
1	125	10.6	19	6.3			34	8.6	3	3.3	
X	125	10.6	30	9.9			2	0.5	1	1.1	
Overall stage					0.24						0.078
0	185	15.7	55	18.2			75	19	17	18.9	
1	251	21.3	75	24.8			96	24.4	30	33.3	
2	330	27.9	80	26.5			78	19.8	23	25.6	
3	288	24.4	73	24.2			106	26.9	18	20	
4	125	10.6	19	6.3			38	9.6	2	2.2	
X	2	0.2	0	0			1	0.3	0	0	
Mucosal margins					0.82						0.556
Clear margin	289	24.5	72	23.8			76	19.3	15	16.7	
Measured	892	75.5	230	76.2			318	80.7	75	83.3	

Circumferential margins					0.53						0.948
Not reported	637	57.3	152	54.1			47	12.3	10	11.2	
Negative (>1mm)	455	40.9	125	44.5			320	84	76	85.4	
Positive (<=1mm)	20	1.8	4	1.4			14	3.7	3	3.4	
Inpatient death					0.36*						0.935
No	1,161	99.7	297	99.3			390	99	89	98.9	
Yes	4	0.3	2	0.7			4	1	1	1.1	
Readmitted within 30 days					0.41						0.673
No	1064	90.1	278	92.1			333	84.5	78	86.7	
Yes (Related to surgery)	88	7.5	16	5.3			47	11.9	8	8.9	
Yes (Unrelated to surgery)	29	2.5	8	2.6			14	3.6	4	4.4	
30-day mortality					0.99*						0.635

No	1,162	99.74	298	99.67			393	99.7	90	100	
Yes	3	0.26	1	0.33			1	0.3	0	0	
Metastasis					0.91						0.263
No	1061	89.8	272	90.1			342	86.8	82	91.1	
Yes	120	10.2	30	9.9			52	13.2	8	8.9	
Recurrence					0.87						0.655
No	1168	98.9	299	99			387	98.2	89	98.9	
Yes	13	1.1	3	1			7	1.8	1	1.1	
Died					0.73						0.514
No	1060	89.8	269	89.1			351	89.1	78	86.7	
Yes	121	10.2	33	10.9			43	10.9	12	13.3	

‡ Wilcoxon Rank Sum test, § Chi-squared test, * Fisher's Exact test

Table 3. Logistic regression modelling results for factors affecting surgical complications (BMI continuous)

Surgical complications	Odds Ratio	95% Confidence	Interval
BMI	1.038	1.005	1.059
Female	0.562	0.454	0.817
Surgical entry			
Laparoscopic	Reference group		
Conversion of laparoscopy	3.839	2.389	6.085
Hybrid	4.233	1.771	5.162
Open	2.990	1.738	3.598
Robotic	1.742	0.567	3.269
Rectal cancer	1.638	1.181	2.273

Table 4. Linear regression results for factors affecting hospital length of stay

Variable	Coefficient	95% Confidence	Interval
Age	0.042	0.021	0.063
Female (relative to male)	-0.887	-1.581	-0.192
Surgical complications	9.930	7.728	12.13
Medical complications	5.609	3.642	7.576
Surgical entry			
Laparoscopic	Reference group		
Conversion of laparoscopy	1.112	-0.223	2.447
Hybrid	0.877	-0.314	2.068
Open	3.716	2.634	4.797
Robotic	-0.139	-1.925	1.647

Table 5. Cox proportional hazards model for disease-free survival

Predictor	Hazard Ratio	95% Confidence	Interval
LN ratio	3.849	1.816	8.160
Surgical complications	1.503	1.033	2.187
Overall stage			
0	Reference group		
1	1.884	0.525	6.753
2	5.937	1.838	19.173
3	9.243	2.872	29.741
4	35.99	10.79	119.99

Table 6. Logistic regression model for conversion from laparoscopic to open surgery

Variable	Odds Ratio	95% Confidence	Interval
BMI group			
<30	Reference group		

30-<35	1.740	1.018	2.976
35-<40	2.758	1.193	6.376
40+	10.215	2.869	36.37
Rectal cancer	2.632	1.677	4.131

Table 7: Open and attempted laparoscopic surgery rate by BMI split at 30kg/m^2, (n=1344)

Surgical entry	**BMI<30**	**BMI≥30**	**Total**
Colon			
Open	139	56	195
	81.8%	72.3%	79.8%
Attempted laparoscopy	625	146	771
	18.2%	27.7%	20.2%
Converted to open			
% converted from lap			

	18.2%	27.7%	20.2%
Total colon	764	202	966
Rectum			
Open	167	54	221
	54.7%	74.0%	58.5%
Attempted laparoscopy	138	19	157
	45.3%%	26.0%	41.5%
Converted to open	26	9	35
% converted from lap	18.65	47.4%	22.3
Total rectum	305	73	378

Figure 1. Oncological outcomes by BMI group

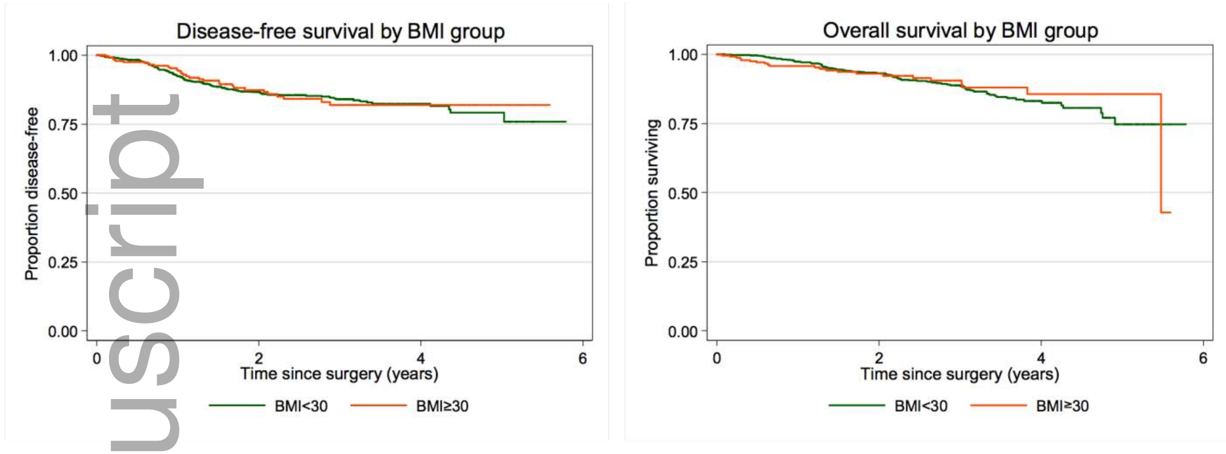

Figure 2. The rate at which laparoscopic surgery was offered, and the conversion rate relating to BMI.

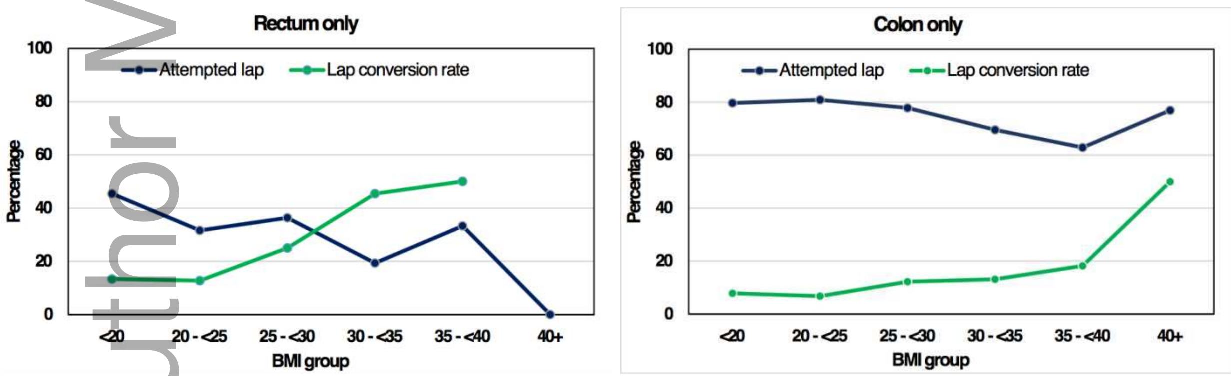

Table 1. Pre-operative patient characteristics by BMI grouped as <30 and ≥30 kg/m^2

	BMI<30				BMI≥30				
	N	Median	Range		N	Median	Range		p-value‡
Age at surgery (yrs)	1165	71.66	18.38	99.27	299	68.27	30.38	91.93	**0.005**
Height (cm)	1165	168	140	196	299	167.5	136	194	0.12
Weight (kg)	1165	70	37	113.2	299	94	63	152	**<0.001**
BMI	1165	24.6	14.1	29.9	299	32.9	30	55.2	**<0.001**
	N		%		N		%		p-value§
Male	610		51.7		152		50.3		0.68
Female	571		48.3		150		49.7		
Colon	787		66.6		787		66.6		0.24
Rectal	394		33.4		394		33.4		
Tumour type									0.17
Adenocarcinoma	893		75.8		234		77.5		

Adenocarcinoma mucinous	119	10.1	23	7.6	
Adenocarcinoma signet	14	1.2	0	0	
Dysplastic Adenoma	66	5.6	24	7.9	
Other tumour	2	0.2	1	0.3	
No residual	84	7.1	20	6.6	
Pre-op staging					
T stage					0.19
0	7	2.3	0	0	
1	10	3.2	3	4.1	
2	76	24.4	13	17.6	
3	198	63.7	57	77	
4	17	5.5	1	1.4	
X	3	1	0	0	
N stage					0.51
0	103	33.1	24	32.4	

1	53	17	18	24.3	
2	27	8.7	5	6.8	
X	128	41.2	27	36.5	
M stage					0.46
0	1055	89.4	276	91.4	
1	100	8.5	19	6.3	
X	25	2.1	7	2.3	
Neoadjuvant therapy					0.61
No	200	50.8	43	47.8	
Yes	194	49.2	47	52.2	
Surgical entry (Colon & rectum)					
Conversion of laparoscopic	84	7.1	33	10.9	**<0.001**
Hybrid	83	7	18	6	
Laparoscopic	679	57.5	132	43.7	

Open	306	25.9	110	36.4	
Robotic	29	2.5	9	3	
Operative urgency					-
Elective	1181	100	302	100	
Surgical entry (Colon only)					
Conversion of laparoscopic	57	7.3%	24	11.5%	**0.002**
Hybrid	22	2.8%	7	3.3%	
Laparoscopic	559	72%	122	58.4%	
Open	137	17.7%	54	25.8%	
Robotic	1	0.1%	2	1%	
Total	776	100	209	100	
Surgical entry (Rectum only)					

Conversion of laparoscopic	26	6.6%	9	10%	**0.003**
Hybrid	61	15.5%	10	11.1%	
Laparoscopic	112	28.4%	10	11.1%	
Open	167	42.4%	54	60%	
Robotic	28	7.1%	7	7.8%	
Total	394	100	90	100	

Table 2. Post-operative characteristics

	Colon BMI<30		Colon BMI≥30				Rectum BMI<30		Rectum BMI>30		p-value
Post-operative	N	Medi	N	Media	p-value‡		N	Mean	N	Mean	

characteristics		an		n						
Length of stay (days)	776	7	299	8	**0.005**		394	10.9	90	12.7	**0.01**
LN harvested	1153	16	293	15	0.62		391	15.1	90	15.5	0.76
LN positive	1157	0	296	0	0.73		391	0.9	90	0.8	0.13
Mucosal margins	821	40	210	40	0.33		307	30.0	73	32.7	0.42
	N	%	N	%	p-value§		N	%	N	%	
Surgical complications					**0.002**						**0.02**
No	996	84.3	236	78.1			301	76.4	58	64.4	
Yes	185	15.7	66	21.9			93	23.6	32	35.6	
Medical complications					0.88						0.844
No	1071	90.7	273	90.4			353	89.6	80	88.9	
Yes	110	9.3	29	9.6			41	10.4	10	11.1	

Return to theatre					0.84						0.408
No	1118	94.7	285	94.4			362	91.9	85	94.4	
Yes	63	5.3	17	5.6			32	8.1	5	5.6	
Post-op staging											
T stage					0.41						0.19
0	195	16.5	55	18.2			7	2.3	0	0	
1	109	9.2	36	11.9			10	3.2	3	4.1	
2	206	17.4	56	18.5			76	63.7	13	17.6	
3	558	47.2	135	44.7			198	63.7	57	77	
4	103	8.7	18	6.0			17	5.5	1	1.4	
X	10	0.8	2	0.7							
N stage					0.52						0.51
0	795	67.3	212	70.2			103	33.1	24	32.4	
1	263	22.3	56	18.5			53	17	18	24.3	
2	115	9.7	31	10.3			27	8.7	5	6.8	

X	8	0.7	3	1.0			128	41.2	27	36.5	
M stage					0.07						0.19
0	931	78.8	253	83.8			358	90.9	86	95.6	
1	125	10.6	19	6.3			34	8.6	3	3.3	
X	125	10.6	30	9.9			2	0.5	1	1.1	
Overall stage					0.24						0.078
0	185	15.7	55	18.2			75	19	17	18.9	
1	251	21.3	75	24.8			96	24.4	30	33.3	
2	330	27.9	80	26.5			78	19.8	23	25.6	
3	288	24.4	73	24.2			106	26.9	18	20	
4	125	10.6	19	6.3			38	9.6	2	2.2	
X	2	0.2	0	0			1	0.3	0	0	
Mucosal margins					0.82						0.556
Clear margin	289	24.5	72	23.8			76	19.3	15	16.7	
Measured	892	75.5	230	76.2			318	80.7	75	83.3	

Circumferential margins					0.53						0.948
Not reported	637	57.3	152	54.1			47	12.3	10	11.2	
Negative (>1mm)	455	40.9	125	44.5			320	84	76	85.4	
Positive (<=1mm)	20	1.8	4	1.4			14	3.7	3	3.4	
Inpatient death					0.36*						0.935
No	1,161	99.7	297	99.3			390	99	89	98.9	
Yes	4	0.3	2	0.7			4	1	1	1.1	
Readmitted within 30 days					0.41						0.673
No	1064	90.1	278	92.1			333	84.5	78	86.7	
Yes (Related to surgery)	88	7.5	16	5.3			47	11.9	8	8.9	
Yes (Unrelated to surgery)	29	2.5	8	2.6			14	3.6	4	4.4	
30-day mortality					0.99*						0.635

No	1,162	99.74	298	99.67			393	99.7	90	100	
Yes	3	0.26	1	0.33			1	0.3	0	0	
Metastasis					0.91						0.263
No	1061	89.8	272	90.1			342	86.8	82	91.1	
Yes	120	10.2	30	9.9			52	13.2	8	8.9	
Recurrence					0.87						0.655
No	1168	98.9	299	99			387	98.2	89	98.9	
Yes	13	1.1	3	1			7	1.8	1	1.1	
Died					0.73						0.514
No	1060	89.8	269	89.1			351	89.1	78	86.7	
Yes	121	10.2	33	10.9			43	10.9	12	13.3	

‡ Wilcoxon Rank Sum test, § Chi-squared test, * Fisher's Exact test

Table 3. Logistic regression modelling results for factors affecting surgical complications (BMI continuous)

Surgical complications	**Odds Ratio**	**95% Confidence**	**Interval**
BMI	1.038	1.005	1.059
Female	0.562	0.454	0.817
Surgical entry			
Laparoscopic	Reference group		
Conversion of laparoscopy	3.839	2.389	6.085
Hybrid	4.233	1.771	5.162

Open	2.990	1.738	3.598
Robotic	1.742	0.567	3.269
Rectal cancer	1.638	1.181	2.273

Table 4. Linear regression results for factors affecting hospital length of stay

Variable	**Coefficient**	**95% Confidence**	**Interval**
Age	0.042	0.021	0.063
Female (relative to male)	-0.887	-1.581	-0.192
Surgical complications	9.930	7.728	12.13
Medical complications	5.609	3.642	7.576
Surgical entry			

Laparoscopic	Reference group		
Conversion of laparoscopy	1.112	-0.223	2.447
Hybrid	0.877	-0.314	2.068
Open	3.716	2.634	4.797
Robotic	-0.139	-1.925	1.647

Table 5. Cox proportional hazards model for disease-free survival

Predictor	**Hazard Ratio**	**95% Confidence**	**Interval**
LN ratio	3.849	1.816	8.160
Surgical complications	1.503	1.033	2.187
Overall stage			
0	Reference group		

1	1.884	0.525	6.753
2	5.937	1.838	19.173
3	9.243	2.872	29.741
4	35.99	10.79	119.99

Table 6. Logistic regression model for conversion from laparoscopic to open surgery

Variable	**Odds Ratio**	**95% Confidence**	**Interval**
BMI group			
<30	Reference group		
30-<35	1.740	1.018	2.976
35-<40	2.758	1.193	6.376
40+	10.215	2.869	36.37
Rectal cancer	2.632	1.677	4.131

Table 7: Open and attempted laparoscopic surgery rate by BMI split at 30kg/m^2, (n=1344)

Surgical entry	**BMI<30**	**BMI≥30**	**Total**
Colon			
Open	139	56	195
	81.8%	72.3%	79.8%
Attempted laparoscopy	625	146	771
	18.2%	27.7%	20.2%
Converted to open			
% converted from lap			
	18.2%	27.7%	20.2%
Total colon	764	202	966
Rectum			
Open	167	54	221
	54.7%	74.0%	58.5%
Attempted laparoscopy	138	19	157

	45.3%%	26.0%	41.5%
Converted to open	26	9	35
% converted from lap	18.65	47.4%	22.3
Total rectum	305	73	378